Two papers on development models for physical products

These are the notes behind the Section 1 article, for the review paper and the PPT. Both papers are open access, appeared in Scopus-indexed engineering or science journals within the last five years, and were read in full. Page numbers follow the published versions.

	PAPER [1]: DEMŠAR ET AL. (2023)	PAPER [2]: FARGHER ET AL. (2026)
Journal	*Polymers* (MDPI), 15(1), 68. Published 24 Dec 2022	*Concurrent Engineering: Research and Applications* (SAGE), 34(2), 115–137. Online 16 Feb 2026
Institution	Faculty of Mechanical Engineering, University of Ljubljana; Lund University	Cranfield University; Atlas Copco Henrob R&D
Model	Scrum-based agile product development combined with concurrent engineering, for mechatronic products	LAMPD: Stage-Gate + set-based concurrent engineering (SBCE) + Scrum + Kanban + agile principles
Case	E-bike central drive with polymer gears; five sub-teams from several partner firms	Rivet feed-stick for self-piercing riveting; UK site with 200 employees; 4 months
Method	Participant-observer case study with critical post-project review	Embedded single case (Yin) with triangulation across four data sources
Headline result	Absorbed two major specification changes by starting new sprints; product approved for series production	53% fewer parts, false readings from 12% to almost zero, payback within one year
Key limitation	One project, the team's first drive; outcomes are qualitative	One low-risk case; team already knew Scrum; researchers embedded in the team

HOW THE TWO MODELS RELATE

Both keep a structured backbone and add agile execution inside it. Paper [1] starts from Scrum and adapts it to hardware through prototype stages and parallel component testing. Paper [2] starts from lean, set-based exploration and uses Scrum and Kanban to give it a rhythm and stop analysis paralysis. Paper [1] stresses **responsiveness to change**, and paper [2] stresses **exploring broadly before converging**. Both use virtual prototypes and test data to cut down on costly physical iterations.

PAPER [1]

Agile development of polymer power transmission systems for e-mobility: a novel methodology based on an e-bike drive case study

I. Demšar, B. Černe, J. Tavčar, N. Vukašinović, D. Zorko. *Polymers* 15(1), 68, 2023. doi: 10.3390/polym15010068.
Open access (CC BY 4.0).

PROBLEM

Agile methods are well established in software but rarely used for physical products, and they cannot be transferred directly [1, p. 1]. Physical development needs binding decisions early, and after that point changes are expensive [1, p. 2].

CASE AND METHOD

- The project was a new pedelec e-bike central drive. The authors designed the polymer-gear transmission inside sub-team P3 [1, pp. 4–6].
- Five sub-teams (P1–P5), covering coordination and motor, customer and system, powertrain, torque sensor, and electronics, each worked as a Scrum team [1, pp. 5–6].
- The method was participant observation followed by a critical post-project review against Scrum guidelines [1, pp. 4–5, 13].

WHAT HAPPENED

- **Change 1, at week 5:** after the customer saw a virtual prototype, durability rose by 10%, length fell by 12%, width by 7%, height by 4% and weight by 25% [1, p. 6].
- **Change 2, 17 weeks later:** a competitor benchmark led to a 100% increase in peak power and a 25% lower housing temperature. The team started a new sprint instead of restarting the process [1, p. 6].
- The prototype path was VP A0 → A1 → A2 → A3 → B1 → B2 → B3 → C, and prototype C was approved for mass production [1, pp. 7–9].
- The transmission team was spread over three locations. It met online every day, met on site monthly, and was co-located for two months during the critical B phase [1, p. 13].

SEVEN PROBLEMS FOUND IN THE POST-PROJECT REVIEW [1, P. 14]

The review found seven problems: (1) physical prototypes are slow and costly; (2) specifications changed late; (3) virtual prototypes have limits, so partial physical prototypes are needed; (4) the response to changes was too slow without systematic CAD/CAE and model-based definition; (5) electronics could not be tested until the mechanics were built; (6) meetings were too broad; (7) the backlog and information flow were poorly managed.

THE PROPOSED MODEL [1, PP. 15–17]

- The product is split into interdependent modules that can be developed in parallel, and each has its own Scrum team.
- Development runs in stages, each made up of several sprints and ending in a functional prototype.
- Each sprint follows the same steps: plan, develop, decide whether a physical prototype is needed, test the virtual or physical prototype, and review with the customer. The results go into the backlog.
- Testing happens at four levels: virtual prototype, partial physical prototype, full prototype of each stage, and the whole product.
- A five-step accelerated polymer-gear procedure (preliminary design, step tests, lifetime tests, detailed calculation, validation) ensures the injection-moulding tools are made only once.

LIMITATIONS [1, PP. 19–20]

The evidence comes from one project, the mechanics team's first drive, and the outcomes are qualitative. The core team had to be dedicated to the project, which the authors note conflicts with resource-efficiency findings elsewhere. The agile tool set has to be customised for each organisation.

USE IN OUR REVIEW

The paper shows a concrete development model from mechanical engineering for products whose requirements keep changing. It links to **barriers** (distributed teams, document access, late specifications) and to **design-stage integration** (virtual prototyping, CAE, model-based definition).

PAPER [2]

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

G. P. Fargher, M. Aboudaber, T. Bruneau, J. Pandjawatchou, J. Reynaud, M. Regnier, M. Khan, A. Al-Ashaab. *Concurrent Engineering: Research and Applications* 34(2), 115–137, 2026. doi: 10.1177/1063293X261423822.
Open access (CC BY 4.0).

PROBLEM

Lean product development front-loads analysis, while agile prioritises fast iteration. Integrating the two is not straightforward, and few documented cases show how to do it in hardware [2, pp. 116–117].

METHOD [2, PP. 116–117]

The study is an embedded single case (Yin) in six phases: literature foundation, analysis of the current state, integration planning, harmonisation strategy, a 4-month implementation, and evaluation. Data came from four sources (documents, observation, meetings and simulation) and were triangulated, coded and checked with the team members.

THE LAMPD MODEL [2, PP. 118–123]

- The model was built by mapping the company's Stage-Gate process onto Khan's SBCE model and then adding Scrum, Kanban and the agile principles.
- **Stage 1, Project definition:** market study (A), explore customer value (B), align with strategy (C), define system functionality (D).
- **Stage 2, Project feasibility:** map design space (E), develop concepts (F), filter alternatives (G).
- **Stage 3, Project realisation:** converge on system (H), release final specification (I), full system definition (J).
- **Scrum** sets the cadence: all activities form the product backlog, which feeds stage and sprint backlogs, followed by a review and retrospective. **Kanban** handles prioritisation, visualisation and work-in-progress limits. The **agile principles** drive the change in mindset. A gate review closes each stage.

CASE: RIVET FEED-STICK AT ATLAS COPCO HENROB [2, PP. 123–129]

- The site in Deeside, UK, has 200 employees. A 2022 assessment found four gaps: unclear product definition, premature convergence on one design, weak knowledge management, and poor subsystem integration.
- The analytic hierarchy process gave the key value attributes these weights: reliability 30%, cost 25%, manufacturability 15%, maintenance 11%. "Check rivet presence" was the highest-risk function.
- The team generated 33 concepts (23 for the feeder body, 10 for the frame) and two sensor types, giving up to 2,640 configurations. Filtering by impact on key value attributes and TRL left nine; trade-off curves left eight; DFMEA followed.
- Six system configurations were compared in a Pugh matrix, and C3 was chosen. It uses an inductive sensor because coating dust could block a laser sensor.

RESULTS [2, PP. 129–133]

- Components fell from 19 to 9 (−53%), with two fewer sensors. False readings fell from 12% to almost zero, assembly time by about 35%, and manufacturing complexity from level 4 to level 2.
- Cross-functional meetings went from weekly to daily, decision cycles from 3 weeks to a few days, and documentation completeness rose by 25%.
- Savings were about £12,000 in material and about £30,000 from avoided false readings per line each year, plus 22% more capacity. The implementation paid for itself within one year.

CHALLENGES AND LIMITATIONS [2, PP. 131–133]

Fitting sprint cadence to phase boundaries was difficult, and the team handled it by treating the gates as knowledge gates rather than time gates. Running several methods at once needed training. The study has one benign case, the team already knew Scrum, the observation lasted 4 months, and the researchers were embedded in the team. The authors say the findings apply mainly to medium-sized manufacturers that already use Stage-Gate.

USE IN OUR REVIEW

The paper gives a fully specified, stage-by-stage hybrid model with measured **outcomes**. It uses classic Total Design tools such as the Pugh matrix and DFMEA, and its findings on change management and training feed into the **barriers** section.