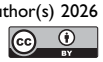
Original research article

Concurrent Engineering: Research and Applications
2026, Vol. 0(0) 1–23
© The Author(s) 2026

Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/1063293X261423822
journals.sagepub.com/home/cer


An industrial application of the lean and agile model for product development: A manufacturing case study

Glyn P Fargher[1], Marwan Aboudaber[2], Thomas Bruneau[2], Jordan Pandjawatchou[2], Julie Reynaud[2], Marie Regnier[2], Muhammad Khan[3] and Ahmed Al-Ashaab[2]

Abstract

Manufacturing organisations face pressure to develop effective engineering solutions while maintaining their competitiveness in rapidly evolving markets. This challenge necessitates product development approaches that balance rigorous knowledge-driven methodswith responsive adaptation to changing requirements. This research presents an empirical application of the Lean and Agile Model for Product Development (LAMPD) in a manufacturing environment, addressing critical gaps in integrated methodologies for hardware contexts. LAMPD was implemented through a 4-month case study at Atlas Copco Henrob, a UK manufacturer of self-piercing riveting systems, focusing on enhancing a rivet feeder system used in automotive manufacturing that had not previously undergone dedicated design optimisation. The research aimed to document LAMPD implementation processes, determine its impact on design efficiency, identify process benefits and challenges, and explore implications for manufacturing product development practices. The LAMPD framework systematically integrated Set-Based Concurrent Engineering principles with Agile methodologies including Scrum ceremonies and Kanban visualisation techniques across three development phases: Project Definition, Project Feasibility, and Project Realisation. The integrated approach facilitated evidence-based decision-making, which resulted in a 53% component reduction, eliminated two sensors from the original design, and improved system reliability by reducing false readings from 12% to near zero principally through the rigorous application of SBCE methodology combined with continuous integration cycles. Challenges identified included harmonising sprint cadences with traditional phase boundaries and balancing multiple methodological frameworks without compromising their individual strengths. Despite these implementation complexities, the research demonstrates that combining Lean knowledge management principles with Agile responsiveness creates substantial value in manufacturing product development. The LAMPD model provides organisations with practical mechanisms to enhance both design efficiency and process adaptability, contributing to theory and practice by showing how integrated approaches can significantly improve product development outcomes in hardware manufacturing contexts.

Keywords

set-based concurrent engineering, methodology integration, hardware development, manufacturing case study, lean product development, agile product development, Scrum, Kanban, stage-gate process

Introduction

Manufacturing organisations face increasing pressure to develop effective and economical engineering solutions while maintaining competitiveness in rapidly evolving markets (Blais et al., 2023; Civelek et al., 2023). This dual challenge requires product development (PD) approaches that balance rigorous front-loaded knowledge management with responsive adaptation to changing requirements. Two influential methodologies that address these needs are Lean Product Development (Lean PD) and Agile Product Development (Agile

[1]Research and Development Department, Atlas Copco Henrob, Flintshire, UK
[2]Manufacturing and Materials Department, Cranfield University School of Applied Sciences, Cranfield, UK
[3]Data and AI Department, Northeastern University London, London, UK

Corresponding author:
Glyn P Fargher, Research and Development Department, Atlas Copco IAS UK Ltd, Deeside Industrial Park, Parkway One, DeesideS CH5 2N, UK.
Email: glyn.p.fargher@cranfield.ac.uk

PD). While both seek to maximise efficiency and value creation, they traditionally operate under differing philosophies: Lean PD emphasises structured analysis and early learning, while Agile PD prioritises rapid iteration and adaptive response. This distinction introduces a central tension: Lean emphasises early, detailed planning and knowledge generation (often associated with front-loading), while Agile focuses on responsive adaptation. Integrating these approaches is thus a non-trivial challenge.

Lean PD, derived from Toyota's manufacturing principles, has demonstrated effectiveness as a knowledge-driven approach for forward-thinking companies (Al-Ashaab et al., 2021; Spinelli et al., 2022). Its exploration of design alternatives through Set-Based Concurrent Engineering (SBCE) increases confidence in design decisions and yields cost and time benefits, reducing rework, warranty, and material costs (Khan et al., 2013; Rismiller et al., 2023). Our research team has observed these outcomes across PD transformations in organisations producing complex electro-mechanical systems, confirming the value of comprehensive early design analysis.

However, early analysis can yield diminishing returns in contexts involving highly complex products and services. Many organisations in such environments have adopted Agile approaches to PD, attracted by the benefits of structured iterations, frequent customer feedback, and flexibility to incorporate evolving requirements (Scharold and Paetzold-Byhain 2024; Weichbroth 2022). Therefore, practitioners should view the value of integrating the Lean PD and Agile PD approaches to develop innovative product. To empirically demonstrate the value and feasibility of resolving this tension in hardware contexts, theauthors, developed a Lean and Agile Model for Product Development (LAMPD) that systematically integrates and unifies these methodologies. The theoretical foundation and validation are presented in our companion paper (Fargher, G et al., 2025), which provides the comprehensive theoretical grounding for this empirical application.. This paper presents a detailed case study documenting LAMPD's practical implementation to enhance a rivet feeder system in collaboration with Atlas Copco Henrob, a manufacturer of self-piercing rivets for automotive applications:

(1) To empirically document the application of the LAMPD Process Model in a manufacturing environment, providing a detailed account of implementation activities, challenges, and adaptations.
(2) To evaluate the impact of the LAMPD approach on design outcomes, measuring improvements in efficiency (resource utilisation), effectiveness (performance), and economy (cost) compared to previous methods.
(3) To identify specific effects on development processes and management practices, including changes to decision-making frameworks, team dynamics, and knowledge management processes.
(4) To determine the broader implications for PD practice by analysing the challenges encountered, lessons learned, and potential for generalisation across manufacturing contexts.

This research contributes to theory and practice by providing empirical evidence of how a structured yet flexible approach combining Lean with Agile responsiveness can significantly improve product design and development processes in manufacturing contexts.

The remainder of this paper is organised as follows. The research methodology is first described, outlining the approach used to implement and evaluate the LAMPD Process Model. This is followed by a review of related research on Lean and Agile product development, identifying the theoretical gap addressed by this case study. An overview of the LAMPD Process Model and its key components is then provided. The case study is subsequently presented, including the organisational context, implementation approach, and results. The discussion section examines the key findings, challenges encountered, and lessons learned. The paper concludes by outlining implications for practice, limitations of the study, and directions for future research.

Research methodology

This research employed a systematic qualitative methodology following Yin's (2018) embedded single-case design approach with data triangulation from multiple sources to ensure comprehensive validation. The methodology was structured around six sequential phases designed to comprehensively evaluate the LAMPD model's implementation in a manufacturing context:

(1) Theoretical Foundation Development: We conducted a structured literature review to establish the state-of-the-art principles across Lean PD, SBCE, and Agile hardware development approaches. This review informed our theoretical framework and provided the conceptual foundation for the case study design (Blessing and Chakrabarti 2009; Eckert et al., 2019).
(2) Current State Analysis: We systematically decomposed Atlas Copco Henrob's existing Stage-Gate model, identifying specific activities, inputs, outputs, decision points, and stakeholder interactions. This analysis established the baseline for improvement and provided essential context for the case study implementation.
(3) Integration Planning: We created a detailed mapping between the Company's Stage-Gate PD process and Khan's (2012) SBCE process model to transform the current PD process into a LeanPD environment. The transformation approach focused on systematically integrating SBCE principles within existing governance frameworks through structured workshops and integration matrices

(4) Harmonisation Strategy Development: We developed a model for incorporating Agile Principles, Scrum practices, and Kanban visualisation systems at strategic points within the integrated process model to enhance responsiveness and development speed.
(5) Implementation and Data Collection: We implemented the LAMPD model through a controlled case study on an active PD project over 4 months. Data collection employed four primary methods: document analysis of Company PD documentation, templates, and technical specifications; observation of development sessions and team interactions; structured and semi-structured meetings with the development team; and simulation and modelling of design alternatives. Qualitative data validity was rigorously managed through triangulation across these four sources. Furthermore, observations and interview notes were subject to coding and iterative member-checking with key development team members to ensure empirical findings accurately reflected in-situ organisational dynamics.
(6) Evaluation Framework Application: We established and measured tangible benefits of the LAMPD model implementation using quantitative metrics (component reduction, manufacturing complexity reduction, reliability improvements) and qualitative assessments from team members and stakeholders.

Related literature: Lean and agile product development

Despite distinct origins, Lean and Agile methodologies share common efficiency and value creation goals (Granato et al., 2022). However, they differ fundamentally in their approaches: Lean PD prioritises systematic design space exploration through structured analysis (Khan et al., 2013), whilst Agile emphasises rapid iteration and adaptive responses to change through time-boxed iterations and close customer collaboration (Beck et al., 2001; Gren and Lenberg, 2020). Lean PD has demonstrated considerable effectiveness in hardware development contexts (Battistella et al., 2023), whereas Agile methodologies have achieved comparable success primarily in software development environments (Palsodkar et al., 2023; Silvério et al., 2020). This traditional domain separation creates challenges when organisations attempt to leverage both methodologies simultaneously.

Agile in hardware product development

Several researchers have explored applying Agile principles to hardware development contexts. Albers et al. (2020) proposed a nine-principle Agile System Design framework specifically addressing limitations in applying traditional Agile approaches to physical PD. Their work includes establishing shared understanding, addressing time and physical constraints, and navigating organisational change. Similarly, Glazkova et al. (2019) proposed a six-phase PD process for medical devices that selectively deploys Lean and Agile techniques at each process stage. Recent empirical studies have strengthened this foundation by documenting the practical challenges and benefits of agile implementation in physical product contexts. Combined hardware-software development projects present three key challenges specific to agile application in hardware environments, though practical adjustments can enhance success rates (Drutchas and Eppinger, 2022). Agility in hardware contexts proves more complex than simply adopting fast-paced development practices, requiring instead a quality-driven approach for core components alongside frequent user testing (Berg et al., 2020). Whilst scaled agile has succeeded in software, significant differences emerge in hardware contexts - particularly around synchronisation, coordination, and resource allocation across organisational units (Michalides et al., 2023). Persistent challenges including physical constraints, organisational inertia, and cultural resistance continue to complicate agile adoption in hardware development (Müller et al., 2024).

Despite these theoretical advances, a significant gap persists in documented case studies demonstrating practical implementation of integrated Lean-Agile approaches in hardware PD environments. Whilst several conceptual frameworks have been proposed, empirical evidence of their applications, particularly in traditional manufacturing contexts, remains limited (Albers et al., 2020; Godbole et al., 2019; Glazkova et al., 2019; Drutchas and Eppinger, 2022; Berg et al., 2020; Michalides et al., 2023; Müller et al., 2024).

Overview of LeanPD\SBCE

The literature emphasises on the importance of set-based concurrent engineering (SBCE) within the lean product development (LeanPD) application (Kennedy et al., 2008; Khan et al., 2013; Levandowski et al., 2014; Sobek et al., 1999; Toche et al., 2020). This is because SBCE represents the definition of the process that will be followed to develop a product. It focuses on value creation, provision of a "knowledge environment", continuous improvement and SBCE process that encourage innovation and collaboration. LeanPD provides a process model and associated tools that consider the entire product life cycle. It provides knowledge-based user-centric design and a development environment to support value creation to the customers in terms of innovation and customisation, and quality as well as sustainable and affordable products.

Several studies developed a different LeanPD framework (Anand and Kodali, 2008; Hoppmann et al., 2011; Wang

et al., 2011). All the developed frameworks have been graphically represented in the form of tables based on the review of other LeanPD and product development literature. The researchers of these LeanPD frameworks have appreciated the foundation of LeanPD to be the Toyota product development system (TPDS). They incorporated some elements of TPDS into the five lean principles from [68] which are combined with ideas from traditional product development to formulate their frameworks. Nevertheless, limited applications of SBCE are documented in detail [21]; (Toche et al., 2020). Sobek et al. (1999) describes SBCE as a process of reasoning, developing, and communicating a set of solutions in parallel. As the design progresses, the set is gradually narrowed down the gained knowledge. [42] stressed that SBCE, thoroughly, explores alternative solutions until there is maximum "design space".

Lean-agile integration

A relatively robust literature exists regarding LeanPD/SBCE. Toche et al. (2020) conducted a comprehensive review of set-based design literature, finding that whilst SBD has relatively low theoretical development, methodologies for practical SBCE implementation require better understanding, with limited holistic models that effectively integrate people, product, and process elements in traditional industrial contexts. Early foundational work on Concurrent Engineering established the importance of integrating product and process development across the life cycle to improve design efficiency and responsiveness (Prasad, 1996a, 1997). Cukor Kirinić and Hegedić (2023) analysed 85 publications from 2011 to 2022, identifying trends towards the synergy of LeanPD with sustainability, Industry 4.0, and digitalisation, which suggests increasing relevance for integrated approaches that leverage both lean methodologies and agile responsiveness in hardware development. Furthermore, research on Lean in engineering contexts emphasises that maturity depends heavily on structured information and process structuring, rather than simply tool adoption (Silvério et al. 2020a, 2020b), confirming the necessity of a systematic process like LAMPD to successfully embed Lean knowledge principles.

Addressing this gap, LAMPD specifically targets integration challenges in physical PD environments characterised by heightened variability and extended development cycles (De Toledo et al., 2023; Varl et al., 2020). By combining Lean's structured exploration with Agile's adaptive principles, LAMPD enables organisations to benefit from systematic design space analysis whilst maintaining the responsiveness and continuous improvement cycles essential for managing evolving requirements. The literature review reveals that whilst several attempts have been made to utilize SBCE (Al-Ashaab et al., 2013; Ammar et al., 2019), these efforts remain anchored in its principles rather than offering actionable frameworks.

Practitioners seek a clear pathway to implement set-based concurrent engineering, yet identifying a well-structured process model that guides companies step-by-step through the early stages of product development proves elusive. This research provides a detailed industrial case study documenting practical LAMPD application, offering empirical evidence of both benefits and implementation challenges to inform future adoption of combined Lean-Agile approaches in physical PD. Table 1 compares the key characteristics and potential benefits of an integrated approach across dimensions relevant to hardware PD, highlighting the theoretical potential for harmonisation while acknowledging distinct challenges in physical product contexts (Battistella et al., 2023; Cano et al., 2021; Reiff and Schlegel, 2022; Silvério et al., 2020; Varl et al., 2020). The following sections detail the LAMPD process model, describing the structure designed to achieve this harmonisation.

Overview of the LAMPD process model

The LAMPD strategically integrates Lean PD and Agile PD approaches within a structured Stage-Gate model. This integration creates a harmonised system that organises inputs, tasks, and outputs while seeking to mitigate conflicts typically arising from their concurrent application in hardware development contexts.

Development approach

The LAMPD Process Model was developed through three stages: (1) Company Engagement, identifying challenges at Atlas Copco Henrob; (2) PD Model Integration, mapping the Company's Stage-Gate PD process to Khan's (2012) SBCE model; and (3) Lean-Agile Harmonisation, introducing Scrum, Kanban, and Agile Principles to create a structured yet flexible model.

LAMPD derivation and structure

Building upon this foundation, the LAMPD Process Model is structured around three primary stages (Figure 1) - Project Definition, Project Feasibility, and Project Realisation - each integrating elements from both Lean PD and Agile methodologies. The modular structure of LAMPD, which decomposes product development into value-driven stages and iteratively integrates subsystem-level knowledge, aligns with the foundational principles of Concurrent Engineering proposed by Prasad (1996a; 1996b).

Figure 2 illustrates the initial integration of Atlas Copco's current PD practices with Khan's SBCE process model. The Figure demonstrates how the Company's first PD process stage, 'Project Definition,' (*2A*) aligns with SBCE's 'Define Value' phase (*2B*), resulting in the harmonised Atlas Copco Lean PD Stage 1: Project definition (*2C*), Stage 2: Lean-Agile PD Process Model: Project Feasibility (2D) and

Table 1. Comparison of lean PD, agile PD, and harmonised approaches.

Dimension	Lean PD	Agile PD	Lean and agile PD integrated approach
Knowledge management	• Systematic documentation (A3s, trade-offs)	• Ad-hoc team-based sharing	• Structured capture within sprints
	• Explicit, codified knowledge	• Knowledge is often tacit	• Balances documentation with tacit exchange
	• Emphasis on organisational learning	• Limited formal documentation	• Creates reusable assets while maintaining pace
Design space exploration	• Multiple parallel alternatives	• Single solution with iterations	• Multiple options within time-boxed sprints
	• Broad initial solution space	• Early convergence	• Structured convergence via value attributes
	• Delayed decisions until knowledge gained	• Adaptation rather than exploration	• Balances exploration breadth with pace
Iteration approach	• Structured cycles for knowledge creation	• Rapid iterations via short sprints	• Time-boxed iterations in a knowledge framework
	• Sequential phase-based process (shorter knowledge loops occur within longer phases)	• Working prototypes for feedback	• Sprints aligned with phase boundaries
	• Subsystem iteration before integration	• Continuous adjustment	• Structured flexibility
Customer involvement	• Upfront value analysis	• Continuous collaboration	• Structured key value attributes with regular review points
	• Limited interaction during development	• Product owner role	• Balances targets with adaptation
	• Requirements-focused	• Frequent demonstrations	• Uses metrics and direct feedback
		• Adapts to changing needs	
Risk management	• Front-loaded analytical techniques (FMEA)	• Reactive approach	• Combines upfront analysis with sprint discovery
	• Extensive subsystem testing	• Limited formal risk analysis	• Addresses identified and emergent risks
	• May miss emergent risks	• Relies on iterations to reveal issues	• Balanced anticipatory and responsive
Decision making	• Data-driven, analysis-based	• Empowered team decisions	• Knowledge-based at appropriate levels
	• Milestone-focused decisions	• Limited analysis, high frequency	• Balances data needs with decision velocity
	• Emphasis on ''right' decisions	• Reversible and adjustable	• Structured evaluation criteria
Resource efficiency	• Eliminates waste via standardisation	• Quick value delivery, minimal overhead	• Strategic allocation based on value/complexity
	• Extensive planning	• Limited planning	• Right-sized analysis effort
	• Risk of over-processing	• Responsive allocation	• Optimises lifecycle efficiency
	• Front-loaded resources	• Risk of rework	
Team structure	• Functional expertise by subsystem	• Cross-functional, end-to-end teams	• Hybrid with cross-functional teams
	• Chief engineer leadership	• Self-organising within constraints	• Technical leadership with balanced autonomy
	• Matrix organisation	• Scrum master as facilitator	• Flexible composition based on phase
Technology integration	• Systematic but potentially slow	• Early, frequent integration	• Regular subsystem verification
	• Extensive testing before assembly	• Continuous integration practices	• Balances early critical interface testing
	• Late integration issues possible	• Hardware constraint challenges	• Proactive integration risk management
Adaptability to change	• Formal change management	• Highly adaptable	• Structured flexibility
	• Strong baseline control	• Embraces late changes	• Distinguishes value-adding vs. disruptive changes
	• Changes viewed as potential waste	• Changes as opportunities	• Maintains options for anticipated changes

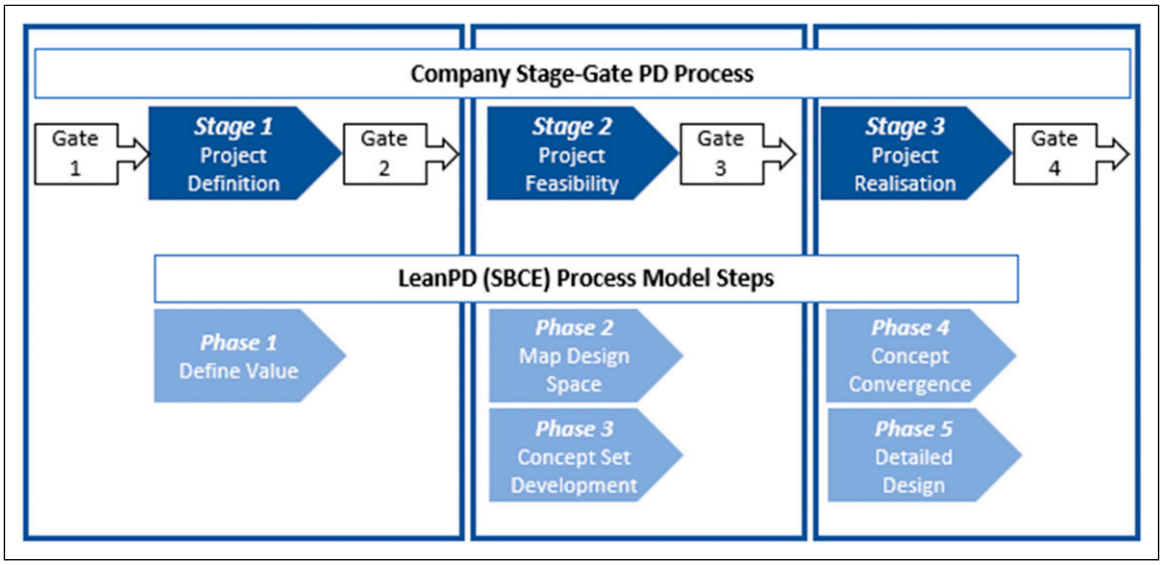


Figure 1. Aligning company stage-gate PD process stages with Lean-PD (SBCE) process model phases.

Stage 3: Lean-Agile PD Process Model: Project Realisation (2E). The new LeanPD model follows SBCE phases with detailed activities designed to deliver necessary outcomes for the design review stages. For example, SBCE activity 1.2 'Explore Customer Value' was decomposed into four sub-activities: B1 Identify General Product Value Attributes, B2 Categorise Product Value Attributes, B3 Weight Key-Value Attributes which are the essential, quantifiable features of a system or product that directly define its value from the perspective of the consumer and other

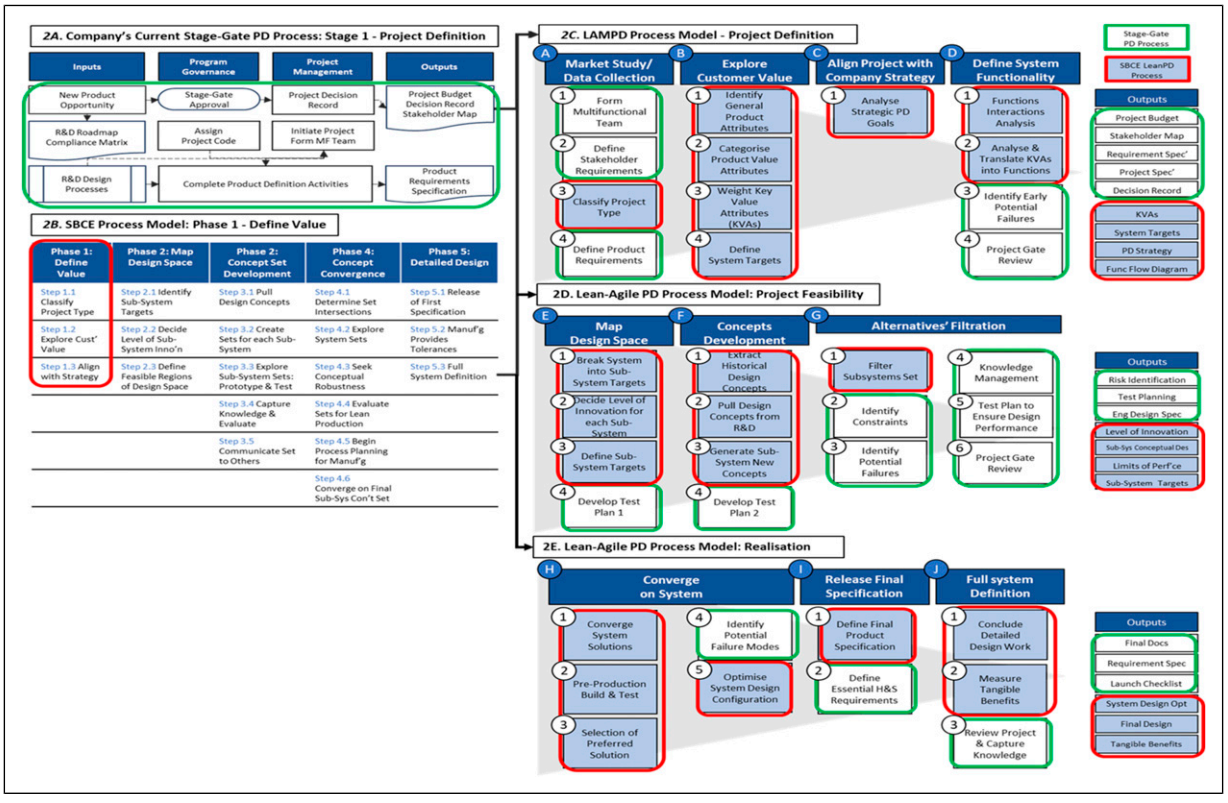


Figure 2. LAMPD process model: Project definition stage, project feasibility stage and project realisation stage. Integrating stage 1 of Atlas Copco's current stage-gate PD process model (project definition) and Phase 1 of the SBCE model (define value).

stakeholders, and B4 Define System Targets. Activities preserved from the company's existing Stage-Gate process (white blocks) were deemed necessary for corporate governance, ensuring organisational compliance and maintaining the necessary stability for Lean's long-term knowledge-building infrastructure. Activities highlighted in blue shading represent SBCE best practices. Similarly, the Project Feasibility and Project Realisation stages were transformed into the LeanPD environment following the same systematic integration approach.

Stage 1: LAMPD process model - Project definition. The LAMPD Process Model Project definition stage is the initial step that aligns the Company's 'Project Definition' stage with SBCE's 'Define Value' phase and focuses on establishing scope, requirements, and functional outcomes. It comprises four key phases, as follows:

(1) Market Study/Data Collection (A1-A4): Form cross-functional teams, define stakeholder requirements, and classify project types. Uses a Kanban-based approach for product prioritisation.
(2) Explore Customer Value (B1-B4): Identifies general product value attributes, classifies and prioritises them using weighted criteria and establishes tangible system targets aligned with customer expectations.
(3) Align Product with Company Strategy (C1): Evaluates alignment with the firm's long-term goals and examines how the PD process enhances company capabilities and stakeholder relationships.
(4) Define System Functionality (D1-D4): Translates customer value into key-value attributes, converts these into functional requirements, and analyses interactions between functions at system, subsystem, and component levels through functional flow diagrams.

The primary outputs from this stage include project and requirements specifications that define customer value creation and clarify departmental roles. A formal gate review assesses these outputs before proceeding to the next phase.

Stage 2: LAMPD process model - Project feasibility. The second stage integrates the Company's existing 'Project Feasibility' stage with SBCE's 'Map Design Space' and 'Concept Set Development' phases. This step focuses on generating and evaluating alternative design solutions for the identified sub-assemblies through three phases:

(1) Map Design Space (E1-E4): Applies systems engineering principles to decompose the overall system into subsystems and sub-assemblies. Components are categorised on a predefined innovation scale, and specific, measurable targets are established for subsystems under active development. The Functional Flow Diagram (Figure 6) was developed collaboratively by the cross-functional team, drawing on expert interviews and operational data to ensure the subsequent system decomposition and target setting (E1–E4) were based on shared, accurate process knowledge, fulfilling the SBCE requirement for cross-functional knowledge input at this stage.
(2) Concepts Development (F1–F4): Considers historical concepts from relevant previous projects and newly developed ideas. These are evaluated against defined targets, and a new set of subsystem concepts is generated for assessment.
(3) Alternatives Filtration (G1–G6): Filters candidate designs against previously identified key value attributes (KVAs) while applying design and operational constraints. This critical activity avoids premature rationalisation that could limit innovation potential. Knowledge was continuously captured and categorised throughout this step.

The output is a comprehensive engineering design specification that communicates tangible design sets to stakeholders and enables evaluation against the KVAs identified in the Project definition stage.

Phase 3: LAMPD process model - Project realisation. In the final stage, the 'Company's Project Realisation stage is integrated with SBCE's 'Concept Convergence' and 'Detailed Design' phases. In this step, the subsystems proposed in Project Feasibility are further refined, evaluated against the criteria, and merged to propose an optimised whole-product solution.

(1) Converge on System (H1–H5): Involves extensive integration of the product's subsystems into potential configurations, evaluating these combinations against cost, quality, feasibility, risk, and performance criteria and testing preferred groupings.
(2) Release Final Specification (I1–I2): Formally documents the product's design specification after reaching a consensus on the final design, avoiding premature declaration that could lead to costly modifications.
(3) Full System definition (J1–J3): Finalises the system definition after obtaining approval from operations, procurement, and quality teams, allowing further refinement, validation, and qualification of design solutions for release.

The outputs include the final specification, project benefits summary, and launch checklist. A final gate review permits the selected design to proceed to production.

Agile integration

With Stage-Gate and LeanPD approaches integrated, the next step in developing the LAMPD was to incorporate three complementary Agile elements, each serving distinct but interconnected roles.

Scrum as governance framework. The Scrum framework is the primary governance mechanism underpinning delivery cadence across all three LAMPD phases. Scrum provides a time-bounded structure as the coordinating framework through sprint cycles, reviews, and retrospectives. This rhythmic cadence helps maintain consistent progress, despite the longer lead times typically required for physical prototyping and testing in hardware development. Within each phase, the totality of activities forms a Product Backlog. When planning each sprint, the team pulls prioritised tasks to create a Sprint Backlog with a specific goal for a time-boxed period. At each sprint's end, a review assesses the value added and allows stakeholders to provide feedback, followed by a sprint retrospective to identify improvements for future ones. This is followed by a sprint retrospective to facilitate organisational learning and root cause identification (Kaizen), enabling continuous refinement of the PD process itself.

Kanban for prioritisation, visualisation, and work management. Kanban methods serve three specific purposes within LAMPD: facilitating product prioritisation through cross-functional evaluation against company vision; visualising design sets and knowledge flows to make complex SBCE activities transparent across functional boundaries; and preventing team overloading through work-in-progress limits while maintaining the breadth of exploration required in set-based design.

Agile principles as mindset and cultural drivers. The 12 Agile Principles are selectively harmonised with specific steps within each LAMPD stage, serving as the philosophical foundation governing the development approach, team interactions, and organisational culture. Rather than procedural elements, these principles drive the mindset transformation necessary for successful implementation, encouraging adaptability, customer focus, and continuous improvement, essential cultural shifts for organisations transitioning from traditional development approaches.

Conceptual integration: Bridging exploration and convergence. The effectiveness of the LAMPD model relies on the interplay between its components. SBCE encourages the disciplined mechanism for parallel design space exploration and systematic risk reduction. Simultaneously, the elements from Agile - time-boxed constraints, frequent feedback cycles (Sprint Review/Retrospective), and visualisation tools (Kanban) - provides the development rhythm to drive convergence, mitigate analysis paralysis, and ensure early, continuous stakeholder involvement. This dynamic creates a structured yet balanced tension between exploration and urgency that is crucial for accelerating decision-making in complex hardware PD environments.

LAMPD final model

Figure 3 depicts how Scrum, Kanban, Stage-Gate, and SBCE methodologies are synthesised within the LAMPD model's Product Definition phase. All activities across the three stages of the Model form the Product Backlog per Scrum methodology, starting with Stage 1 and evolving through stage transitions. The implementation process begins when the team extracts prioritised tasks from the Product Backlog (1) to create the Stage Product Backlog (2) (indicated by the red box), defines a specific goal for the Sprint duration (3), and generates Sprint Backlogs (4) (marked by green boxes). The Figure shows a Stage Product Backlog connecting to three consecutive Sprint Backlogs (A1–A4, B1–B4, and C1–D4). Throughout implementation, the Scrum framework coordinates development work (5), establishing rhythmic patterns for daily teamwork and progress monitoring. At the same time, Agile Principles (6) influence team perspectives and methods, and Kanban's work-in-progress constraints (7) maintain focus on priority tasks while preventing resource overextension.

A review is conducted at each Sprint's end to assess the value added and allow stakeholders to provide feedback (8). Following this, a sprint retrospective identifies ways to improve future sprints and development direction (9). This cyclical approach helps continuously refine the product and PD process until all tasks are completed. At this point, a gate review transitions the project to the next LAMPD phase. This integrated approach enables teams to experience the benefits of both methodologies while maintaining a structured yet flexible development process.

Theoretical foundations and harmonisation approach

The LAMPD model addresses critical hardware PD tensions by integrating complementary aspects of both methodologies. It combines SBCE's systematic documentation with Agile's collaborative knowledge sharing, creating structured capture mechanisms within sprint cycles. The model maintains parallel exploration of multiple design alternatives while introducing time constraints and prioritisation from Agile for timely convergence. Customer involvement is enhanced through frequent sprint review feedback while maintaining systematic value analysis through key-value attributes. Analytical decision tools from Lean PD (trade-off curves, FMEA) are integrated with Agile's rapid feedback cycles, enabling evidence-based yet responsive decision-making.

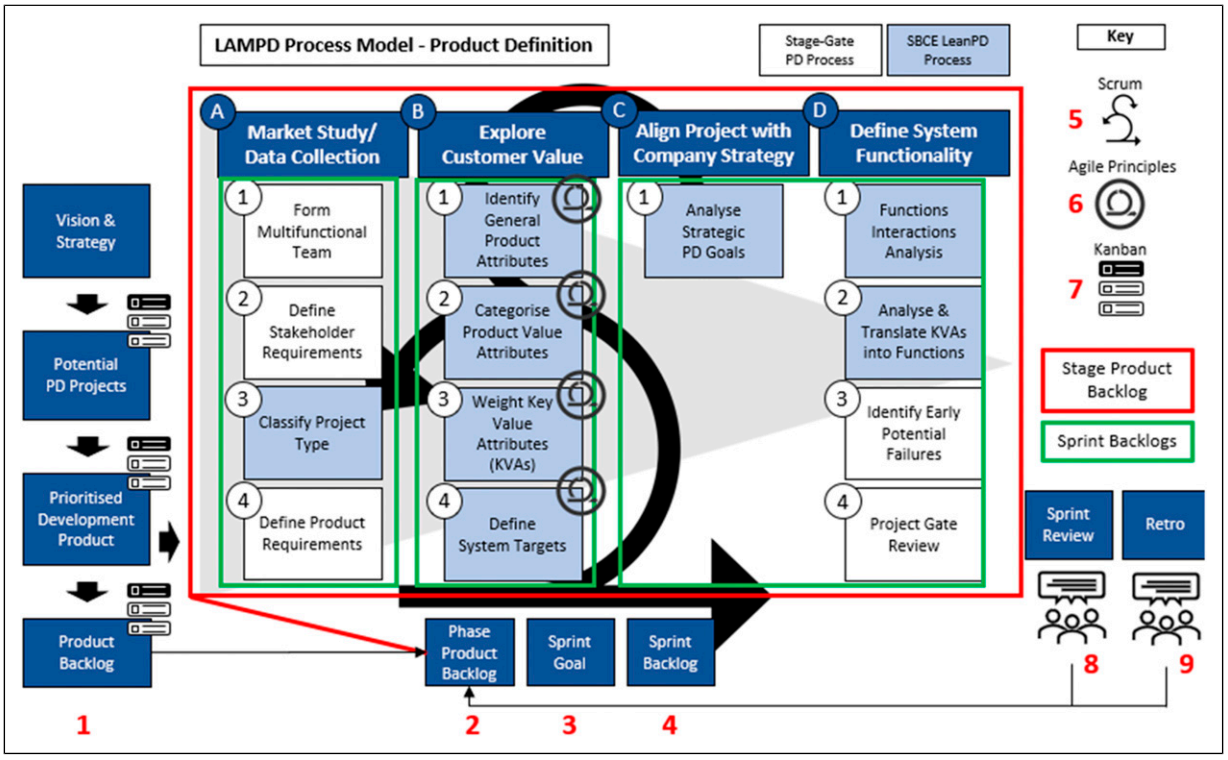


Figure 3. Harmonisation of Kanban, Scrum, and Agile principles and Artefacts into the project definition stage of the LAMPD process model.

This integration addresses key limitations each approach faces individually: Scrum's struggle with longer hardware prototyping cycles, Kanban's lack of systematic design exploration, and SBCE's perceived slow convergence. By combining these approaches, LAMPD creates a balanced tension between exploration and convergence, structure and flexibility, well-suited to hardware development's unique challenges.

Case study context

Atlas Copco Henrob, a UK manufacturer of self-piercing riveting systems with 200 employees at Deeside, serves global automotive OEMs and tier-one suppliers. While the RandD department had implemented various improvement initiatives, these were done in isolation, hindering transformation toward an integrated Lean-Agile PD environment. An initial performance assessment conducted in 2022 identified four LeanPD improvement opportunities: unclear product definition and value alignment at the project outset; premature convergence on single design solutions; insufficient knowledge management; and difficulty integrating multiple subsystems cohesively (Flores et al., 2023). These challenges provided the foundation for implementing the LAMPD model within a controlled case study environment to evaluate its practical effectiveness in addressing real-world manufacturing constraints.

The Rivet Feed-Stick system (shown in Figure 4-(c)) was selected as the focus for the LAMPD implementation case study for several reasons:

(1) It offered a low-risk opportunity to explore a project aligned with the Company's strategic vision
(2) It presented a manageable challenge with several possible creative design solutions
(3) It allowed for the practical application of 3D modelling and printing techniques
(4) It provided a representative but controlled environment to evaluate the LAMPD model

Figure 4 shows the configuration of a typical blow-feed SPR tool, highlighting the Rivet Feed-Stick's location on the rivet setter. Figure 4-(a) shows the rivet feeder system mounted on robotic arm ready for operation. The rivet setter mounted on a C-Frame as depicted in Figure 4-(b). The Rivet Feed-Stick (Figure 4-(c)) is fitted to the river setter and it is a critical component used on SPR tools to guide and position rivets precisely for insertion by the rivet punch.

The specific focus of improvement was the area at the bottom of the Rivet Feed-Stick, where rivets are guided and positioned for insertion, as shown in Figure 4-(1), delivered to punch nose as shown in Figure 4-(2), and pushed into punch-ready position as shown in Figure 4-(3).

LAMPD implementation: Approach and activities

To enhance clarity and analytical rigour, this section examines the implementation through the lens of the LAMPD.

LAMPD phase 1: Project definition

Activities B: Explore customer value. Activities A: 'Market Study/Data Collection' had been completed separately and the Rivet Feed-Stick system identified as the priority product for development. Following the LAMPD process model, the team began by implementing activity B1 'Identify Generic Product Value Attributes' to identify value attributes of the Rivet Feed-Stick sub-assembly. These attributes were systematically extracted from the requirement specification and project scope documents and refined through team discussions. The resulting attributes were classified into eight categories to group similar values and emphasise primary focus areas, as shown in Figure 5-(a).

Once values were identified and classified, the application of activity B3 of 'Weight Keyvalue Attributes' started using the Analytical Hierarchy Process (AHP) matrix shown in Figure 5-(b). This was used to systematically prioritise the value attributes through pairwise comparisons.

The Company's project team provided input values to ensure that the results accurately reflected organisational priorities. The AHP analysis at Table 3 resulted in the following prioritisation of value categories: Reliability (30%), Cost (25%), Manufacturability (15%), and Maintenance (11%). These top four categories were designated Key-Value Attributes (KVAs) for the new Rivet Feed-Stick system, allowing the team to focus engineering efforts on the most significant areas. For each KVA, the team established tangible, measurable system targets to guide subsequent design evaluations, as shown in Figure 5-(C).

Activities D: Define system functionality. Activity C confirmed that the project continued to align with company strategy. Phase 1 then concluded with system function analysis through a Functional Flow Diagram that visualised operations and component interactions (Figure 6).

The FFD enabled functional statements and failure mode analysis, identifying 'Check Rivet Presence' as the highest-risk function. A gate review confirmed the project's foundation, addressing the initial challenge of unclear product definition.

LAMPD phase 2: Project feasibility

Activities E: Map design space. Following LAMPD principles, the team developed an innovation classification diagram to identify and prioritise subsystems for focused innovation efforts. This classification considered the potential improvement of each subsystem while maintaining

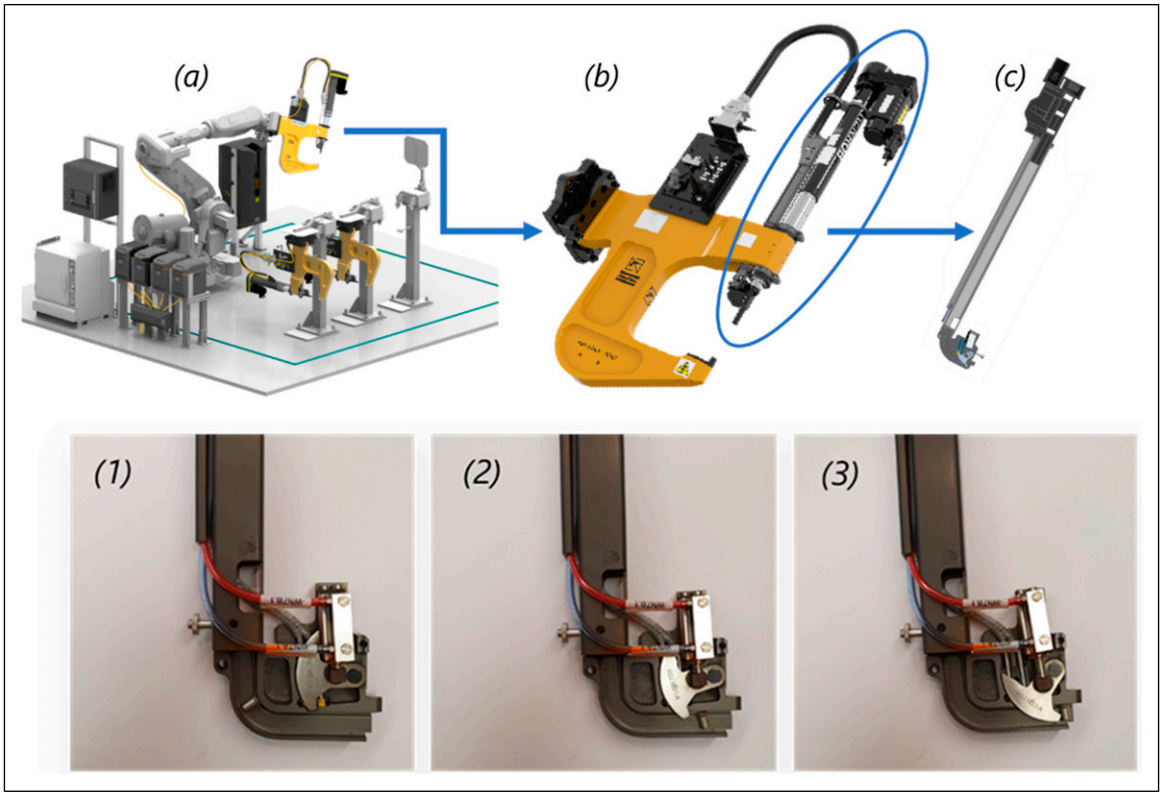
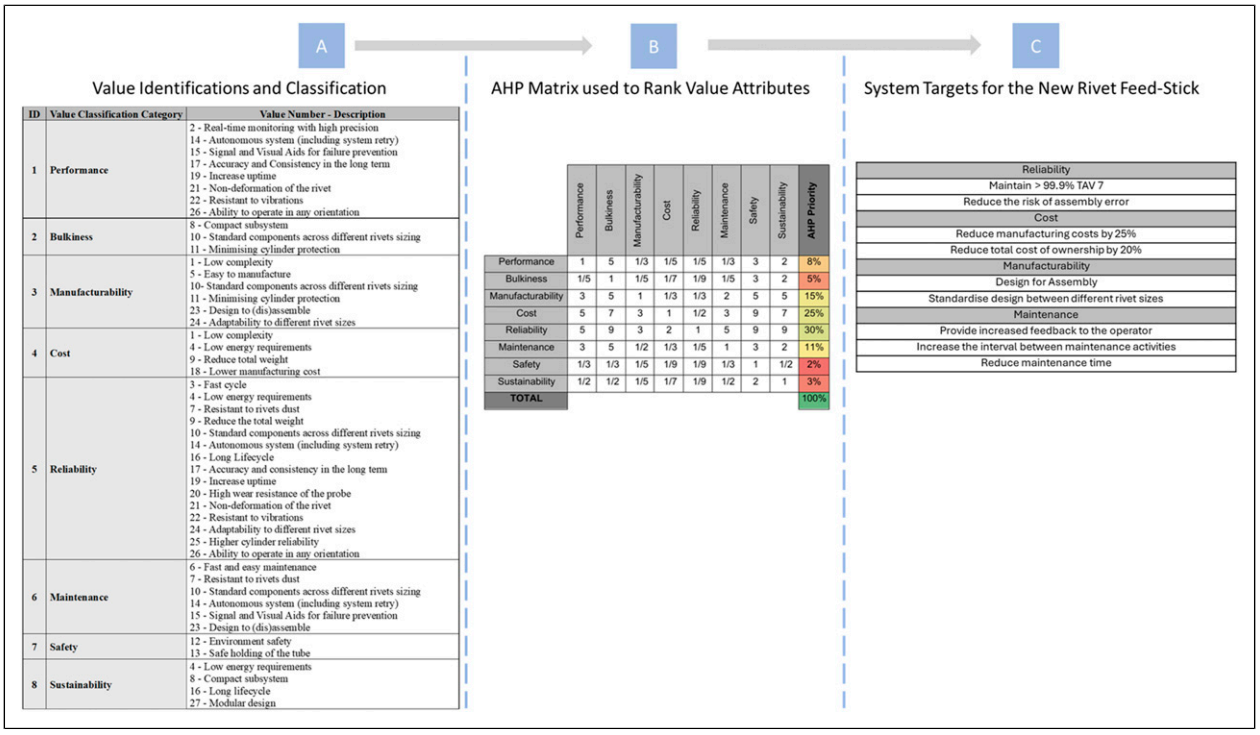


Figure 4. The configuration of a typical blow-feed SPR tool.



ID	Value Classification Category	Value Number - Description
1	Performance	2 - Real-time monitoring with high precision 14 - Autonomous system (including system retry) 15 - Signal and Visual Aids for failure prevention 17 - Accuracy and Consistency in the long term 19 - Increase uptime 21 - Non-deformation of the rivet 22 - Resistant to vibrations 26 - Ability to operate in any orientation
2	Bulkiness	8 - Compact subsystem 10 - Standard components across different rivets sizing 11 - Minimising cylinder protection
3	Manufacturability	1 - Low complexity 5 - Easy to manufacture 10- Standard components across different rivets sizing 11 - Minimising cylinder protection 23 - Design to (dis)assemble 24 - Adaptability to different rivet sizes
4	Cost	1 - Low complexity 4 - Low energy requirements 9 - Reduce total weight 18 - Lower manufacturing cost
5	Reliability	3 - Fast cycle 4 - Low energy requirements 7 - Resistant to rivets dust 9 - Reduce the total weight 10 - Standard components across different rivets sizing 14 - Autonomous system (including system retry) 16 - Long Lifecycle 17 - Accuracy and consistency in the long tem 19 - Increase uptime 20 - High wear resistance of the probe 21 - Non-deformation of the rivet 22 - Resistant to vibrations 24 - Adaptability to different rivet sizes 25 - Higher cylinder reliability 26 - Ability to operate in any orientation
6	Maintenance	6 - Fast and easy maintenance 7 - Resistant to rivets dust 10 - Standard components across different rivets sizing 14 - Autonomous system (including system retry) 15 - Signal and Visual Aids for failure prevention 23 - Design to (dis)assemble
7	Safety	12 - Environment safety 13 - Safe holding of the tube
8	Sustainability	4 - Low energy requirements 8 - Compact subsystem 16 - Long lifecycle 27 - Modular design

	Performance	Bulkiness	Manufacturability	Cost	Reliability	Maintenance	Safety	Sustainability	AHP Priority
Performance	1	5	1/3	1/5	1/5	1/3	3	2	8%
Bulkiness	1/5	1	1/5	1/7	1/9	1/5	3	2	5%
Manufacturability	3	5	1	1/3	1/3	2	5	5	15%
Cost	5	7	3	1	1/2	3	9	7	25%
Reliability	5	9	3	2	1	5	9	9	30%
Maintenance	3	5	1/2	1/3	1/5	1	3	2	11%
Safety	1/3	1/3	1/5	1/9	1/9	1/3	1	1/2	2%
Sustainability	1/2	1/2	1/5	1/7	1/9	1/2	2	1	3%
TOTAL									100%

Reliability
Maintain > 99.9% TAV 7
Reduce the risk of assembly error
Cost
Reduce manufacturing costs by 25%
Reduce total cost of ownership by 20%
Manufacturability
Design for Assembly
Standardise design between different rivet sizes
Maintenance
Provide increased feedback to the operator
Increase the interval between maintenance activities
Reduce maintenance time

Figure 5. Exploring customer value *(TAV: total asset visibility - concept for real-time tracking and visibility of assets).

alignment with the established KVAs. The analysis identified three primary subsystems for the Rivet Feed-Stick: the feeder body, the frame, and the sensor housing, as shown in Figure 7.

The system-level KVAs were then cascaded to create specific targets for each subsystem, ensuring all development activities aligned with the overall value objectives (Table2). These subsystem targets provided a framework for

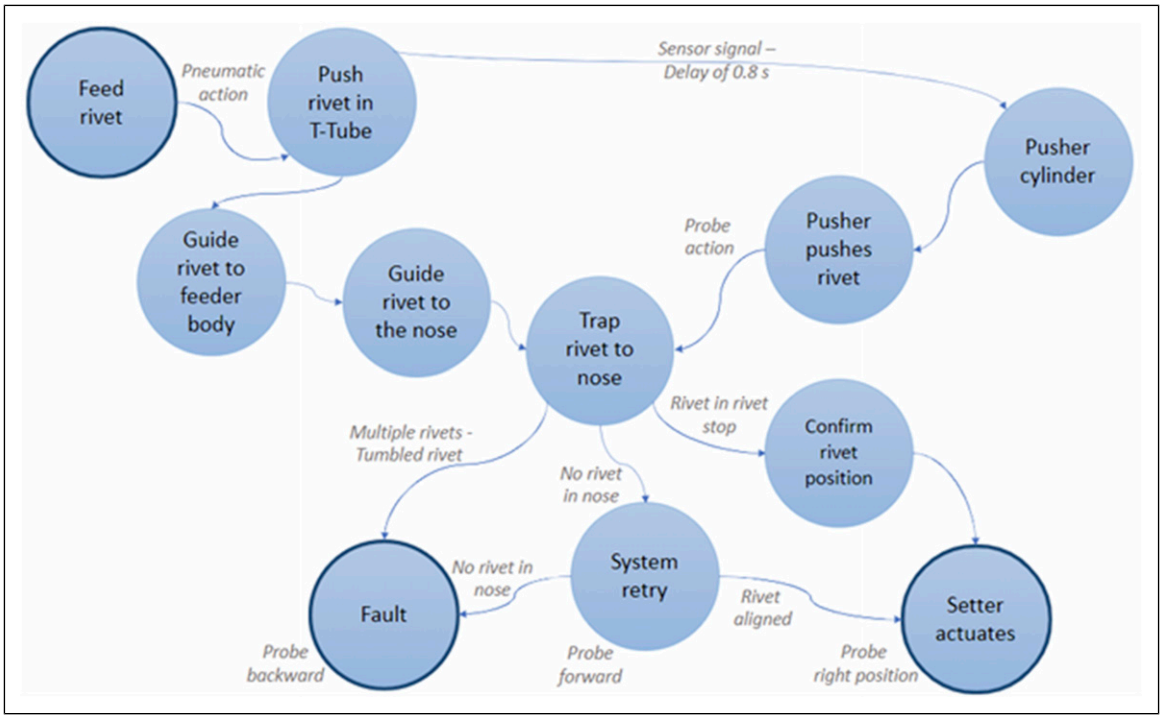


Figure 6. Simplified functional flow diagram of the Rivet Feed-Stick sub-assembly.

evaluating design alternatives in the subsequent development activities. A Design Verification Plan and Report was prepared based on these subsystem targets, outlining the functional tests and qualification activities required to evaluate the design solutions.

Activities F: Concepts' development. The team began by examining previous design concepts and test reports from earlier generations of the Rivet Feed-Stick system. This retrospective analysis revealed a history of continuous system improvements and recurrent issues, including wear, robustness, and rivet positioning challenges. This knowledge formed an essential foundation for the current development, ensuring that previous learnings were integrated into the new design approach. Following SBCE principles, the team systematically mapped each subsystem's design space, identifying potential solution alternatives. This process generated 33 conceptual designs (23 for the feeder body and 10 for the frame) categorised by function. Two distinct sensor technologies were considered for rivet monitoring: inductive and laser-based. This structured exploration created a comprehensive design space with up to 2640 potential configurations, as illustrated in Figure 8.

Activities G: Alternatives' filtration. To narrow this extensive design space within the project timeline, the team applied a systematic filtration process employing four weighted criteria. These criteria were weighted based on the KVAs established in Phase 1 (Reliability 30%, Cost 25%, Manufacturability 15%), ensuring that all decisions prioritised organiational value.

(1) Impact on KVAs
(2) Technology Readiness Level (TRL)
(3) Manufacturing complexity (via trade-off curve analysis)
(4) Manufacturing cost (via trade-off curve analysis)

Initial evaluation against criteria 1 and 2 reduced the number of design concepts to nine. The team then developed trade-off curves comparing manufacturing cost versus complexity for the remaining options, as shown in Figure 9. These trade-off curves were constructed using relative cost estimations from the procurement team and complexity scores derived from Design for Manufacture and Assembly (DFMA) guidelines (part of the KVA framework). This visual approach ensured transparent decision-making by forcing trade-offs to be made through the lens of efficiency.

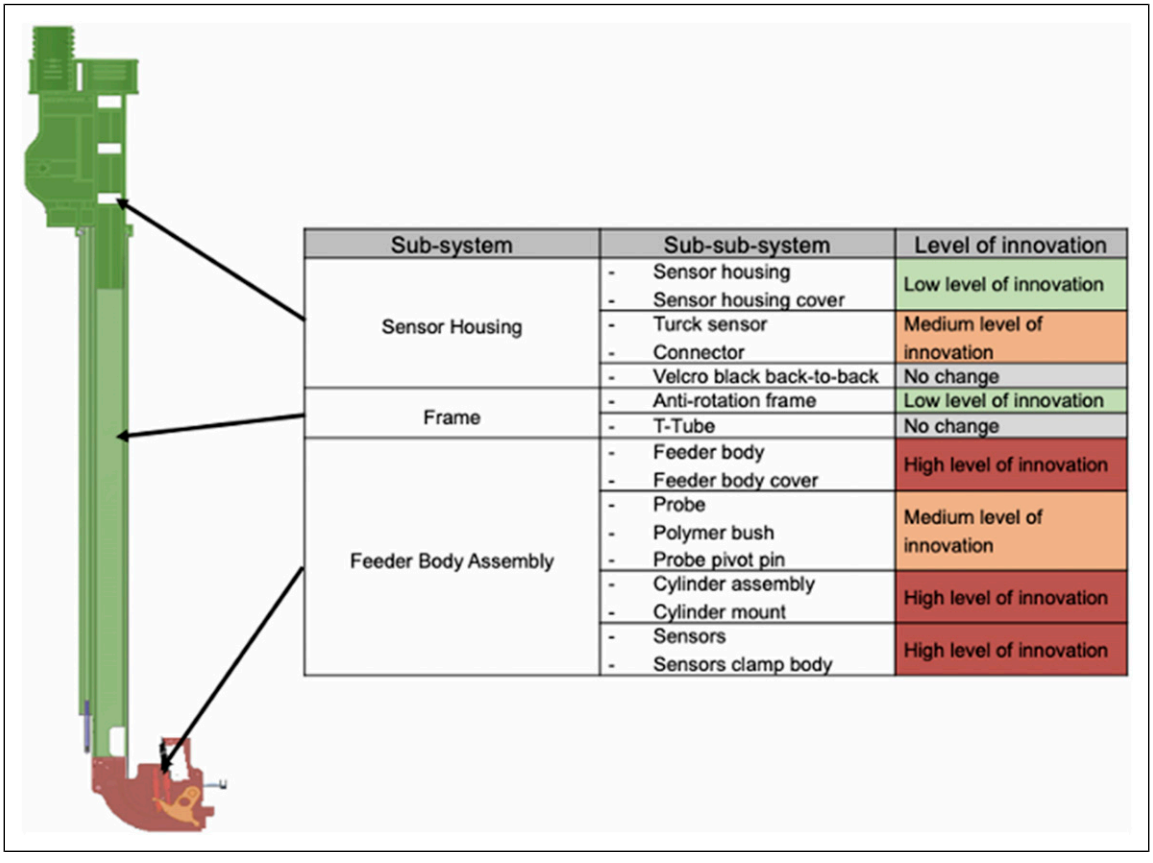


Figure 7. Innovation classification diagram for the three Rivet Feed-Stick subsystems.

Table 2. Subsystem targets for the new Rivet Feed-Stick.

Subsystem	Subsystem targets
Frame	• Low manufacturing cost • Safe and reliable holding of the tube • Lighter weight
Feeder body	• Low manufacturing cost • Low complexity – DFMEA • Reliable and performant • Compact • Adaptability • Integration of sensors
Sensor housing	• Low manufacturing cost • Low complexity – DFMEA • Integration of sensors

This analysis eliminated two additional design configurations (2.4 and 2.8) based on their unfavourable cost-complexity positioning. The filtration process resulted in eight remaining design options for further evaluation in the next phase (Table 3).

The team then conducted a Design Failure Mode and Effects Analysis (DFMEA) to systematically evaluate potential failure modes of the selected design options (Table 4). This analysis further enhanced understanding of design risks and provided additional criteria for the final convergence process. The Project Feasibility phase successfully addressed another key improvement opportunity from the initial assessment: the tendency to converge on a single design solution too quickly. By implementing SBCE principles within the LAMPD, the team maintained multiple design alternatives throughout the feasibility phase, enabling more comprehensive solution space exploration. Systematic approaches to root cause analysis are necessary for identifying waste sources in product development processes.

A methodological framework mapping causal relationships between common product development issues and their underlying waste mechanisms is proposed by Pessôa and Seering (2014). Their study shows how, if ignored, waste traps - interconnected networks of causative factors - can seriously impair development performance. Organisations can more successfully prioritise improvement initiatives based on measurable impact assessments rather than

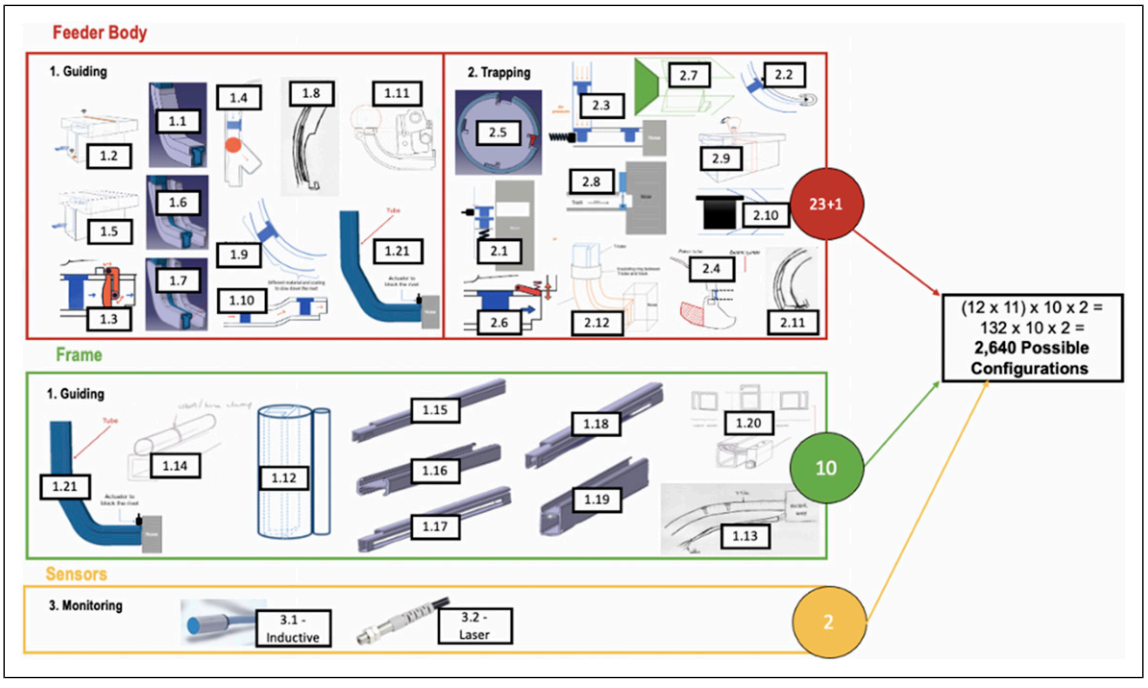


Figure 8. Rivet feed-stick subsystem sets.

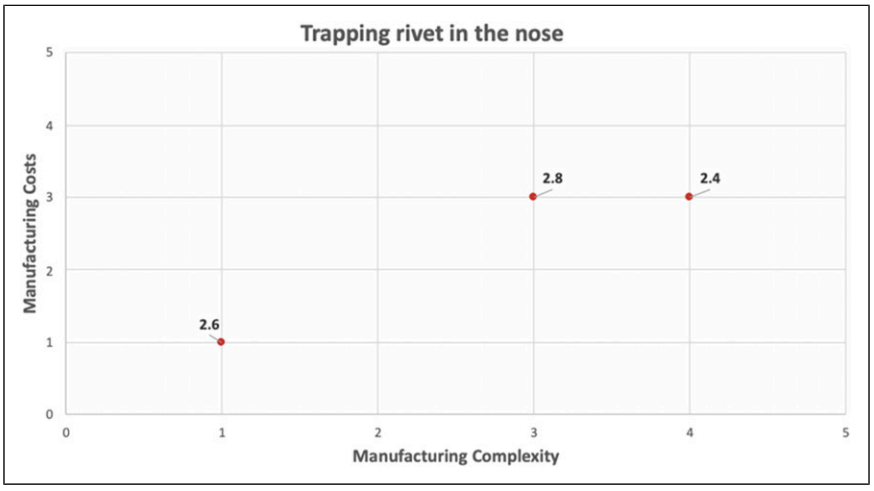


Figure 9. Scatter graph comparing manufacturing cost and complexity of trapping systems within the feeder body.

subjective opinions by combining this waste identification method with Design Failure Mode and Effects Analysis (DFMEA) applications. In this application, combining the DFMEA methodology with insights from waste-trap analysis (Pessôa and Seering, 2014) allowed the team to not just identify potential failures, but also uncover their underlying causal mechanisms and systemic inefficiencies, thereby strengthening the filtration rationale. Development teams can systematically find hidden inefficiencies that conventional process improvement techniques might miss thanks to this integration.

LAMPD phase 3: Project realisation

Activities H: Converge on system. The final phase focused on integrating subsystem solutions into coherent system configurations and converging on an optimal design. The team employed an Integration Conflict analysis technique to evaluate how different subsystem options would function together, identifying potential interface challenges or performance conflicts. This analysis resulted in six viable system configurations (C1–C6), each representing a different combination of subsystem solutions, as shown in Figure 10-(a).

The team developed a Pugh matrix evaluating each system against the established KVAs to select the optimal configuration. This systematic assessment, shown in Table 5, identified configuration C3 (with rivet guidance through the feeder body and inductive sensor monitoring) as the highest-performing option. Configuration C1 was chosen as the datum (baseline concept) for the Pugh Matrix analysis because it represented the lowest-complexity system that still satisfied all minimum functional requirements identified in Phase 1, offering a realistic, feasible benchmark against which alternatives could be rigorously compared.

Detailed design and prototyping. Following the configuration selection, the team developed detailed CAD models of configuration C3 as shown in (Figure 10-(b)) and produced physical pre-production prototypes using 3D printing technologyas presented in Figure 10-(c). These prototypes enabled further optimisation and validation of the design concept through physical testing and evaluation.

Table 3. Final subsystem options.

All proposed alternatives sub-system concepts													
Sub-system	Functions	Alt sol 1	Alt sol 2	Alt sol 3	Alt sol 4	Alt sol 5	Alt sol 6	Alt sol 7	Alt sol 8	Alt sol 9	Alt sol 10	Alt sol 11	Alt sol 12
Guiding system	Guiding through feeder body	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.21
	Guiding through frame	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.20			
Trapping system	Trapping rivet in nose	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12
Monitoring system	Detecting rivet in system	3.1	3.2										

Table 4. DFMEA for new Rivet Feed-Stick design options.

Loose feed stick system - Designs								General customer impact			
ID	Sub-Assy	Concept	Potential failure mode	Potential effect of failure	Potential mechanism/Cause of failure	Current detection method	Current controls	S	O	D	RPN
1	Feeder body assembly	1.11	Feeder body does not bring the rivet to the nose	No rivets in nose	Rivet blocked in T-tube Dust on track	None	None	2	3	10	60
2	Frame assembly	1.12	Frame bends	Rivet stuck	Robot controlling loose feed stick system moving	None	Plastic material not rigid enough	3	5	10	150
3	Frame assembly	1.16	T-tube not fixed to the frame	T-tube moving causes jam	Space designed for T-tube incorrect	None	Design dimensions validation	3	5	10	150
4	Frame & feeder assembly	1.21	Rivet blocked in T-tube	No rivet in nose	Dust/friction	None	T-tube bending angle controlled	2	3	10	60
5	Frame & feeder assembly	1.21	T-tube damaged by surroundings	Rivet stuck	Environment can damage T-tube	None	None	8	3	10	240
6	Feeder body assembly	2.6	Spring does not allow rivet to travel through	No rivet in nose	Excessive pivot/ spring wear	None	None	6	2	10	120
7	Feeder body assembly	2.6	Spring does not return and trap rivet	No rivet in nose	Excessive pivot/ spring wear	None	None	6	2	10	120
8	Sensor housing	3.1	Rivet not detected in nose	System stop	Rivet too small/fast	No sensor signal	Careful sensor choice	4	4	1	16
9	Sensor housing	3.1	Rivet not detected in nose	System stop	Rivet too small/fast	No sensor signal	Careful sensor choice	4	4	1	16

The selection of the preferred solution at Figure 10-(c) integrated the optimal subsystems comprising configuration C3. Key design decisions included:

(1) Selecting a feeder body design that guided rivets internally rather than through the frame, avoiding bend radius issues that could limit operation in space-restricted applications.
(2) Choosing inductive sensors over laser-based alternatives after identifying that dust particles from the rivet's protective coating could potentially obstruct laser beams and prevent reliable operation.

This second decision exemplifies the value of the LAMPD approach. Initial design space mapping identified both sensor types as viable alternatives, but knowledge gained during concept development revealed the potential dust interference issue, a previously unidentified constraint. Trade-off analysis showed that inductive sensing scored higher on reliability and manufacturability requirements when these constraints were incorporated despite higher initial component costs. This outcome demonstrates how LAMPD's structured yet flexible approach facilitates knowledge-based convergence toward optimal solutions.

The Project Realisation phase concluded with release of the final specification, and full system definition. This phase successfully addressed the remaining improvement opportunities identified in the initial assessment: knowledge management gaps and system integration challenges. The systematic approach to concept evaluation and integration enabled effective knowledge capture and transfer, while the structured convergence process facilitated logical system-level integration.

Results and benefits

The implementation of the LAMPD Process Model resulted in a significantly improved Rivet Feed-Stick design with measurable benefits across multiple dimensions:

(1) Component Reduction: The design achieved a 53% component reduction (nineteen to nine), addressing manufacturability and cost KVAs. This yielded cascading benefits: 35% reduced assembly time,

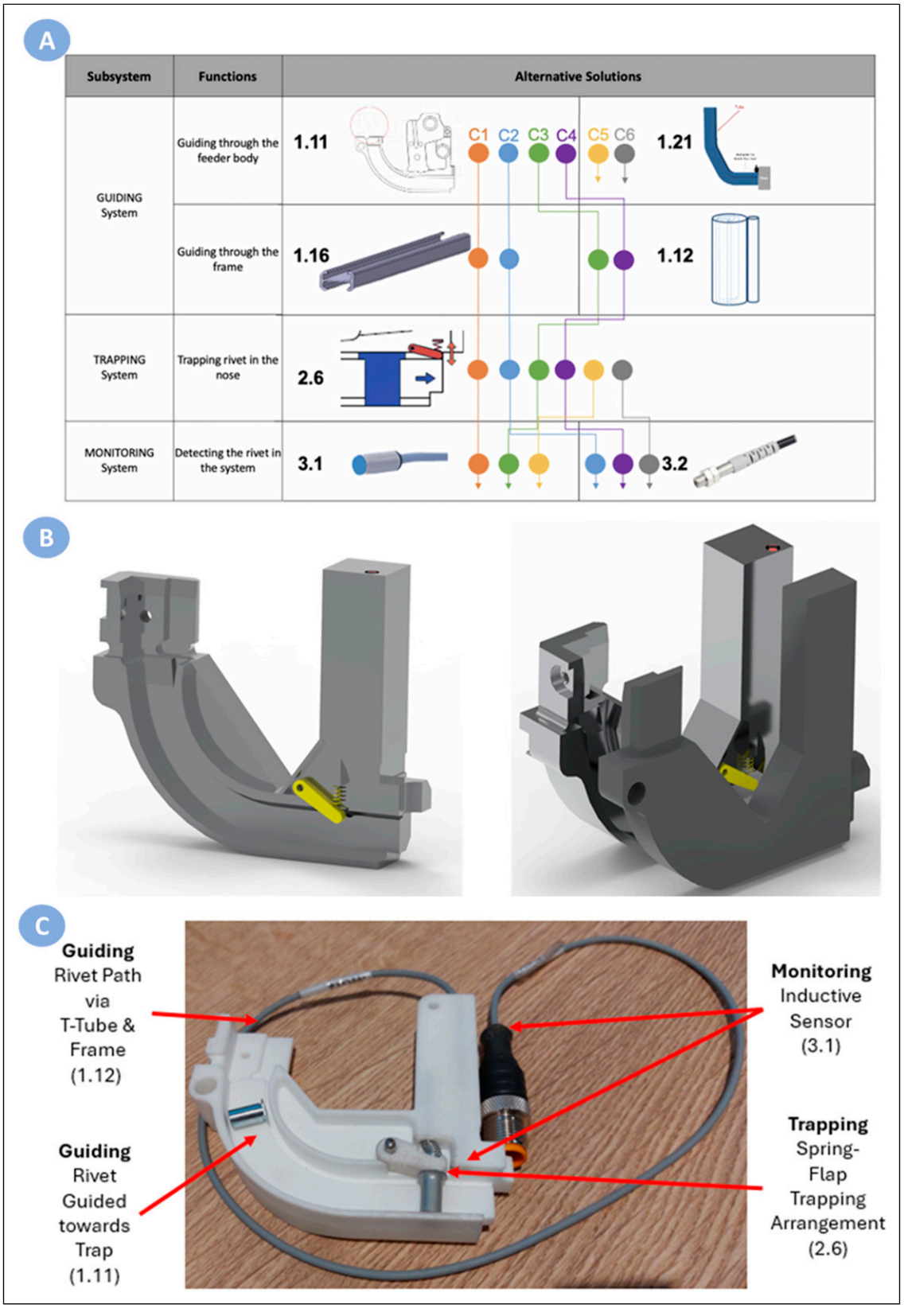


Figure 10. (a) Converged upon system configurations for the new Rivet Feed-Stick design; (b) CAD models of alternative rivet feed stick subsystem designs; (c) 3D-printed example of the guiding, trapping, and monitoring subsystems.

Table 5. Pugh matrix used to assess the final sets of subsystem design options.

		System configuration					
KVA	Loads of importance	C1	C2	C3	C4	C5	C6
Reliability	37%	6	5	7	6	3	3
Cost	31%	4	2	6	4	6	4
Manufacturability	19%	7	5	7	5	7	7
Maintenance	13%	4	4	3	3	5	5
Score		5.3	3.9	6.2	4.8	5.0	4.3

decreased manufacturing complexity (level 4 to 2), and enhanced reliability. This simplification created sustainability advantages through reduced material consumption. This initial application of SBCE confirmed the tendency for first-time SBCE use to uncover and eliminate significant, previously hidden inefficiencies inherent in the legacy design.

(2) Sensor Optimisation: The revised design eliminated two sensors and implemented a more reliable inductive sensing approach, addressing the high-risk 'Check Rivet Presence' function.
(3) Reliability Improvement: The new sensor arrangement eliminated false readings (previously occurring in 12% of operations), addressing the highest-priority KVA.
(4) Manufacturing Simplification: The design reduced manufacturing complexity and decreased assembly time by approximately 35% in initial trials.
(5) Knowledge Capture: Process metrics demonstrated measurable improvements: cross-functional meeting frequency increased from weekly to daily or bi-daily, decision cycle time reduced from 3 weeks to days for concept evaluation, and knowledge documentation completeness improved by 25%.

These tangible benefits demonstrate the effectiveness of the LAMPD Process Model in delivering improvements aligned with the prioritised KVAs. The implementation successfully transformed the specific product design and the development process used to create it.

Discussion

Implementation challenges

The principal implementation challenges identified during LAMPD application yield valuable insights for future implementations. Aligning Sprint cadence with phase boundaries emerged as a significant challenge, requiring flexibility where activities sometimes crossed phase boundaries to maintain momentum. The team managed this tension through close collaboration between Scrum masters and development teams, ensuring meaningful transitions while maintaining an agile cadence. This dual-cadence alignment issue is consistent with findings in hardware-Agile literature (Drutchas and Eppinger 2022) and was mitigated here by defining stage gates as 'knowledge-gating' points rather than rigid time barriers, allowing sprints to complete their goals even if they slightly overlapped traditional phase timelines.

The concurrent adoption of multiple methodologies presented challenges despite the team's experience with Scrum. Integrating Lean PD approaches with Agile principles, and Kanban required substantial adaptation to work practices. This was addressed through comprehensive training and selecting a straightforward project that allowed thorough process exploration. Sprint retrospectives identified mistakes that became learning opportunities, reinforcing the continuous improvement mindset essential to both methodologies. Balancing historical knowledge with innovation proved challenging. While SBCE encourages evaluating historical concepts, this presented hurdles when reliable existing knowledge was scarce. The team addressed this by defining targets and KVAs collectively, creating a mechanism for assessing solutions against measurable criteria. This prevented decision paralysis while ensuring historical knowledge informed but didn't constrain innovation.

Defining appropriate scope and requirements depth presented challenges in Phase 1. The team needed sufficient information for effective decisions without analysis paralysis. Through cross-functional collaboration, they developed a methodical approach balancing comprehensiveness with practicality, ensuring that requirements guided development while remaining adaptable to new insights. These challenges highlight areas for future improvement: establishing common terminology across business units, developing knowledge-based environments that enable dynamic knowledge capture and reuse throughout PD, and addressing supply chain collaboration more effectively. Addressing these challenges will further enhance LAMPD implementation in manufacturing contexts.

Practical implications

The LAMPD Process Model offers significant practical implications for engineering organisations, particularly those in manufacturing sectors:

Implementation strategy. Organisations seeking to implement LAMPD should consider the following staged approach to mitigate transition risks while building organisational capability. This staged approach aligns with established change management principles and reduces implementation risk.

(1) Map existing PD processes against LAMPD principles, identifying specific pain points addressable through integration
(2) Identify a non-critical, medium-complexity pilot project with a team willing to experiment and learn
(3) Conduct training workshops on key LAMPD techniques, including SBCE, Sprint planning, and knowledge capture
(4) Implement LAMPD with coach/facilitator support
(5) Document measurable outcomes and identify improvement areas
(6) Refine the approach based on the organisational context before broader deployment

Implementation costs and benefits. LAMPD implementation costs (training, temporary productivity decreases, tool investments) were outweighed by substantial benefits: £12,000 annual material cost savings per line, 22% increased production capacity, and approximately £30,000 annual savings per line from eliminating false readings. Returns exceeded costs within the first year.

Engineering process transformation. For engineering managers, LAMPD offers a strategic approach to process transformation through three key elements:

(1) Functional mapping to identify critical uncertainties and quantifiable KVAs
(2) Exploring component interactions via hypothesis-driven development
(3) Accelerated prototyping using targeted subsystem testing

Composing design challenges into manageable subsystems reduces complexity, minimises experimental noise, and generates more meaningful performance trade-offs. This approach enables more efficient knowledge generation and design refinement, particularly in early-stage PD.

Sustainability implications. The significant reduction in component count achieved through applying the LAMPD Process Model has broader sustainability implications. Fewer components result in reduced material consumption, simplified supply chains, extended product longevity, and reduced manufacturing costs. These outcomes align with circularity principles, suggesting that the model may effectively enhance a company's sustainability credentials.

Broader impact on engineering practice. The case study demonstrates how the LAMPD Process Model contributes to advancing manufacturing practice by providing a harmonised approach that leverages both Lean and Agile methodologies. Key impacts include enhanced decision quality by integrating analytical tools (AHP, trade-off curves, DFMEA) with iterative feedback mechanisms, enabling more informed design decisions based on validated knowledge rather than assumptions. The model also improves resource utilisation by structuring the exploration of multiple design alternatives, focusing innovation efforts on high-value subsystems while standardising proven solutions for lower-priority components.

Additionally, LAMPD accelerates knowledge creation by combining set-based exploration with time-boxed iterations, generating and validating design knowledge that creates organisational assets applicable beyond individual projects. Perhaps most significantly, it drives cultural transformation, shifting engineering mindset from sequential, single-solution thinking to parallel exploration of alternatives, fundamentally transforming organisational capability. These impacts suggest that LAMPD offers potential benefits beyond immediate project outcomes to enhance overall organisational adaptability and innovation capacity in manufacturing environments.

Limitations. While the findings of this study are promising, several limitations should be acknowledged:

(1) Single case context: The study focused on a relatively benign project in a specific environment. Findings may apply primarily to medium-sized manufacturing organisations with established Stage-Gate processes, while applicability to large-scale, regulated environments remains untested.
(2) Limited historical data: Reliance on qualitative feedback and limited field data may not represent contexts with more comprehensive historical information.
(3) Team composition: The team's prior experience with Scrum practices may have facilitated adoption more readily than in organisations with limited agile expertise.
(4) Project complexity: Applications to more complex systems may reveal additional implementation challenges.
(5) Timeframe constraints: The 4 months limited observation of long-term effects.
(6) Observer Effect: As the research team was embedded directly within the Atlas Copco project team, the potential for an observer effect influencing team behaviour (e.g., increased cross-functional participation or process adherence) must be acknowledged as a limitation. We addressed this through ongoing team retrospectives and critical self-reflection throughout

the study to maintain transparency regarding the nature of the research involvement.

These limitations suggest the need for further validation across multiple settings with varying project complexity and organisational contexts to substantiate the model's broader applicability.

Conclusion

This empirical case study promising empirical evidence of successful LAMPD implementation in manufacturing contexts. We documented the model's application, demonstrating the successful integration of Lean knowledge-driven practices with Agile responsiveness within a Stage-Gate model. The rigorous application of triangulated data collection methods strengthens the validity of these findings. The implementation yielded quantifiable benefits: 53% component reduction, elimination of false readings, and reduced manufacturing complexity, validating LAMPD's potential to deliver superior design solutions. Implementation transformed the Company's approach through enhanced collaboration and knowledge capture. Concrete improvements included increased capacity to evaluate multiple design alternatives (from 1 to 2 to 33 designs), 40% greater cross-functional participation, and a shift from solution-focused to exploration-oriented thinking. Analysis of challenges and lessons revealed the importance of mindset transformation, adaptive methodology implementation, and structured knowledge management for successful application.

The LAMPD model addresses a critical gap in manufacturing PD by empirically validating methodology harmonisation, demonstrating SBCE within time-boxed iterations, and providing implementation patterns and metrics for evaluating hybrid approaches. This enables organisations to develop products meeting customer needs while optimising resources. Future work will validate the model across different sectors, conduct longitudinal studies, and explore advanced tools to enhance its effectiveness. This research makes three distinct contributions: (1) empirical validation of integrated methodology implementation, (2) systematic documentation of transformation processes, and (3) quantified benefits assessment in manufacturing contexts.

ORCID iD

Glyn P Fargher https://orcid.org/0000-0003-2134-274X

Ethical considerations

Respondents gave verbal consent for the collection, analysis and publication of the anonymised data for this study.

Consent to participate

Verbal consent has been granted for the use of personal information through informed consent processes that ensured participants received clear communication of information, demonstrated comprehension of that information, and participated voluntarily.

Consent for publication

Consent for publication was obtained from all participants in this case study.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

References

Al-Ashaab A, Golob M, Attia UM, et al. (2013) The transformation of product development process into lean environment using set-based concurrent engineering: a case study from an aerospace industry. *Concurrent Engineering Research and Applications* 21(4): 1063293X13495220.

Albers A, Heimicke J, Spadinger M, et al. (2020) 'A systematic approach to situation-adequate mechatronic system development by ASD - agile systems design'. *Procedia CIRP* 91: 766-775.

Al-Ashaab A, Araci ZC, Ikmal M, et al. (2021) Set-based concurrent engineering process model and systematic application on an electronic card reader. *WSEAS Transactions on Computers* 20: 329–351.

Ammar R, Hammadi M, Choley JY, et al. (2019) Narrowing the set of complex systems' possible design solutions derived from the set-based concurrent engineering approach. *Concurrent Engineering Research and Applications* 27(3): 233–248.

Anand G and Kodali R (2008) Development of a conceptual framework for lean new product development process. *International Journal of Product Development* 6(2): 190.

Battistella C, Fornasier A and Pessot E (2023) How can lean tools support the innovation process of SMEs? *Journal of Manufacturing Technology Management* 34(6): 1004–1024.

Beck K, Beedle M, Bennekum A, et al. (2001) Manifesto for agile software development. https://agilemanifesto.org/

Berg V, Birkeland J, Nguyen-Duc A, et al. (2020) Achieving agility and quality in product development - an empirical study of hardware startups. *Journal of Systems and Software* 167: 110599.

Blais C, St-Pierre J and Bergeron H (2023) Performance measurement in new product development projects: findings from successful small and medium enterprises. *International Journal of Project Management* 41(2): 102451.

Blessing LTM and Chakrabarti A (2009) *DRM, a Design Research Methodology.* Springer.

Cano EL, García-Camús JM, Garzás J, et al. (2021) A Scrum-based framework for new product development in the non-software industry. *Journal of Engineering and Technology Management - JET-M* 61: 101634.

Civelek F, Brem A, Fritz K-P, et al. (2023) Product development processes for individualised products: a case study. *IEEE Transactions on Engineering Management* 71: 6190–6204.

Cukor Kirinić I and Hegedić M (2023) Trends and future research direction of lean product development. *Sustainability* 15(24): 16721.

De Toledo JC, Pinheiro LMP, Poltronieri CF, et al. (2023) Lean development and its impacts on the performance of new product processes: an analysis of innovative Brazilian companies, research in engineering design. *Research in Engineering Design* 34(3): 285–300. doi: 10.1007/s00163-023-00408-4.

Drutchas J and Eppinger S (2022) Guidance on application of agile in combined hardware and software development projects. *Proceedings of the Design Society* 2: 151–160.

Eckert CM, Jankovic M and Lugo DA (2019) A review of design process improvement methods and models. *Annual CIRP* 68(1): 607–632.

Fargher G, Khan MS and Al-Ashaab A (2025) LAMPD: a combined lean and agile model for product development. *International Journal of Agile Systems and Management* 18(6): 1–25, Open Access paper. Accepted July 2025.

Flores M, Vincke J and Al-Ashaab A (2023) The lean diamond awards, lean thinking evolution: getting prepared for the digital Era. *Lean Analytics Association.*

Glazkova N, Fortin C and Podladchikova T (2019) Application of lean-agile approach for medical wearable device development. In: 2019 14th annual conference system of systems engineering, sose 2019, Anchorage, AK, USA, 19–22 May 2019, pp. 75–80.

Godbole H, Esterman M, Palekar S, et al. (2019) *Successes and challenges in implementing lean product development*. Volume 7: 31st International Conference on Design Theory and Methodology. https://doi.org/10.1115/detc2019-98078

Granato G, Fischer ARH and van Trijp HCM (2022) Misalignments between users and designers as source of inspiration: a novel hybrid method for physical new product development. *Technovation* 111: 102391.

Gren L and Lenberg P (2020) Agility is responsiveness to change: an essential definition. In: Proceedings of the 24th international conference on evaluation and assessment in software engineering, Trondheim, Norway, 17 April 2020, pp. 348–353.

Hoppmann J, Rebentisch E, Dombrowski U, et al. (2011) A framework for organizing lean product development. *EMJ - Engineering Management Journal* 23(1): 3–15.

Kennedy M, Harmon K and Minnock E (2008) *Ready, Set, Dominate: Implement Toyota's Set-Based Learning for Developing Products and Nobody Can Catch You*. OakleaPress.

Khan MS (2012) *The Construction of a Model for Lean Product Development. Phd Thesis*. Cranfield University.

Khan MS, Al-Ashaab A, Shehab E, et al. (2013) Towards lean product and process development. *International Journal of Computer Integrated Manufacturing* 26(12): 1105–1116.

Levandowski C, Michaelis MT and Johannesson H (2014) Set-based development using an integrated product and manufacturing system platform. *Concurrent Engineering Research and Applications* 22(3): 234–252.

Michalides M, Bursac N, Nicklas SJ, et al. (2023) Why companies scale agile development of physical products: an empirical study. In: Chakrabarti A and Singh V (eds) *Design in the Era of Industry 4.0*. Springer, Vol. 3, pp. 1163–1174.

Morgan JM and Liker JK (2006) *The Toyota Product Development System: Integrating People, Process, and Technology*. Productivity Press.

Müller J, Pendzik M, Schock M, et al. (2024) Development of a methodology profile based on the current maturity level of agile development in mechatronic product engineering. In: Proceedings of Norddesign 2024, Reykjavik, Iceland, 12–14 August 2024, pp. 153–162.

Palsodkar M, Yadav G and Nagare MR (2023) Recent trends in agile new product development: a systematic review and agenda for future research. *Benchmarking: An International JournalBenchmarking* 30(9): 3194–3224.

Prasad B (1996a) Towards the concurrent engineering of mechanical systems. *Concurrent Engineering: Research and Applications* 4(4): 351–361.

Prasad B (1996b) Enabling concurrent product and process design: a life-cycle engineering approach. *Concurrent Engineering: Research and Applications* 4(2): 125–135.

Prasad B (1997) Information requirements in concurrent engineering. *Concurrent Engineering: Research and Applications* 5(2): 105–115.

Reiff J and Schlegel D (2022) Hybrid project management – a systematic literature review. *International Journal of Information Systems and Project Management* 10(2): 45–63.

Rismiller S, Cagan J and McComb C (2023) Exploring the impact of set-based concurrent engineering through multi-agent system simulation. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 37: e16.

Scharold F and Paetzold-Byhain K (2024) Towards agile automotive development: benefits, challenges and organisational changes. *Proceedings of the Design Society* 4: 345–352.

Silvério L, Trabasso LG and Pereira Pessôa MV (2020) A roadmap for a leanness company to emerge as a true lean organization. *Concurrent Engineering Research and Applications* 28(1): 3–19.

Silvério L, Trabasso LG and Pessôa MVP (2020a) Application phases for productivity improvement through lean methods assessments in an aeronautical company - case study. *IOP Conference Series: Materials Science and Engineering* 859(1): 0–8.

Silvério L, Trabasso LG and Pessôa MVP (2020b) Performance measurement and improvement of lean manufacturing operations: a leanness assessment literature review for the product development industry. *IOP Conference Series: Materials Science and Engineering* 859(1): 012017.

Sobek D, Ward A and Liker J (1999) Toyota's principles of set-based concurrent engineering. *Sloan Management Review* 40(2): 34–36.

Spinelli A, Anderson L, Enalou HB, et al. (2022) Application of probabilistic principles to set-based design for the optimisation of a hybrid-electric propulsion system. *IOP Conference Series: Materials Science and Engineering* 1226(1): 012064.

Toche B, Pellerin R and Fortin C (2020) Set-based design: a review and new directions. *Design Science* 6: e18.

Varl M, Duhovnik J and Tavčar J (2020) Application of lean methods into the customised product development process of large power transformers. *Tehnički Vjesnik* 27(1): 276–282.

Wang L, Ming XG, Kong FB, et al. (2011) Focus on implementation: a framework for lean product development. *Journal of Manufacturing Technology Management* 23(1): 4–24.

Weichbroth P (2022) A case study on implementing agile techniques and practices: rationale, benefits, barriers and business implications for hardware development. *Applied Sciences* 12(17): 8457.

Yin RK (2018) *Case Study Research and Applications: Design and Methods*. 6th edition. Sage Publications.

Author biographies



Dr Glyn P. Fargher is Global R&D Manager at Atlas Copco Henrob. His doctoral research and academic interests focus on the industrial application of harmonised Lean Product Development, Set-Based Concurrent Engineering, and Agile methodologies to advance the principles and practice of hardware product development. He is a Chartered Engineer and holds an MBA from Durham University and an MSc in Military Electronic Systems Engineering from Cranfield University.



Marwan Aboudaber is a PhD candidate in manufacturing whose research focuses on the development of an agile enterprise framework based on the digital technologies. He holds an MSc in Finance and Management from Cranfield University. His doctoral work has resulted in an agile enterprise framework that applies agile principles in a non-software context. His work demonstrates how agile practices can be combined with the enabling digital technologies to enhance adaptability and resilience in modern enterprises.



Thomas Bruneau holds an MSc in Global Product Development from Cranfield University and an MSc in Mechanical Engineering from UTC, France. He has over two years of professional experience as an engineer at Toyota Motor Europe, where he works in the design and development of vehicle shell and exterior parts.



Jordan Pandja Watchou holds an MSc in Global Product Development and Management from Cranfield University, as well as an MSc in Robotics from Centrale Nantes, a French engineering school. During his studies at Cranfield University, he investigated the implementation and integration of Lean Product Development and Set-Based Concurrent Engineering (SBCE) across product lifecycles under the supervision of Dr Ahmed Al-Ashaab. He subsequently gained professional experience as an Associate Product Manager, Product Marketing Engineer, and Product Owner, spending the last two years exploring the full spectrum of product development activities.



Julie Reynaud holds an MSc in Engineering and Management of Manufacturing Systems from Cranfield University as well as an MSc in Mechatronics from EIGSI, a French engineering school. She has been working as a project manager in a French hospital for over 2 years.



Marie Regnier holds an MSc in Global Product Development from Cranfield University and an MSc in Mechanical Engineering from UTC, France. Currently, she is an engineer at ENGIE Solutions Franc working on energy decarbonization locally available renewable resources.



Dr Muhammad Khan is an Associate Professor of Project Management in the Data and AI Department at Northeastern University, London. His research and professional practice focus on Lean Product Development, innovation, and project management. His doctoral and subsequent research have contributed to design and innovation process transformation within large engineering organisations, many of which he has supported directly through academic–industry collaboration. His current work centres on advancing engineering management through the integration of AI capabilities with Lean principles, processes, tools, and project management methods.



Dr Ahmed Al-Ashaab is Reader in Lean Product Development and Leader of the LeanPPD Research Group in the Manufacturing Materials and Design Department at Cranfield University. He received his PhD from Loughborough University in 1994 and served as Technical Coordinator of the LeanPPD European project, as well as an expert contributor to the CONGA aircraft project. His research spans lean product development, set-based concurrent engineering, knowledge management, and AI-driven design. With over 30 years of teaching experience across four countries, he has authored more than 150 research publications, co-authored several books including DARE to Gemba Walk, supervised over 180 postgraduate theses, and collaborated extensively with industry partners such as Rolls-Royce, Airbus, Jaguar Land Rover, and Volkswagen.



https://dspace.org/

An industrial application of the lean and agile model for product development: a manufacturing case study

Fargher, Glyn P.; Aboudaber, Marwan; Bruneau, Thomas; Pandjawatchou, Jordan; Reynaud, Julie ...

2026-12-31
Sage
https://doi.org/10.1177/1063293x261423822
Fargher GP, Aboudaber M, Bruneau T, et al., (2026) An industrial application of the lean and agile model for product development: a manufacturing case study. Concurrent Engineering, Available online 16 February 2026

Downloaded from a DSpace repository. https://dspace.org/