A New Product Development Model for SMEs

Subjects: Engineering, Manufacturing

Contributor: Tomaž Berlec

The success of new product development (NPD) is of vital importance for the growth and prosperity of manufacturing companies. Complex product demands are increasing and companies must be able to produce the right products at the right time and at an affordable price; otherwise, they can quickly lose their competitive advantage. Especially vulnerable are small and medium-sized enterprises (SMEs) that can find it difficult to compete with larger companies on a global market and are also more prone to suffer from potential losses related to unsuccessful NPD, as they have a smaller set of both financial and non-financial resources. In order to survive in today's highly competitive global market, small and medium-sized enterprises (SMEs) have had to transition from sequential to concurrent product development, which significantly shortens development cycles, reduces costs, and ensures high product quality.

concurrent product development   SMEs

1. Concurrent Product Development

Concurrent product development first appeared in the late 1980s as an upgrade of the traditional sequential product development. It is defined as "… a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers from the very outset to consider all elements of the product life cycle, from conception to disposal, including quality, cost, schedule, and user requirements" [1].

In concurrent product development, the traditionally sequential development stages overlap. For performing the interactions between the overlapping stages, the track-and-loop approach has been proposed. In the track-and-loop approach, the overlapping stages are combined into development loops; this facilitates communication and enables constant information sharing. For SMEs, Winner et al. propose the adoption of 3-T loops, which means that three consecutive stages overlap and interact [1]. The general concurrent product development process with the application of 3-T loops is shown in **Figure 1** [2].
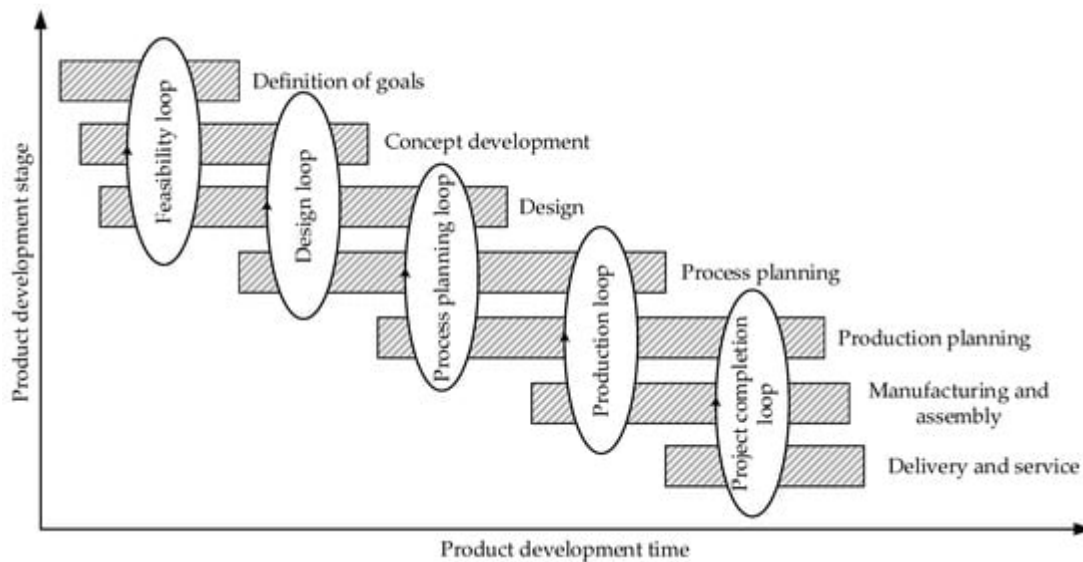
Figure 1. General concurrent product development process with the application of 3-T loops [2].

For efficient execution of development loops, good multidisciplinary teamwork is a must. According to Duhovnik et al., SMEs should adopt a two-level team structure: the core team and the project team [3]. The core team consists of the core team leader, representatives of individual functional departments, and project manager. Its composition is permanent and does not change during the project. The project team is responsible for carrying out project activities. The project manager represents a standing member of the project team, while other team members change depending on the development loop underway. With this structure, it is ensured that at each moment, the right experts from different functional departments are working on the project. Constant collaboration and information sharing between team members with different expertise allow for a better understanding of the problem and timely detection of potential discrepancies. The two-level team structure in SMEs is shown in **Figure 2** [3].
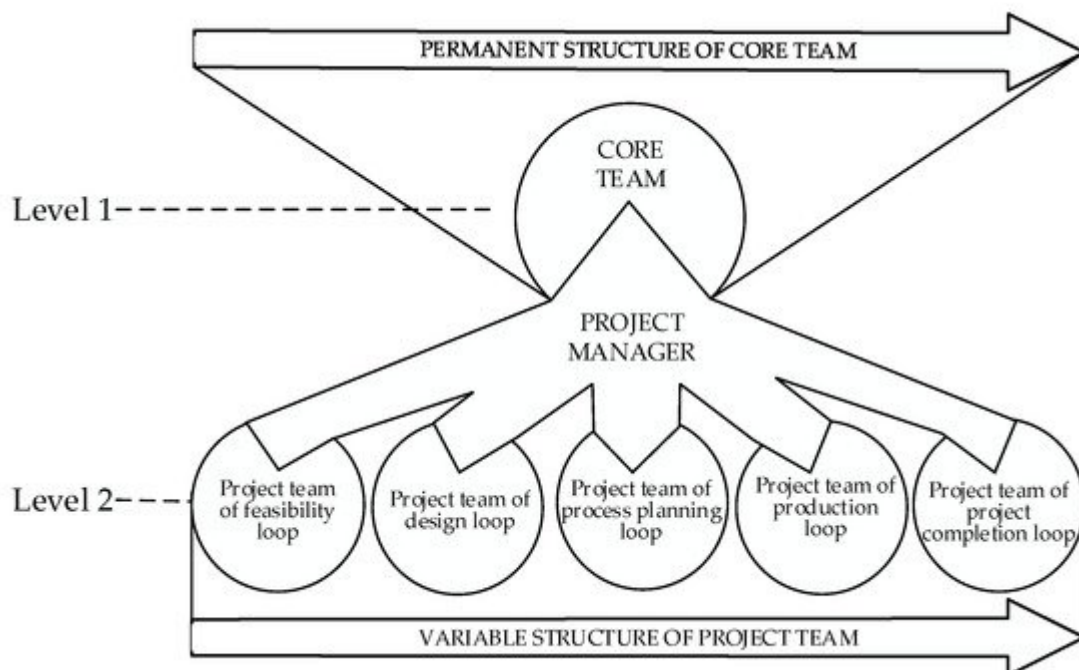
Figure 2. Two-level team structure in SMEs [3].

The main goal of concurrent product development is achieving higher project efficiency, as customers are primarily interested in the price, quality, and functionality of the product [4]. Studies have shown that applying concurrent product development strategies (parallelism, standardization, and integration [5]), track-and-loop approach, and appropriate concurrent engineering tools (e.g., design for manufacturability (DFM), design for assembly (DFA), quality function deployment (QFD), failure mode and effects analysis (FMEA), etc. [6]) can lead to up to 60% shorter development times, up to 50% lower costs, and as much as 95% fewer errors and necessary changes [7]. Another important factor in achieving greater project efficiency is also detailed upfront planning. While in the traditional sequential product development, on average 3% of total order development time is used for planning, in concurrent product development this time increases to about 20% [8]. This enables detection and elimination of discrepancies early on when the implementation of potential changes is easier and less expensive [9].

Although concurrent product development, based on detailed upfront planning, enables greater project efficiency in rather stable project environments, it does not offer the necessary means to address the challenges of today's turbulent environment. Companies are becoming more and more aware that they need to upgrade their standard development approach with appropriate principles that will introduce greater flexibility and enable a more rapid and effective response to change.

2. Agile Project Management

APM approach first emerged in the software industry as an alternative to traditional deterministic approaches that no longer allowed for effective development in highly unpredictable and competitive environments [10]. It became widely popular with the release of the Agile Manifesto in 2001, where 17 prominent practitioners presented better ways of developing software. Through their work, they have come to value (1) individuals and interactions over processes and tools; (2) working software over comprehensive documentation; (3) customer collaboration over contract negotiation; (4) responding to change over following a plan [11]. The main goal of APM is to ensure greater flexibility and faster response to change by reducing documentation and minimizing upfront planning [12]. The main differences between traditional and agile project management approaches are presented in **Table 1**.

Table 1. The main differences between traditional and agile project management approaches.

Characteristic	Traditional Project Management Approach	Agile Project Management Approach
Environment	Stable, predictable	Turbulent, dynamic, unpredictable
Project size	Large projects	Small projects
Requirements and specifications	Known upfront, big changes not expected	Rough initial definition, gradual development, in a form of user stories, changes encouraged

Characteristic	Traditional Project Management Approach	Agile Project Management Approach
Planning	Detailed upfront planning for the whole project	Iterative and adaptive planning, detailed planning for one iteration upfront only
Development approach	Sequential development stages, strictly following an initial project plan	Short iterations, iterative and incremental development
Teamwork	Larger teams, high level of specialization, hierarchy levels, responsibilities clearly assigned	Smaller teams, generalizing specialists, self-organization, full dedication, colocation, daily meetings
Management style	Control and command	Leading and cooperating
Customer collaboration	Initial involvement (project definition)	Active involvement in product development, frequent feedback information
Communication	Formal	Informal
Quality control	Process-oriented, detailed planning, strict control, testing later on	People-oriented, constant control of requirements and solutions, frequent testing
Goals	Optimization, predictability	Adaptability, flexibility, responsiveness, quick value delivery
Project success	Project triangle (time, costs, quality)	Project triangle (time, costs, quality), stakeholder satisfaction

flexibility, simplicity, iterations in short period of time, and incrementally add value [13]. In APM, the whole development process is partitioned into short iterations, and after each iteration, a working, potentially marketable partial product is delivered to the customer. The customer, who is actively involved in the development process, tests the product increments and constantly provides feedback information. This allows for faster identification of discrepancies, rapid response to change, and development of the product that the customer wants and needs.

For achieving greater project agility, many practices have proven to be very beneficial and are nowadays frequently used for managing complex software projects. Some of the most popular APM practices are listed and briefly described in **Table 2**.

Table 2. Popular APM practices.

APM Practice	Description
Iterative development	The whole development process is partitioned into short iterations (1–4 weeks long).
Iterative planning	Instead of upfront planning, a plan is developed iteratively for one iteration upfront only.
Incremental development, frequent value delivery	Each iteration results in a working product increment customers can already use.

APM Practice	Description
Time boxing	The duration of activities (meetings, iterations) is defined upfront and is fixed.
Active customer collaboration	The customer is involved in the development throughout the project and constantly provides feedback and collaborates with the project team.
Product backlog	The project is cut into small pieces that are prioritized based on customers' business needs. Project backlog is flexible and updated frequently.
User stories	Customer requirements and needs are provided in terms of short and simple descriptions of desired functionalities.
Small self-organized interdisciplinary teams	Teams are small (usually 7 ± 2 members), all team members are equal (no team leader), tasks are internally rearranged between team members, each team member can take on each task
Colocation	All team members are located in the same room.
Daily standup meetings	Short standup meetings (15 min) are carried out every day at the same time and in the same location where project progress is discussed.
Test-driven development	Before fully developing software, test cases are prepared to test new code.
Pair programming	Team members work in pairs, one writes the code while the other supervises. Roles are frequently switched.
Burndown chart	For greater transparency, work left to do versus time is graphically represented.
Simplicity	Designing simple software is cheaper and quicker, and it allows for easier problem fixing.
Continuous integration	All new code is first verified and then connected with the existing code.
Retrospectives	Retrospectives should be carried out frequently to analyze good and bad practices and identify possibilities of improving processes.

Based on the APM best practices, many different structured agile methods have been developed over the years. All of the existing methods are based on iterative and incremental development, collaboration, simplicity, and adaptability [14] but differ in their depth of guidance and breadth of their life cycles [15]. Among the most popular APM methods are scrum, kanban, scrumban, extreme programming (XP), feature-driven development (FDD), dynamic system development method (DSDM), crystal methods, etc. [15][16][17].

The benefits of APM methods, which are nowadays considered to be the mainstream in software development [10], are numerous: more effective and rapid response to change, timely identification of errors, greater flexibility, improvements in teamwork, greater transparency, etc. [18][19]. Consequently, APM has started to gain recognition also outside the software industry. Due to some discipline-specific differences, a direct transfer of APM methods to other industry sectors is not possible [20], but the so-called hybrid models have started to emerge that can represent a good alternative for non-software companies [21].

3. Hybrid Models

Hybrid models combine agile methods with traditional product development models [22][23], thus enabling companies to take advantage of agility without sacrificing the stability provided by traditional approaches [22][24]. Many researchers agree that it is the balance between agile and traditional approaches that is usually the most effective for managing projects [12][25][26][27]. A study by Gemino et al. showed that hybrid approaches lead to higher stakeholder satisfaction than traditional approaches while allowing for a comparable project efficiency as completely agile approaches [26].

Of all the existing agile methods, scrum has the greatest potential for physical product development [28][29]. The reason for this can be found in the fact that scrum is relatively simple, direct, and well documented, compared with other agile methods. Additionally, Sommer et al. (2015) state that scrum is the only agile method that directly addresses all aspects of project management and is explicitly intended for managing projects across the development process [30]. Most often, scrum is combined with the traditional stage-gate model, which is still very frequently used in product development [31][32].

Cooper, the father of the stage-gate model, addressed a number of criticisms of this traditional model in his 2014 article [32], such as strict linearity, rigidity, inflexibility, and a high level of bureaucracy. He discussed the next generation of the stage-gate model, which needs to become more flexible, agile, and accelerated in order to be able to effectively manage innovative and dynamic projects. He also introduced the idea of a protocept, equivalent to a working product increment in agile software development. A protocept can represent anything from the initial concept to the final working prototype, something that leads us closer to the final product and enables customers to provide feedback information on [32].

Based on Cooper's work, Sommer et al. later developed the agile–stage-gate hybrid, proposing the use of a stage-gate model on the strategic management level and scrum on the operational level [30]. The hybrid is based on the adaptation of typical scrum events (sprint planning, sprint review, sprint retrospective, daily scrum), scrum roles (scrum master, product owner, development team), and scrum artifacts (product backlog, sprint backlog, sprint increment, i.e., protocept). Case studies in various multinational corporations (Lego Group, Danfoss, Tetrapak, etc.) have shown that the implementation of the proposed hybrid leads to significant improvements, such as design flexibility, faster response to change, improved productivity, better communication, improved productivity, and raised team morale [28][33][34][35]. There have also been some attempts to implement the proposed agile–stage-gate hybrid in SMEs. The study of Edwards et al. has shown that the implementation is possible; however, it requires some additional adaptations and leads to less evident improvements [36].

Conforto and Amaral developed the IVPM2 method for managing innovative product development projects. The method combines the traditional stage-gate model approach (phase definition, standardized documentation, and checkpoints) with different scrum elements (iterative cycles, visual boards, and daily standup meetings) [27]. Research has shown that simple iterative and visual agile practices, combined with good practices of traditional product development, lead to greater creativity and innovation, greater added value for the customer, shorter planning time, and improved communication between all stakeholders [27][37].

Schuh et al. designed a customized scrum model for a highly iterative innovation process and rapid realization of physical product ideas [38]. The model is based on continuous integration of customers and production engineers and early and stepwise development of prototypes. As key enablers, integrated ICTs, interdisciplinary teams, a product lifecycle management system, and scalable manufacturing technologies are suggested. The authors also highlight the potential advantages of running individual cycles in parallel, which could further accelerate development [38].

Ullman presented an adapted scrum framework for hardware design and proposed its use in the combination with the stage-gate model [29]. In his book, he presented thirteen steps of the proposed framework that are being executed within the *organize–plan–do–review* cycle. Similar to the agile–stage-gate hybrid [30], Ullman's adapted scrum framework also preserves the typical scrum events, roles, and artifacts [29].

Reichwein et al. recognized APM as a potential solution to the problems of the additive manufacturing industry. They designed additive manufacturing adapted scrum procedure that stresses the importance of frequent production of prototypes, which allows for early testing of product functionality and facilitates the introduction of changed or new requirements [39].

As a first attempt to combine scrum with a concurrent product development model, Žužek et al. presented a conceptual agile–concurrent hybrid [40]. They propose that concurrent product development framework remains unchanged (stages overlap, the track-and-loop approach is preserved, etc.), while scrum is proposed for the execution of day-to-day work. As the main advantage of the proposed hybrid, the authors stress a more comprehensive protocept that in agile–concurrent hybrid represents the result of an entire development loop, not only of one stage. This allows for a broader insight into the project progress and more extensive customer feedback.

Combining APM and concurrent product development elements has also been recognized as a promising solution for advanced mass customization and one-of-a-kind production [41]. The study of Varl et al. showed that such a combination can result in great direct savings (reduced time to market, rework, man-hours, etc.) and indirect savings (improved knowledge management, improved information flow, etc.). They have also reported increased team motivation, a lower number of changes during later phases, and enhanced effectiveness.

The results of hybrid models applied to physical product development in large organizations are very promising; however, there is a great lack of literature regarding agile and hybrid approaches in SMEs [36]. This is rather surprising, concerning SMEs account for the majority of businesses worldwide. The few existing studies indicate that the implementation of APM in SMEs is feasible but much more challenging than in larger enterprises [36][42]. Both Edwards et al. [36] and Žužek et al. [42] showed that ensuring fully dedicated team members, which represents an important element of APM, is almost impossible in SMEs. Additionally, the implementation of existing hybrids requires a complete company reorganization, which usually calls for employing agile experts [35][43]. Most SMEs usually do not have enough financial and non-financial resources to afford such an extensive transformation and

therefore need an alternative approach that will still allow them to increase their agility but without such high inputs and risks related to it.

References

1. Winner, R.I.; Pennell, J.P.; Bertrand, H.E.; Slisarczuk, M.M.G. The Role of Concurrent Engineering in Weapons System Acquisition; Institute for Defense Analyses: Alexandria, VA, USA, 1988.

2. Duhovnik, J.; Starbek, M.; Dwivedi, S.N.; Prasad, B. Development of innovative products in a small and medium size enterprise. Int. J. Comput. Appl. Technol. 2003, 17, 187–201.

3. Duhovnik, J.; Starbek, M.; Dwivedi, S.; Prasad, B. Development of New Products in Small Companies. Concurr. Eng. 2001, 9, 191–210.

4. Grznar, P.; Gregor, M.; Gaso, M.; Gabajova, G.; Schickerle, M.; Burganova, N. Dynamic Simulation Tool for Planning and Optimisation of Supply Process. Int. J. Simul. Model. 2021, 20, 441–452.

5. Duhovnik, J.; Žargi, U.; Kušar, J.; Starbek, M. Project-driven Concurrent Product Development. Concurr. Eng. 2009, 17, 225–236.

6. Rihar, L.; Žužek, T.; Kušar, J. How to successfully introduce concurrent engineering into new product development? Concurr. Eng. 2021, 29, 87–101.

7. Gatenby, D.A.; Lee, P.M.; Howard, R.E.; Hushyar, K.; Layendecker, R.; Wesner, J.; Layendacker, R. Concurrent Engineering: An Enabler For Fast, High-Quality Product Realization. AT T Tech. J. 1994, 73, 34–47.

8. Kušar, J.; Bradeško, L.; Duhovnik, J.; Starbek, M. Project management of product development. Strojniški Vestn. J. Mech. Eng. 2008, 54, 588–606.

9. Kennedy, B.M.; Sobek, D.K.; Kennedy, M.N. Reducing Rework by Applying Set-Based Practices Early in the Systems Engi-neering Process. Syst. Eng. 2014, 17, 278–296.

10. Stavru, S. A critical examination of recent industrial surveys on agile method usage. J. Syst. Softw. 2014, 94, 87–97.

11. Beck, K.; Beedle, M.; Van Bennekum, A.; Cockburn, A.; Cunningham, W.; Fowler, M.; Grenning, J.; Highsmith, J.; Hunt, A.; Jeffries, R.; et al. Manifesto for Agile Soft-ware Development. Available online: http://agilemanifesto.org/ (accessed on 14 September 2021).

12. Serrador, P.; Pinto, J.K. Does Agile work?—A quantitative analysis of agile project success. Int. J. Proj. Manag. 2015, 33, 1040–1051.

13. Azanha, A.; Argoud, A.R.T.T.; de Camargo Junior, J.B.; Antoniolli, P.D. Agile project management with Scrum: A case study of a Brazilian pharmaceutical company IT project. Int. J. Manag. Proj. Bus. 2017, 10, 121–142.

14. Abrahamsson, P.; Warsta, J.; Siponen, M.; Ronkainen, J. New directions on agile methods: A comparative analysis. In Proceedings of the 25th International Conference on Software Engineering, Portland, OR, USA, 3–10 May 2003; IEEE: New York, NY, USA, 2003; pp. 244–254.

15. PMI. Agile Alliance. In Agile Practice Guide; Project Management Institute, Inc.: Newtown Square, PA, USA, 2017; ISBN 978-1-62825-199-9.

16. Williams, L. Agile Software Development Methodologies and Practices. Adv. Comput. 2010, 80, 1–44.

17. Abrahamsson, P.; Salo, O.; Ronkainen, J.; Warsta, J. Agile Software Development Methods: Review and Analysis; VTT: Espoo, Finland, 2002.

18. Kumar, G.; Bhatia, P.K. Impact of Agile Methodology on Software Development Process. Int. J. Comput. Technol. Electron. Eng. 2021, 2, 46–50.

19. Thesing, T.; Feldmann, C.; Burchardt, M. Agile versus Waterfall Project Management: Decision Model for Selecting the Appropriate Approach to a Project. Procedia Comput. Sci. 2021, 181, 746–756.

20. Schuh, G.; Riesener, M.; Diels, F. Structuring highly iterative product development projects by Using HIP-indicators. In Proceedings of the 2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Bali, Indonesia, 4–7 December 2016; pp. 1171–1175.

21. Riesener, M.; Dolle, C.; Ays, J. Hybridization of Development Projects Through Process-related Combination of Agile and Plan-driven Approaches. In Proceedings of the 2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Bangkok, Thailand, 16–19 December 2018; IEEE: New York, NY, USA, 2018; pp. 602–606.

22. Magistretti, S.; Trabucchi, D.; Dell'Era, C.; Buganza, T. A New Path toward a Hybrid Model. Res. Manag. 2019, 62, 30–37.

23. Papadakis, E.; Tsironis, L. Hybrid methods and practices associated with agile methods, method tailoring and delivery of projects in a non-software context. In Proceedings of the Procedia Computer Science; Elsevier B.V.: Amsterdam, The Netherlands, 2018; Volume 138, pp. 739–746.

24. Ciric, D.; Lalic, B.; Gracanin, D.; Palcic, I.; Zivlak, N. Agile Project Management in New Product Development and Innovation Processes: Challenges and Benefits beyond Software Domain. In Proceedings of the TEMS-ISIE 2018—1st Annual International Symposium on Innovation and Entrepreneurship of the IEEE Technology and Engineering Management Society, Beijing, China,

30 March–1 April 2018; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2018.

25. Špundak, M. Mixed Agile/Traditional Project Management Methodology—Reality or Illusion? Procedia—Soc. Behav. Sci. 2014, 119, 939–948.

26. Gemino, A.; Horner Reich, B.; Serrador, P.M. Agile, Traditional, and Hybrid Approaches to Project Success: Is Hybrid a Poor Second Choice? Proj. Manag. J. 2021, 52, 161–175.

27. Conforto, E.C.; Amaral, D.C. Agile project management and stage-gate model—A hybrid framework for technology-based companies. J. Eng. Technol. Manag. 2016, 40, 1–14.

28. Cooper, R.G.; Sommer, A.F. The Agile-Stage-Gate Hybrid Model: A Promising New Approach and a New Research Opportunity. J. Prod. Innov. Manag. 2016, 33, 513–526.

29. Ullman, D.G. Scrum for Hardware Design; David Ullman LLC: Independence, OR, USA, 2019.

30. Sommer, A.F.; Hedegaard, C.; Dukovska-Popovska, I.; Steger-Jensen, K. Improved Product Development Performance through Agile/Stage-Gate Hybrids: The Next-Generation Stage-Gate Process? Res. Manag. 2015, 58, 34–45.

31. Ahmed-Kristensen, S.; Daalhuizen, J. Pioneering the combined use of agile and stage-gate models in new product develop-ment—Cases from the manufacturing industry. In Proceedings of the 22nd Innovation and Product Development Management Conference, Copenhagen, Denmark; 2015.

32. Cooper, R.G. What's Next?: After Stage-Gate. Res. Manag. 2014, 57, 20–31.

33. Cooper, R.G.; Sommer, A.F. Agile-Stage-Gate: New idea-to-launch method for manufactured new products is faster, more responsive. Ind. Mark. Manag. 2016, 59, 167–180.

34. Sommer, A.F. Agile Transformation at LEGO Group. Res. Manag. 2019, 62, 20–29.

35. Cooper, R.G.; Sommer, A.F. Agile–Stage-Gate for Manufacturers: Changing the Way New Products Are Developed. Res. Manag. 2018, 61, 17–26.

36. Edwards, K.; Cooper, R.G.; Vedsmand, T.; Nardelli, G. Evaluating the Agile-Stage-Gate Hybrid Model: Experiences from Three SME Manufacturing Firms. Int. J. Innov. Technol. Manag. 2019, 16, 1–31.

37. Conforto, E.C.; Amaral, D.C. Evaluating an Agile Method for Planning and Controlling Innovative Projects. Proj. Manag. J. 2010, 41, 73–80.

38. Schuh, G.; Gartzen, T.; Basse, F.; Schrey, E. Enabling Radical Innovation through Highly Iterative Product Expedition in Ramp up and Demonstration Factories. Procedia CIRP 2016, 41, 620–625.

39. Reichwein, J.; Vogel, S.; Schork, S.; Kirchner, E. On the Applicability of Agile Development Methods to Design for Additive Manufacturing. Procedia CIRP 2020, 91, 653–658.

40. Žužek, T.; Kušar, J.; Rihar, L.; Berlec, T. Agile-Concurrent hybrid: A framework for concurrent product development using Scrum. Concurr. Eng. 2020, 28, 255–264.

41. Varl, M.; Duhovnik, J.; Tavčar, J. Agile product development process transformation to support advanced one-of-a-kind manufacturing. Int. J. Comput. Integr. Manuf. 2020, 33, 590–608.

42. Žužek, T.; Gosar, Ž.; Kušar, J.; Berlec, T. Adopting Agile Project Management Practices in Non-Software SMEs: A Case Study of a Slovenian Medium-Sized Manufacturing Company. Sustainability 2020, 12, 9245.

43. Sommer, A.F.; Slavensky, A.; Nguyen, V.T.; Steger-Jensen, K.; Dukovska-Popovska, I. Scrum integration in stage-gate models for collaborative product development—A case study of three industrial manufacturers. In Proceedings of the 2013 IEEE International Conference on Industrial Engineering and Engineering Management, Bangkok, Thailand, 10–13 December 2013; IEEE: New York, NY, USA, 2013; pp. 1278–1282.