



Integrating Product and Technology Development A Proposed Reference Model for Dual Innovation

Meijer, Ellen Brilhuis; Pigosso, Daniela Cristina Antelmi; McAloone, Tim C.

Published in:
Procedia CIRP

Link to article, DOI:
[10.1016/j.procir.2016.05.037](https://doi.org/10.1016/j.procir.2016.05.037)

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Meijer, E. B., Pigosso, D. C. A., & McAloone, T. C. (2016). Integrating Product and Technology Development: A Proposed Reference Model for Dual Innovation. *Procedia CIRP*, 50, 32-37.
<https://doi.org/10.1016/j.procir.2016.05.037>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Integrating product and technology development: A proposed reference model for dual innovation

Ellen Brilhuis-Meijer^{a,*}, Daniela C.A. Pigosso^a, Tim C. McAlloone^a

^aTechnical University of Denmark, Produktionstorvet, Building 426, 2800 Kgs. Lyngby, Denmark

* Corresponding author. Tel.: +45 4525 6287; E-mail address: ebrmei@mek.dtu.dk

Abstract

Although dual innovation projects, defined in this article as the concurrent development of products and technologies, often occur in industry, these are only scarcely supported methodologically. Limited research has been done about dual innovation projects and their inherent challenges (e.g. managing dependencies) and opportunities (e.g. streamlining development). This paper presents five existing reference models for technology development (TD), which were identified via a systematic literature review, where their possible integration with product development (PD) reference models was investigated. Based on the specific characteristics desired for dual innovation projects, such as integrated product development and coverage of multiple development stages, a set of selection criteria was employed to select suitable PD and TD reference models. The integration and adaptation of the selected models has led to a proposed integrated reference model for dual innovation that is currently being instantiated in the context of an ongoing action research project.

© 2016 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference

Keywords: product development; technology development; concurrent engineering; reference model; technology readiness level

1. Introduction

When studying the domains of technology- and product development, there are several possibilities regarding the order in which they occur. One situation is that technology development (TD) takes place before product development (PD), after which the developed technology is applied in PD. It can also occur that a PD project is initiated, only to discover that the concept is not feasible with existing technology. In such situations, it can be decided to halt the development of the product until the technology has been developed, or the development of the product can continue alongside the development of the technology. In the latter case, the result is the concurrent development of a new technology and product. This situation is named dual innovation by the authors and is illustrated in Figure 1. Innovation is defined here as *the process of making changes, large and small, radical and incremental, to products, processes, and services that results in the introduction of something new for the organization that adds*

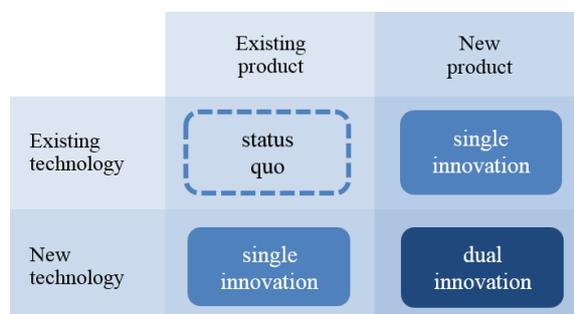


Fig. 1 The concept of dual innovation

value to customers and contributes to the knowledge store of the organization [1]. Dual innovation is defined here as *the simultaneous innovation of a product and a technology to be applied in that product*. A possible expansion would be the additional development of a new market, resulting in triple innovation. The definition of technology that is used here is the

one given by Burgelman, Christensen and Wheelwright [2], namely: “*The theoretical and practical knowledge, skills, and artifacts that can be used to develop products and services as well as their production and delivery systems.*” In other words, technology development supplies necessary input for product development.

While there has been much attention on cross-functional integration over the last decades, TD appears to have largely been kept out of the scope. As a result, while the metaphorical walls within the PD process have been taken down, the wall between technology- and product development often remains. Nobelius [3] concludes that this is because of the inherent difference in uncertainty and complexity between technology- and product development. Schuh and Apfel [4] argue that the number of companies that separate technology- and product development is actually increasing, because the timelines and levels of urgency are very different. Drejer [5] confirms that different time horizons are often used in these processes and adds that the two process “*speak different languages*” because they operate from very different angles. Separating the two development tracks makes it possible to plan product development more accurately, allowing for more stable product launch plans.

In the situation where a product concept sparks the need for a new technology this would mean halting the product development until the technology is developed, causing delays. As an alternative, the PD can be continued concurrently with the TD. This requires attention for the proper integration between the two. A lot of attention has been given to the integration of technology- and product development in literature. For example, Drejer [5] classified over 100 integration models to three dimensions of integration: activities, aspects and time horizons. These models focus on specific aspects of technology- and product development integration, posing questions to the decision makers. The interface between technology- and product development has also been given attention in research, for example by Schuh and Apfel [4], Jacoby et al. [6] and Lakemond et al. [7]. However, the existing research is focused on a fairly detailed level, discussing specific aspects of integration, such as a technology transfer moment, and tools that can be used. In addition, the attention for dual innovation is limited.

In practice, different degrees of integration between technology- and product development exist, ranging from separate development departments with a formal handover process to integrated teams that work on both types of tasks simultaneously. Nobelius [3] studied these two extremes in a case study, concluding that each approach has advantages and disadvantages. A separate TD department is often capable of delivering high quality results within the budget. However, they depend on a formalized knowledge handover. TD teams that also work on PD projects generally have more trouble working within budget. However, the result is often better suited for application within PD and no formal handover is needed, since many informal transfers occur throughout the development.

The specific situation of dual innovation has not been extensively investigated in literature. However, based on its characteristics, it may be expected to pose a unique set of inherent opportunities and challenges. Concurrent development

of both the technology and the product might benefit from a high amount of flexibility and may allow for a large amount of optimization from both ends, which could result in an optimized solution. The potential to streamline the development may also exist, where both tracks work towards the same goal and focus on what is needed for implementation. The potential flexibility of dual innovation may also result in challenges, for example related to knowledge transfer, project management and decision making. This may be further complicated by interdependencies between the two development tracks. There could also be trade-offs between the technology and the product, which could put a high pressure on good decision-making.

A large amount of PD reference models exists. The definition of a reference model by Costa et al. [8] is used here, namely: “*A generic process model of a specific domain. ... A representation of business processes containing best practices of an application area, which have a set of generic guidelines to be adapted for use in various contexts*”. A recent review in literature identified at least 124 PD reference models [9]. While some models indicate a link between technology- and product development, no reference models for dual innovation were found. This article aims to develop a reference model for dual innovation projects, which is meant to tap into the opportunities offered by dual innovation while providing support to deal with its challenges.

2. Methodology

The methodology adopted in this research consists of seven steps (Figure 2).

- Step 1: Systematic literature review of TD models. A search for journal articles and conference proceedings describing the proposition or application of a TD reference model was done in Web of Science, Scopus and a university-developed global search engine using. A search string based on combinations of the following keywords was used: technology, manufacturing, hardware or production, and development or innovation, and method, approach, model, reference model or process. The selection process consisted of reading the title and keywords, reading the abstract,

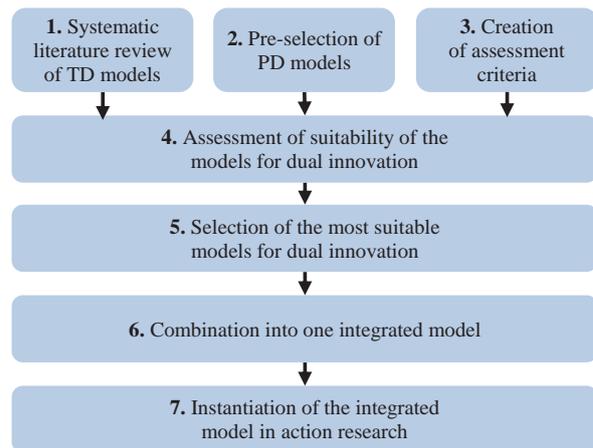


Fig. 2 Methodology steps

reading the introduction and conclusion and finally reading the full article.

- Step 2: Pre-selection of PD models. This was performed based on the work by Costa et al. [8]. Models were selected that already included a discussion regarding their integration with TD, since this provided a starting point for integration with a TD model. In addition, the models were required to be detailed and comprehensive.
- Step 3: Creation of assessment criteria. A set of assessment criteria was set up according to the classification method described by Fettke and Loos [10]. The criteria were split up into must-have and optional criteria based on their importance for dual innovation.
- Step 4: Assessment of suitability of the models for dual innovation. The identified development models were assessed using the created criteria. A three-point scale was used to assign scores. The scale was defined as follows:
 - The reference model does not cover this characteristic (0 points).
 - The reference model states that this characteristic needs to be included/considered (1 point).
 - The reference model describes how to include/consider this characteristic (2 points).
- Step 5: Selection of the most suitable models for dual innovation. Based on the outcome of the assessment, the most suitable TD and PD models were selected.
- Step 6: Combination into one integrated model. The selected reference models were organized to work concurrently and adapted where necessary by studying and removing possible overlaps. Support for handling interfaces and dependencies was added to ensure integration.
- Step 7: Instantiation of the integrated model in action research. The reference model was applied to an ongoing dual innovation project for initial testing.

3. Results

The results that were obtained are discussed here for each of the steps of the methodology.

3.1 Literature review of technology development models

A total of five TD reference models were identified during the literature review. These are shortly described below.

- Exxon Research and Engineering Company (ERE) Stage-Gate, by Cohen et al. [11] adds two stages to cover basic research in front of Cooper's PD reference model [12]. Nine success dimensions are identified to assess the work during the two gates. The need for flexibility and gatekeepers from across the organization are stressed.
- Technology Stage-Gate, by Ajamian and Koen [13] is based on the Technology Realization and Commercialization (TRAC) model by Eldred and McGrath [14]. It argues that with the uncertainty of TD only the next gate can be seen clearly. The work should thus be planned and discussed one stage at a time. The number of stages and gates is undefined. The focus is therefore on the process description.
- 3-Stage Technology Development Process, by Cooper [15] is meant to feed into the original PD stage-gate model by

Cooper [12] at gate 1, 2 or 3. It includes three stages: Project Scoping, Technical Assessment and Detailed Investigation.

- Develop Technology, by Högman and Johansson [16] uses Technology Readiness Levels (TRLs) as stages, with gates that check if the required level has been achieved. TRLs were originally developed by Mankins for NASA [17] (apud [18]) and are meant to assess and communicate the readiness of a technology at various points throughout TD.
- Engineering Practices Approach by Rich et al. [19] focuses on technology for manufacturing processes. It includes 6 stages; each stage is reviewed at a gate and the final phase is a design review. The stages are described, but limited information on the gates is provided.

The amount of detail included in the models varies widely, some merely stating the steps involved [19], others going into metrics that can be used to track progress [13][16], gate requirements [11], or even the possible interface with PD reference models [13][15].

3.2 Pre-selection of product development models

The research carried out by Costa et al. [8] has been used as a starting point to select PD reference models. It includes the most cited PD reference models, plus a group of recently published models, together forming a total of 21 reference models. Their research classified these reference models according to 60 characteristics. This classification supported the pre-selection of the most promising reference models for dual innovation. Two reference models were selected, mainly because they already included a discussion regarding their integration with TD. This provided a starting point for concurrent integration with a TD model. In addition, both these models were detailed and covered many knowledge areas and design stages. The selected models are described shortly below.

- Cross-Functional Integration, by Wheelwright and Clark [20]. This model uses six cross functional phases of development, with activities for engineering, marketing and manufacturing. Key milestones need to be achieved after each phase for approval and continuation to the next phase.
- Stage-Gate Process, by Cooper [12]. This model uses five cross functional stages, each with a number of parallel development activities. The access point for each next stage is a gate, which acts as a quality control. The uncertainty and thus risk is reduced at every gate, while the required investment increases at the same time.

3.3 Creation of assessment criteria

A set of assessment criteria was developed to investigate the suitability of the technology- and product development reference models for dual innovation in detail. The assessment criteria were developed using the classification methodology described by Fettke and Loos [10], which is intended for the selection of a reference model for a specific application.

The first step of this methodology included an initial listing of the classes of characteristics that were of interest. The second step included elaborating on these classes to obtain a complete list. The third step was to further specify these into

the actual characteristics belonging to each class. The resulting list can be seen in the two columns on the left of Table 1.

3.4 Assessment of reference models

The created list of characteristics was used in the fourth step of the methodology by Fettke and Loos [10] to classify the reference models. The distinction between must-have and optional criteria was applied here, as well as the three-point scale described in the methodology section. The result is shown in Table 1. For the TD models, only the 3-Stage TD Process by Cooper [15] met all 10 must-have characteristics. For PD, neither of the models met all 15 must-have criteria. The fifth

and final step of the classification methodology includes the continuous improvement of the assessment, which is ongoing.

3.5 Selection of reference models for dual innovation

Two reference models were selected to be used for dual innovation: one for TD and one for PD. For TD, the 3-Stage TD Process by Cooper [15] was selected, because it meets all must-have criteria and is one of the top scorers for the optional criteria as well (Table 1). For PD, the Stage-Gate Process was selected, which is also by Cooper [12]. This reference model meets most of the must-have criteria, though it lacks coverage on the detailed design stage. The Stage-Gate Process

Table 1. Assessment of the development models. Solid dots represent the scores for must-have criteria, empty dots the scores for optional criteria. An x indicates that the characteristic was not applicable for this type of development model.

Class	Characteristic	Technology Development					Product Development	
		ERE Stage Gate [11]	Tech SG [13]	3-Stage TD Process [15]	Develop Technology [16]	Engineering Practices Approach [19]	Cross Functional Integration [20]	Stage-Gate Process [12]
Scope	Product development	-	-	-	-	-	●●	●●
	Technology development	●	●	●	●	●●	-	-
Knowledge area	Product engineering/design	○	-	-	-	-	●	●
	Process engineering/design	●	●	●	●	●●	○	-
	Industrial design, esthetics and ergonomics	x	x	x	x	x	○	-
	Marketing and communication management	x	x	x	x	x	○	○
	Technology management	-	●	●	●●	●	●	●
	Quality management	x	x	x	x	x	-	-
	People management and organization	-	-	-	-	-	○	○
Abstraction level	Stages	●	●	●●	●●	●●	●●	●●
	Gates/decision points	●	●	●●	●●	●	●	●●
	Tasks	-	-	●●	●	●	●	●●
	Activities	-	-	●	-	●	●	●●
	Methods/tools/etc.	-	●●	●	●	●	●●	●●
	Roles	-	○	○	-	○	○○	-
	Metrics	-	●	●	●	-	-	●
	Industry examples	-	-	○	○	-	○○	○○
Design approach	Integrated Product Development	x	x	x	x	x	●●	●●
Product development stages	Front-end/product planning	x	x	x	x	x	○	○○
	Requirement definition	x	x	x	x	x	●	●●
	Conceptual design	x	x	x	x	x	●	●
	Embodiment design	x	x	x	x	x	●●	●
	Detailed design	x	x	x	x	x	●●	-
	Production preparation	x	x	x	x	x	○	-
	Commercialization	x	x	x	x	x	-	○
Support	Guidelines	-	○	○	○	-	○	○○
Compatibility	TD-PD integration	●●	-	●	●●	-	-	●
	Must-have characteristics	5/10	7/10	10/10	9/10	8/10	13/15	14/15
	Optional points	1	1	3	2	1	11	8

scored fewer points for the optional criteria, but it is judged that the difference is not large enough to justify the optional criteria compensating for a must-have criterion. In addition, the selected TD model already describes its integration with this PD model for the situation where the technology gets developed before the product, providing a good starting point for adaptation to a concurrent way of working.

3.6 Integrated reference model

The TD and PD reference models were adapted for application to dual innovation projects. The changes included organizing them to operate concurrently instead of in a linear fashion, linking the gates together based on the requirements of both tracks and including a metric to support handling the interdependencies (Figure 3). It can be seen that the PD track starts first, where a product idea is conceptualized. When this idea gets approved for further development at PD Gate 2. The TD then starts to progress in parallel to PD. At first, the focus is on understanding the technology and its possibilities. This knowledge is used at PD Gate 3 to decide if full development will commence. At that point, the detailed development work on both the product and technology commence. The TD needs to be completed and fed back into PD at gate 4, since the final stages of the PD track include test production and product launch on the market.

The two development models are kept in partly separate tracks because of the inherent differences in technology- and product development described earlier, such as different levels of uncertainty and complexity and different timelines. A forced combination into a single track would bring out these differences and hinder successful progress. Keeping them separate allows for individual planning and risk management. To ensure cross functional development, the people in both tracks are all part of the same team, with a shared goal and vision, as defined in stage 1.

To provide further support, the interdependencies between the tracks were captured by adding Technology Readiness Levels (TRL) to the TD and PD gates. This was inspired by the work of Högman and Johannesson [16] and Högman and Bengtsson and is illustrated by the red boxes in figure 3. These levels indicate what level of detail is needed for the PD track to progress to the next stage. If the achieved TRL is too low, the uncertainty is high and it can be expected that many changes are needed later on, causing delays and increasing development

costs. Waiting for a TRL that is higher than required also causes delays, extending time to market, and lowering the potential for optimization of both tracks through optimal cross functional development. At PD Gate 2, a concrete technology principle needs to be determined (TRL1). This provides the starting point for TD, at Gate 1. At TD Gate 2, a better understanding of the applicability of the technology to the product needs to be available (TRL2) to warrant further investigation. At TD and PD Gate 3, the functionality of the technology needs to be understood and insight into the feasibility needs to be given through a proof-of-concept (TRL3). At any gate along the way, it can be decided to stop the development based on the obtained results. However, if the result looks good, the detailed development work can begin for both the product and technology. At TD and PD Gate 4, the technology needs to be validated for application in the product (TRL5). At this point, the development merges into a single track again, where prototypes are made to test the final result (TRL 7). At PD Gate 5, the decision can be made to go to launch, where the real production line gets validated (TRL8) and full scale production takes place (TRL9).

3.7 Action research

To test the suitability of this reference model, it is being applied to a dual innovation project in the form of action research. The project in question concerns the concurrent innovation of a new type of beverage packaging (product) as well as a new production process (technology). Of course, reference models are meant to provide a general way of working and should always be adapted to the specific situation [21]. The instantiation of the dual innovation reference model in this project included the detailed specification of activities, gate requirements, task divisions and interdependencies. Since TD concerns manufacturing, Manufacturing Capability Readiness Levels (MCRLs) were used instead of TRLs. The MCRLs were developed by Ward et al. [22] to provide a direct match with the TRLs. Finally, the naming of various aspects of the model was adapted to the terminology used within the company. This resulted in a detailed development plan for the dual innovation project.

Further testing to validate the reference model is ongoing. At the time of writing work has started on PD Stage 2 and TD Stage 1. The action research will run for another 2.5 years, at which time a more complete evaluation can be made.

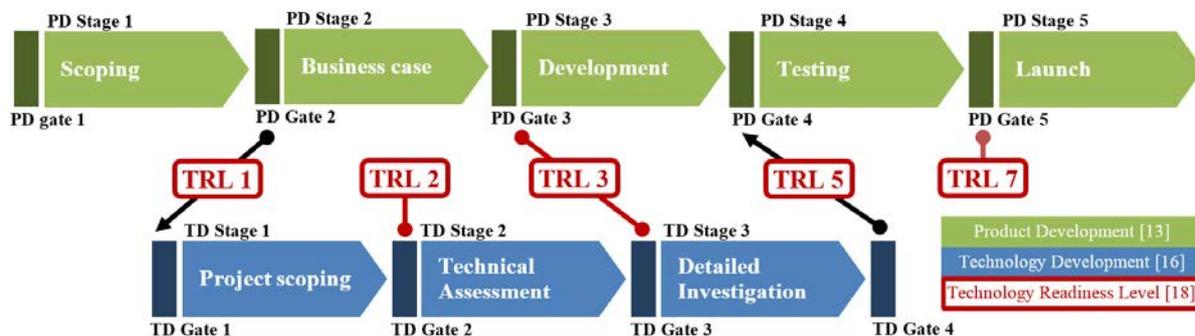


Fig. 3 The proposed dual innovation reference model

4. Discussions and conclusions

This article describes a proposed reference model for dual innovation. This reference model consists of two linked development tracks, one for the technology and one for the product, which are worked on concurrently. The interdependencies between the tracks are captured in Technology Readiness Level requirements at the gates. The model aims to provide insight for the team into the ongoing interaction that is needed throughout the development. These interactions could potentially facilitate communication and knowledge transfer, ensuring that the developed technology is suitable for direct application in the product.

A first instantiation of the model in action research showed promising results. It seemed to provide support to the project managers, who have voiced their appreciation of the insight into the dependencies via the readiness levels. Individual team members seemed to consider the needs of the other track more in their planning and discussions.

Since the action research is still ongoing, there are some open questions that are unanswered at this point. One of these regards the timing of the development steps. While insight now exists into the dependencies between the two tracks, their development speeds are likely to differ. This may result in one track having to wait for the other. The planning of the various activities will therefore have to be investigated carefully throughout the development. This is of course the case for all dual innovation projects, regardless of whether the new reference model is applied, but should nonetheless be given proper attention.

Future research will focus on the integration of ecodesign into the reference model for dual innovation. Challenges may include the high level of uncertainty and balancing ecodesign with the many other actions taking place concurrently. An opportunity may be to use the high degree of flexibility to develop an optimal design from an environmental perspective.

A limitation of the work described in this paper is the incomplete list of product development reference models that have been assessed. While the most cited models, as well as more recent ones, were included in the initial assessment, many more exist. It may be that a better fitting model is available. However, the good score of the selected reference model provides confidence in its appropriateness for dual innovation.

A final reflection is that there are not many cases of dual innovation projects described in literature. This could indicate that separation of the development tracks is easier to handle than integrated tracks. The developed reference model for dual innovation is meant to achieve the benefits of integration while also providing practical handholds for handling these complex projects. This is intended to provide the best of both worlds, but further testing will have to show if this is indeed the case.

Acknowledgements

This research was funded by Innovation Fund Denmark, the Carlsberg Group and the Technical University of Denmark. The authors would like to thank Mogens Myrup Andreassen, Maicon Gouvêa de Oliveira and Henrique Rozenfeld for their contributions.

References

- [1] O'Sullivan D, Dooley L. *Applying Innovation*. SAGE Publications; 2008.
- [2] Burgelman RA, Christensen CM, Wheelwright SC. *Strategic Management of Technology and Innovation*. 5th ed. New York: McGraw-Hill; 2009.
- [3] Nobelius D. Dedicated versus dispersed applied research organisation: implications for technology development and internal transfer to product development. *Int J Technol Transf Commer* 2002;1:249–67.
- [4] Schuh G, Apfel K. Framework to Design the Interface between Technology Development and Product Development. 2014 Proc. PICMET '14 Infrastruct. Serv. Integr., 2014.
- [5] Drejer A. Integrating product and technology development. *Int J Technol Manag* 2002;24:124.
- [6] Jacoby A, De Keersmaecker A, Braet J. Technology Development and Product Development in the Front-end of Innovation: a Review. *Proc. 4th Eur. Conf. Entrep. Innov.*, 2009, p. 657–65.
- [7] Lakemond N, Johansson G, Magnusson T, Säfsten K, Säfsten MK. Interfaces between technology development, product development and production: Critical factors and a conceptual model 2007.
- [8] Costa DG, Macul VC, Costa JMH, Exner K, Pfürtner A, Stark R, et al. Towards the Next Generation of Design Process Models: A Gap Analysis of Existing Models. *Int. Conf. Eng. Des. ICED15*, 2015.
- [9] Gericke K, Blessing L. An Analysis of Design Process Models Across Disciplines. *Int. Des. Conf. - Des.* 2012, 2012, p. 171–80.
- [10] Fettke P, Loos P. Classification of reference models: a methodology and its application. *Inf Syst E-Bus Manag* 2003;1:35–53.
- [11] Cohen LY, Kamienski PW, Espino RL. Gate System Focuses Industrial Basic Research. *Res Technol Manag* 1998;41:34–7.
- [12] Cooper RG. *Winning at New Products*. 3rd ed. New York: Basic Books; 2001.
- [13] Ajamian GM, Koen PA. *Technology Stage-Gate: A Structured Process for Managing High-Risk New Technology Projects*. New York: John Wiley & Sons, Inc.; 2002.
- [14] Eldred EW, McGrath ME. Commercializing new technology I. *Res Technol Manag* 1997;40:41–7.
- [15] Cooper RG. Managing Technology Development Projects. *IEEE Eng Manag Rev* 2007;35:67–77.
- [16] Högman U, Johannesson H. Technology development and normative process models. 11th Int. Des. Conf. Des. 2010, 2010, p. 265–74.
- [17] Mankins JC. Technology readiness assessments: A retrospective. *Acta Astronaut* 2009;65:1216–23.
- [18] Mankins J. *Technology Readiness Levels*. A White Paper. Washington, DC: 1995.
- [19] Rich D, Blanchard M, Giglia S, Straeffler G, Cazeault A, Cleveland S, et al. Engineering Practices During Manufacturing Process Development for New Products. *Pharm Eng* 2013;33.
- [20] Wheelwright SC, Clark KB. *Revolutionizing Product Development*. New York: The Free Press; 1992.
- [21] Browning TR, Fricke E, Negele H. Key Concepts in Modeling Product Development Processes. *Syst Eng* 2006;9:104–28.
- [22] Ward MJ, Halliday ST, Foden J. A readiness level approach to manufacturing technology development in the aerospace sector: an industrial approach. *Proc Inst Mech Eng Part B J Eng Manuf* 2011;226:547–52.