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Salgado, E. G. and Dekkers, R. (2018) Lean product development: nothing new under the sun? *International Journal of Management Reviews*, 20(4), pp. 903-933.

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Salgado, E.G. and Dekkers, R. (2018) Lean product development: nothing new under the sun? *International Journal of Management Reviews*, 20(4), pp. 903-933, which has been published in final form at <http://dx.doi.org/10.1111/ijmr.12169>

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Deposited on: 12 October 2017

Lean Product Development: Nothing New Under the Sun?

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Funding

This work was supported by the FAPEMIG Foundation (APQ-00976-13) and the CNPq (Process 249160/2013-7). We also would like to thank the anonymous reviewers for comments on an earlier version of this manuscript.

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Abstract

The concept of lean product development has attracted the attention of many scholars since its inception in the 1990s derived from practices at Toyota Motor Company. Key to this approach to new product development are a few methods derived from lean production as well as longer established practices, such as concurrent engineering. This makes one wonder whether lean product development is a new practice, a new method or an encapsulation of already existing methods at the time; this quest about the roots and tenets of lean product development, also in comparison to other methods for new product development, is the onus of this paper. This journey takes this propositional paper not only to the roots of lean product development and the context of its era of conception, but also to what this concept adds to other extant methods for new product development. Particularly, this comparison draws out that other methods are trying to achieve the same objectives: the creation of products and services with value to the customer, the reduction of time-to-market and the efficient use of resources. This inference implies that managers of new product (and service) development can choose from a wider pallet of methods and approaches to enhance the performance of R&D and to connect better to manufacturing (including supply chains). Inevitably, this has implications for research on (lean) product and service development; hence, this paper sets out a research agenda based on the deliberations and gaps that have been uncovered in the discourse.

Keywords: concurrent engineering; lean product development; lean production; new product development; quality function deployment; value stream mapping

Lean Product Development: Nothing New Under the Sun?

Introduction

Traditionally lean thinking, as an approach to rationalisation, is associated with manufacturing; after its conception for manufacturing (Ohno, 1988; Womack et al., 1991) there is an increasing number of attempts to transfer its principles, tools and techniques to other processes, such as new product development (NPD) (e.g. Baines et al., 2006, p. 1539; Hoppmann et al., 2011, p. 3; Salgado et al., 2014, p. 3). This attempt at applying it to NPD is often designated lean product development. The emergence of lean product development should be set off against other approaches for the processes, methods and management of NPD that appear in literature. In this context, some works expose the existence of a wide array of approaches: sequential phasing for NPD (e.g. Bullinger et al., 2003, p. 281; Krishan et al., 1997; Takeuchi and Nonaka, 1986); product platforms (for example Meyer and Utterback, 1993; Sanchez, 2004; Shamsuzzaho and Kekale, 2010); concurrent engineering (for instance Koufteros et al., 2001); waterfall models (e.g. Bassler et al., 2014, pp. 308–309; Bullinger et al., 2003, p. 281; Joore and Brezet, 2014, p. 93); stage-gate models (for example Cooper, 1990); spiral development (e.g. Bassler et al., 2014, pp. 308–309; Joore and Brezet, 2014, p. 93); capability maturity model (for instance Dooley et al., 2001; Veldman and Klingenberg, 2009); design for six sigma (for example Bañuelas and Antony, 2003); and product life-cycle management (e.g. Hicks and McGovern, 2009). Hence, lean product development can only be seen as one of the approaches currently being adopted by organisations that are attempting to maximise value, increase quality, shorten lead times, increase efficiency of resources and lower costs for NPD. This raises the first question of this review: how is lean product development based on lean thinking positioned in the rationalisation of NPD?

Objectives for Review

In this context of lean product development being one approach to rationalisation, there are three concerns. First, although various studies on NPD have been conducted (Baines et al., 2006, p. 1542), it appears that the mere conversion of principles taken from lean manufacturing to NPD settings does not necessarily equate to an effective, lean NPD; it is sufficient to mention that numerous companies face difficulties in carrying out lean product development appropriately (León and Farris, 2011, p. 29). Second, for some researchers (for instance, Freire and Alarcón, 2002, p. 252; Pernstål et al., 2013, p. 2799) lean product development is not easy or not simply a matter of implementing some of its techniques and methods; they claim that lean is a way of thinking that should be adopted throughout the whole company. Third, MacCormack et al. (2012, p. 34) mention that companies must make substantial efforts to ensure that their NPD approaches are better aligned with their business needs. Thus, it seems clear that NPD needs to be fully integrated with strategic management, which consequently should apply to lean product development, too. This strategic alignment makes it a more difficult task to discern the benefits of lean product development as a singular approach. Therefore, the second objective of this review is to shed some light on this controversy over what the principles and scope of lean product development are versus which benefits it brings to firms.

In addition to addressing this controversy about the uniqueness of its principles what it covers and what it brings to a firm, another reason for this paper is that lean product development is still considered a relatively new and promising approach to NPD, and therefore still lacks systematic comparison with other approaches to NPD (Rozenfeld et al., 2006, p. 34; Schulze and Störmer, 2012, p. 71). Furthermore, Hoppmann et al. (2011, p. 13) assert that there are no empirical studies about the implementation of lean product development, apart from those about Toyota's decades-long evolution of NPD. This stance is supported by Johansson and

Sundin (2014, p. 119), who found that the literature has offered fairly poor evidence regarding the industrial applicability of lean product development. In addition, Letens et al. (2011, p. 69) contend that there is much more understanding of the characteristics of effective lean manufacturing systems than those of effective lean product development. Therefore, a number of questions remain concerning the applicability of lean thinking concepts in NPD to various organisations and contexts. The lack of evidence underlines that it is necessary to conduct a study comparing lean thinking for NPD with lean thinking for manufacturing. Once this comparison has been made, it will be possible to answer the question as to what lean product development brings to the table that other approaches do not. Therefore, this review scrutinises the tenets of lean thinking for NPD and contributes to the debate on its added value relative to other approaches, concepts and methods.

Scope and Outline of Paper

Thus, this review evaluates the conceptualisation of lean product development, identifies the benefits it brings to organisations and compares it to other approaches for NPD. The five principles of lean thinking outlined by Womack and Jones (1996, pp. 16–26) are taken as a starting point, knowing that others have used and extended this view for lean product development. Making use of this particular conceptualisation for lean product development, the review questions for this paper are: (1) beyond lean thinking which characteristics, methods and tools have been added for the conceptualisation of lean product development?, (2) do authors refer to methods and tools other than those covered by this original writing about lean thinking and the original concepts for lean product development?, and (3) is there mention of or comparison to other methodologies for NPD? By addressing these three questions this manuscript adds not only a critical review of lean product development, but also offers a holistic perspective to existing reviews of lean product development.

The paper is organised as follows. The review starts by looking at its rationale and approach in the next section; the results of the systematic retrieval of literature are also found there. A section about the tenets of lean product development follows; this section also discusses the some of the assumptions made by authors about applying lean thinking to NPD. The section thereafter discusses the findings, while a final section concludes with implications for research and practice.

Methodology for Review

The approach to the literature review consists of two stages. The first stage is a systematic literature review, following the guidelines of Cronin et al. (2008) and Tranfield et al. (2003); the purpose of this review is to find what studies about lean product development have covered in terms of lean thinking. The second purpose of this systematic review is to find what conceptualisations of lean product development have been developed in literature beyond lean thinking. This search also covers what evidence is found by authors justifying the focus on lean product development as a solution to increasing NPD productivity. The results of the systematic review give way to a narrative overview (Green et al., 2006, pp. 103–104). This narrative discussion of the papers, as the second stage, is necessary because lean product development is often presented as an integral solution for NPD or as covering many aspects of NPD. Furthermore, attention for lean product development does not rely on evidence but on conceptualisation. Thus, the second stage, the narrative discussion of sources on lean product development allows a wider range of sources to be drawn on than those found during the first stage.

Retrieval of Publications

To find publications relevant to the first stage, the systematic literature review, three databases have been used: EBSCO*Host*, Google Scholar and Scopus; this is commensurate

with recommendations to use at least two databases (Green et al., 2006, p. 107). Subsequently, the search relied on appropriate keywords derived from those most used by previous publications about lean product development: ‘lean design engineering’, ‘lean engineering’, ‘lean product development’ and ‘lean product and process development’. We have retrieved a wide range of publications, including academic articles published in journals and accessible proceedings of conferences up to 2015. Because peer-reviewed journal publications are not necessarily the only reliable source for analysis (see for example, Conn et al. [2003] and Hopewell et al. [2007] about so-called grey literature, and MacDonald and Kam [2007] on how publishing is a game) and because the origin of lean thinking applied to NPD needs to be traced, a wider range of publications has been considered for inclusion: monographs, chapters in edited books, doctoral theses, presentations, professional publications, reports and working papers. Next, studies were selected based on their relevance to research about lean product development and NPD; both empirical and propositional studies were taken into account. Furthermore, snowballing (see Greenhalgh and Peacock [2005] and Wohlin and Prikladnicki [2013]) was applied to the publications found through the databases. This search strategy using three databases and snowballing for the first step of the literature review yielded the foundation for the analysis.

To determine whether retrieved publications would contribute to analysis, exclusion criteria were applied. First, only studies that were focusing on lean product development were used; sources about other applications, such as construction (e.g. Freire and Alarcón, 2002), information technology (for example Pernstål et al., 2013) and service (for instance Joore and Brezet, 2015) were excluded. Also, studies that looked at teaching lean product development (for example, Rossi, Kerga et al., 2012) or student projects (e.g. Graebisch et al., 2007) were

discarded. Second, master's dissertations¹ were omitted since these may vary in quality. A case in point is the dissertation by Bauch (2004) describing three new types of waste applied to lean product development; even though referred to by many (e.g. Darwish et al., 2010; Oehmen and Rebentisch, 2010b; Pessôa et al., 2007; Wang, Ming et al., 2011), it did not make it into the list. Third, books that were not monographs were left out during the retrieval processes, because they did not rely explicitly on extant knowledge; for example, Mynott's (2012) managerial guide was discarded, even though used in other academic works, such as Rauch et al. (2015, p. 112). Fourth, publications in conference proceedings that appeared later in more or less similar form in an academic journal were omitted. Cases in point are the conference proceedings by Browning (2000), which was published in an academic journal (Browning 2003), and by Gudem et al. (2011), later reported as Gudem et al. (2013). The application of these four exclusion criteria led to 207 publications to be considered; see Table 1 and the Appendix for those retrieved publications that are not cited in the text of this paper or its tables.

[Insert Table 1 about here]

[Insert Figure 1 about here]

Descriptive Results of Systematic Literature Review

Due to our search strategy a wide range of publications was found (see Figure 1). The dominating types of publications that we retrieved are contributions to conferences and papers in academic journals. For those who are interested in search strategies for literature reviews it should be noted that most of the other types of sources were obtained through Google Scholar, snowballing and to a lesser extent Scopus; EBSCOHost yielded only one

¹ Note that we follow the British terminology for dissertations (master's degree) and theses (doctoral degrees).

contribution to a conference and one professional publication in addition to the 14 papers in academic journals. The four presentations and the report in our sample were found through Google Scholar and snowballing. In addition to EBSCOHost yielding fewer varieties in types of publications, all its sources except one (Sorli et al., 2011) were also retrieved through the other two search engines. Looking at the types of sources across the years (see Figure 2), it appears that according to our retrieval process initially journal publications paved the way and that from 2005 onwards there was a substantial increase in other types of publication. The large majority of sources are found as contributions to conference proceedings (45%) and as academic papers (39%). However, other types of sources, such as presentations and working papers, yielded additional insight into the conceptualisation of lean product development, as will be emerging in the section ‘Is Lean Product Development the Only Way?’ Furthermore, Figure 2 shows that the attention for lean product development has increased, peaking in 2011. Note that our period of analysis stretches beyond Schulze and Störmer (2012, p. 73), who find an increase in publications only until 2008, but not the flattening out in later years; for the similar period 1996–2008 our retrieved number of papers is lower due to exclusion criteria, for example, excluding master’s dissertations. Also the review by Hille and Eseonu (2015, p. 88) shows a decline in publications after 2011. This means that the number of publications, caused by an increase in publications over approximately 20 years though declining at the end of the period considered, in conjunction with the variety of publications provides possibly rich insight into the conceptualisation of lean product development, even though contributions to conference proceedings and publications in academic journals dominate.

[Insert Figure 2 about here]

[Insert Figure 3 about here]

This surge in publications, particularly from 2006 until 2011, may possibly be linked to specific projects and initiatives. To find out which authors and institutes prevail in publications, dominating institutes have been set off against dominating authors; for each the threshold was five publications in our set of retrieved studies. The classification of the institute was attributed to the first author, unless it was clear from other co-authors that another academic institute dominated; if it was a practitioner co-authoring with an academic, then the academic was taken as being indicative for attributing the academic institute. Figure 3 demonstrates the contributions of the five leading institutes over the period 1996–2015, according to our classification; only Chalmers University of Technology and the Norwegian University of Science and Technology remain active after the peak in 2010–2013 in this figure. The analysis further revealed that Cranfield University and the Massachusetts Institute of Technology (MIT) have yielded most publications in this domain. For Cranfield University this is related to the LeanPPD project (EU funded); this project also had academic partners, such as the École Polytechnique Fédérale de Lausanne and Politecnico di Milano, which also appear in the table. For MIT it is the Lean Aerospace Initiative (part industry funded). Related to the Lean Aerospace Initiative, there is also a UK equivalent: the UK Lean Aerospace Initiative; however, that seems to have yielded less output (for example, the publications of the University of Bath). Both the LeanPPD project and the UK Lean Aerospace Initiative, the latter as a grand challenge, are related to the Innovative Manufacturing Centres (see Dekkers, 2010) and their output could also be considered from the relative performance of these research centres. Given that not only these institutes but also others have contributed multiple studies to the set of retrieved papers, we have not considered ‘marginality’ (see Karabag and Berggren, 2016, p. 15), although we discarded contributions to conferences that were later published in academic journals. The foci of these institutes and their projects are also reflected in the industries covered (see Figure 4).

Compensating for publications that did not specify any industry, such as some of the propositional writings², the aerospace industry appeared in 25% of the publications and the automotive industry in 30%. Although other industries have been investigated, it may well be that these two most frequent industries have particular challenges. The only publication that confirms this stance is the project by Ringen and Welo (2015), also published as Welo and Ringen (2015); they state that systems engineering companies (aerospace and defence) tend to be more immature compared to other sectors when considering lean practices and capabilities for knowledge (Ringen and Welo, 2015, p. 358). Moreover, lean practices are originating in the automotive industry, which may explain its leverage in the adaptive radiation of lean product development. Perhaps the wide range of sources, the specific search strategy, the peak of publications induced by specific projects at specific institutes and the decision not to compensate for marginality may partly explain the increase in publications and the flattening out of the sources after 2011.

[Insert Figure 4 about here]

Analysis of Papers

The retrieved publications were then classified and analysed. In addition to the type of publication and the originating institute, the categorisation noted the research method, the industrial sector or sectors investigated, coverage of the NPD processes and the perspective of scientific disciplines (business and management, engineering, innovation and technology management). Note that a paper was classified as propositional when an example was only used for illustration rather than analysis; Welo (2011) is a case in point. Furthermore, the papers were analysed on how they addressed the review questions; for all sources both

² Quite curiously, in the domain of lean product development some propositional papers, such as Anand et al. (2009), Furian et al. (2013) and Vosgien et al. (2011), are focused on a specific industry.

authors had to agree on the analysis and notes taken, which were recorded on a spreadsheet. The data from the categorisation and the analysis formed the base for the narrative review that follows.

During the analysis, not only did we search for papers about lean product development for the perspective of its conceptualisation as described so far, we also explicitly looked for origins of concepts as a second step of the literature review. When papers were analysed about lean product development, the three databases and search engines were used to look for origins of concepts beyond the period that lean product development was named in literature. Cases in point are the works of Abernathy and Rosenbloom (1969) and Pugh (1981). This search ensured that additional relevant papers were found, akin to Greenhalgh and Peacock's (2005, p. 1065) recommendation for using 'informal approaches', as they call them. Hence, the second step enhanced our search strategy by its wider coverage and broader range of concepts.

3 Examining the Basic Tenets of Lean Product Development

Crucial to understanding the contribution of lean product development as an approach to the processes and management of NPD is to know what it is about. For this purpose, this section explores the relevant features of lean thinking for NPD before moving on to discussing its principles, tools and methods. The final subsection pays attention to performance measures that have been associated with lean product development.

However, before going into detail about the application of principles of lean thinking to NPD, such reasoning should be based on a comparison of manufacturing and NPD. To this purpose, only 15 publications discuss the comparison beyond mentioning that production is based on material flows and that product development concerns the flow of information. In this respect, two of the 15 papers, Gudem and Welo (2010, p. 313) and Gudem et al. (2013, p.

73), mention product development is a more complex process since it concerns the generation and use of information. According to them, waste in product development is to be understood as the wrong input rather than undertaking unnecessary activities, for example, Salgado et al. (2014, p. 6) look at different types of waste. In this spirit, some other of these 15 papers (e.g. Reinertsen, 2005, pp. 41–42; Reinertsen and Shaeffer, 2005, pp. 51–52) take the variability as a starting point; but Welo et al. (2012, p. 5) note that for 'new product development, variability is a means to generate knowledge that reduces the risk of taking new products to the market, and a means to generate those very few exceptional opportunities' (albeit based on another source). Nevertheless, others (e.g. Welo, 2011, pp. 318–319) compare manufacturing and product development on its characteristics but without considering its impact. However, it is noteworthy that Khan et al. (2013, p. 1115) posit that lean product development is not just lean manufacturing applied to product development; this stance can also be found in Bjarnoe (2006, p. 45). Aligned with this perspective, McManus et al. (2007, p. 110) compare product development with mixed-model production. Their stance is closer to Hinckeldeyn et al. (2015, p. 470) who consider product development similar to job shops. These considerations may imply that the degree of novelty plays a role for managing product development (ibid., p. 470), which extends to lean product development. However, none of the studies refers to the degree of novelty, except Raudberget (2010, p. 692) for unproven and new technology in the context of set-based concurrent engineering. This implies that the conceptualisation of lean product development and the application of lean thinking to NPD is based on an incomplete discussion as to what extent they are applicable and how production and product development differ in relevant characteristics.

Application of Lean Thinking to Product Development

Setting aside for the moment the incomplete foundation for applying principles of lean thinking to NPD, its philosophy appears in the original writing by Womack and Jones (1996,

pp. 16–26); they state that lean thinking has five principles: value, value stream (mapping), flow, pull production and perfection (note waste is a consequence of creating value streams, and flow and pull production are interrelated). The thought is that these five principles do apply to lean product development, too, in some way. Whereas according to León and Farris (2011, p. 43), there is agreement that lean thinking must be translated to fit the specific context of NPD, implementing only a few of its principles is not enough for achieving lean product development, according to Pernstål et al. (2013, p. 2799). Based on lean thinking, this makes sense because the implementation of a few principles will not result in the elimination of all waste within the context of NPD. Therefore, León and Farris (2011, p. 43) claim that the critical principles that best describe the application of lean thinking to NPD have not yet been reached. Some have expanded the number of principles; a case in point is the paper by Liker and Morgan (2006, pp. 10–15), who present 13 principles that underpin lean product development. It should be noted that these principles do not really differ from those highlighted by Womack and Jones (1996, pp. 16–26), but should be seen as a more detailed explanation. In addition, Oppenheim et al. (2011) enumerate so-called enablers for systems engineering that are related to lean product development. However, many of these lean practices are not new (Siyam et al., 2015, p. 198) and can be understood as best practices for NPD. Note that for the purpose of this review we have reformulated the lean principles for NPD as: value, value stream (mapping), waste, flow/pull production and perfection; the foci of retrieved papers made this classification a more appropriate interpretation for the further discussion. Thus, these more recent writings do not shed light on the fundamental principles of lean product development.

[Insert Table 2 about here]

Therefore, let us examine the reformaluted five principles of lean thinking applied to NPD by first looking at the concept of value; it is also the principle used in most works in the

retrieved set of publications, see Table 2. However, there are two meanings attributed to the concept of value. The first of these two notions is that value is something found in manufacturing, and therefore focuses on the added value of processes and activities; this interpretation is principally the inverse of waste. In this respect, Vosgien et al. (2011, p. 331) possibly talk about ‘process value’ as distinct from ‘product value’. A case in point is the publication by Gershenson and Pavnaskar (2003); when they refer to value it is to be seen in the context of value stream mapping and waste. As a second interpretation of value, some works, for example, Haque and James-Moore (2004a, p. 12) and von Würtemberg et al. (2011, p. 2), intimate that the philosophy of lean product development has a strong focus on capturing the voice of the customer, and on defining and maximising the perceived value by the customer. However, it is possible to find research in the late 1960s and early 1970s using the voice of the customer to increase the value of the product; for example, there are precedents with quality function deployment (QFD) (Maritan, 2015, pp. 12–13) and a Scandinavian approach called ‘participatory design’ (Vardouli, 2015, pp. 13–14). Both approaches involve customers in NPD (e.g. Chan and Wu, 2002, p. 464; Ind and Coates, 2013, p. 88). Analysis of value – often claimed as central to creating value – dates back to efforts in improving value in 1947 at General Electric during the Second World War (Shillito and De Marle, 1992, p. 237). Hence, it can be concluded that the principle of creating value for the customer predates the conception of lean product development.

The second principle of lean thinking is the optimisation of the value stream; in Table 2 it is ranked as the third-ranking principle in terms of occurrence in the retrieved set of publications. This principle is mostly associated with value stream mapping. According to Dal Forno et al. (2014, p. 780), this is an important facet of lean thinking and is used for identifying value-adding activities and activities that are considered wasteful for materials and the flow of information and people. Furthermore, the deployment of value stream

mapping should lead to highlighting potential areas for improvement, while additional tools are used to conduct analysis (Tyagi et al., 2015, p. 205). However, it is difficult to apply value stream mapping to the analysis of NPD processes due to the difficulties in defining what is value, according to León and Farris (2011, p. 43). Moreover, having a closer look at this, the depiction and its methods are merely an adoption of the ASME process-mapping standard, dating back to the 1920s. Again, this was developed for manufacturing rather than for NPD. In that context, it is worth mentioning that NPD processes have an iterative nature; early decisions are later revisited and perhaps changed due to progressive insight about product specifications and technological capabilities (see Chao and Ishii, 2006, p. 492; Pahl et al., 2007, pp. 126, 410–38; Radhakrishnan and McAdams, 2005, p. 378). None of the literature on lean product development (and it is extensive) has examined this argument. Akin to the concept of value for the customer, the mapping of processes and its analysis are rooted in approaches known before the concept of lean product development came to light; moreover, these principles derived from manufacturing are declared to be valid without argumentation about the iterative character of NPD.

The latter flaw also surfaces for the third principle of lean thinking that is often mentioned in the context of lean product development, which is ‘flow’; from our particular perspective flow and pull production are strongly interrelated and appear in our set of retrieved publications as ranking fourth (Table 2). This principle assumes that NPD and manufacturing are sufficiently isomorph from the perspective of control and process improvement. Contrastingly, Hinckeldeyn et al. (2015, p. 470) have reasoned that NPD processes have more in common with job shops than with production lines; this argument seems to be ignored in the literature. Consequently, Haque and James-Moore (2004b, p. 1394) maintain that to facilitate the principles of flow and pull production several tools for obtaining and processing information may be used in organisations. The same authors claim that if

information is ‘pulled’ it will be more swiftly available to the entity requiring it, and, thus, it will compress the lead time for NPD, while noting that this is dependent on the degree of novelty. This notion is supported by Hinckeldeyn et al. (2015, p. 460) who contend that the application of production management principles to engineering processes is related to the degree of novelty that is inherent in engineering projects in companies. None of the other literature on lean product development has questioned the validity of and the contingencies for transferring principles from manufacturing to NPD; this should be considered a prominent deficit. This discussion brings to the fore that the principle of flow together with the related fourth principle – pull production – carries little relevance to NPD as it stands, albeit that perhaps the degree of novelty is a determinant.

[Insert Table 3 about here]

The final principle of lean thinking is the elimination of waste and striving for perfection (taken in our text as two separate but related principles); whereas the elimination of waste appears in second rank (after value), the principle of explicitly striving for perfection is least mentioned in the set of retrieved publications. To apply this principle seven sources of waste in the context of lean production are described by Shingo (1996). For lean product development Bauch (2004, p. 47) has suggested three additional sources of waste: reinvention, lack of discipline and limitations inherent in ICT (see Table 3). More examples of the categorisation of waste during product development processes can be found in Bauch (2004) and Oppenheim (2004). However, it could be questioned whether these classifications are trivial and often unnecessary because of the degree of novelty as determinant. For instance, according to Baines et al. (2006, p. 1544), work-in-progress and excess inventory in NPD is generally in the form of information; however, they note that information is not perceptible. Consequently, the stance is that waste should be minimised or, if possible, eliminated during NPD (von Würtemberg et al., 2011, p. 6). In practice, it will be difficult to

assign a financial value to information (Baines et al., 2006, p. 1544), except that a distinction between technical information as primary process and information for control processes may be helpful (see concepts of applied systems theory [Dekkers, 2015, p. 83]). Moreover, how does one assess that unnecessary data are stored? Such can only be determined in hindsight rather than by foresight. That becomes even more apparent when considering Stevens and Burley's (1997, p. 16) finding that, on average, 3,000 raw ideas are required to successfully commercialise one new industrial product. This underlines that uncertainties remain until the last moment and that subjectivity is inherent in NPD. Particularly for radical product innovation a new specification for a particular product may not be a task that could simply be eliminated or decreased in lead time. For reducing waste during NPD, one could fall back on striving for perfection (aka the zero-defects approach); Dombrowski and Zahn (2011, p. 1919) and Wang, Ming et al. (2011, p. 13) affirm that it is possible to find errors in all working processes, and in fact this also occurs during product development. The same authors recommend as tools for lean product developments the Kano model, QFD, the target definition matrix and design for assembly to minimise errors. The Kano model was developed during the 1980s by Professor Noriaki Kano and classifies customer preferences into five categories (Shen et al., 2000, p. 92; Yang, 2005, p. 1129). QFD (Chan and Wu, 2002; Cohen, 1988; King, 1987) and design for assembly (Boothroyd, 1987; Sackett and Holbrook, 1988) emerged during the same period. Specifically, design for assembly should be seen as part of the paradigm that design and product engineering should not be disconnected from other functions, which became shortly after known as design for X (e.g. Meerkamm, 1994). Particularly, design for manufacturing and assembly can also be considered similar to lean thinking; after all, its focus is on the development of products to simplify the assembly and manufacturing (Sánchez and Pérez, 2001), nonetheless a way of eliminating waste and adding value. Thus, some of the concepts linked to lean product

development emanated during the 1980s and 1990s from both academics and practitioners searching for better fits between NPD and downstream functions; according to Bralla (1996) this discussion, taken as a starting point by him for applying lean thinking to NPD, began before 1995. Therefore, the search for ‘perfection’ builds on concepts, such as QFD, Kano model and design for X, which were developed simultaneously but separate from lean product development, while sharing the same objectives.

[Insert Figure 5 about here]

Conceptualisation of Lean Product Development beyond Lean Thinking

Though the concepts of lean thinking applied to product development may have precedent in or have been developed in parallel with other techniques and methods, most of all, lean product development should be taken as an approach to NPD. From this perspective, processes of NPD cover capturing customers’ needs and technological developments to generating instructions for supply, production, assembly, distribution logistics, use and recycling; see Figure 5 for that generic process. Such processes should ensure that new products and their related processes match the resources and structures of supply chains, manufacturing and business models, including considerations for sustainability (Figueiredo and Loiola, 2012; Salgado et al., 2012). NPD should be placed in the context of (corporate and) competitive strategies, with time-to-market, including product launch and commercialisation, being dominant. Lean product development (e.g. Baines et al., 2006; Hoppmann et al., 2011; León and Farris, 2011; Siyam et al., 2015; von Würtemberg et al. 2011) aims to achieve these objectives by reducing waste. In addition, Nepal et al. (2011, p. 62) assert that the objective of a lean management structure is ensuring alignment, ownership, teamwork, communications and visibility across the NPD processes. This indicates that lean product development might be associated with different objectives presented by different

authors. Therefore, a discussion about this approach derived from lean thinking is needed to clarify what is really new and if all the tenets are applicable to NPD.

If we equate Toyota's approach to product development as lean product development, 'set-based concurrent engineering' is a central concept, according to Ward et al. (1995, p. 44). Calling it also the 'second Toyota paradox', they describe how this principle of subsequent evaluation of design alternatives and elimination of less preferable ones leads to an effective and efficient process for product development. They announce that Toyota's approach enables reliable and efficient communication, allows better management of parallel development activities and teams, enhances organisational learning and leads to optimal designs. Fifteen years later, Raudberget (2010, p. 685) writes that the evidence until that date seems to be limited to the original case of Toyota. He adds then his own four case studies implying that the cost of products is reduced, but that the lead time for development and the use of resources increased (*ibid.*, pp. 691–692); he also reports that these companies ponder implementing it for successive products. Whereas there is scarce evidence for set-based concurrent engineering, Pugh's controlled convergence method (Pugh, 1981) is seen as a basic tool for designers and engineers (though his thought is preceded by that of Abernathy and Rosenbloom [1969], albeit not very clearly stated). It is Pugh's method, later published in 1991, that set-based concurrent engineering mimics. Others, among them Ulrich and Eppinger (1995) and Wheelwright and Clark (1992), have also adopted this approach. Though advocated as unique by Ward et al. (1995), later in their paper (*ibid.*, pp. 48–49) they link it to Pugh's method without mentioning that Toyota's approach is not different. Subsequent studies (e.g. Khan et al., 2011) are extending this framework of set-based concurrent engineering, though not referring to Pugh (1981) or similar works. Thus, it can be concluded that set-based concurrent engineering is not a unique feature, whereas (recent)

works on lean product development, such as Al-Ashaab, Golob et al. (2013), Belay et al. (2014) and Mund et al. (2015), are even ignoring its heritage.

In addition to the heavily cited paper by Ward et al. (1995) about set-based concurrent engineering as a characteristic of lean product development, one of the most cited papers in this strand of research – that by Karlsson and Åhlström (1996) – addresses the implementation of lean product development in a case study. They explain that lean product development comprises numerous interrelated techniques and methods, including supplier involvement, cross-functional teams, concurrent engineering, integration (as opposed to coordination) of various functional aspects of each project, the use of a heavyweight team structure and the strategic vision and objectives for each development project. However, they (*ibid.*, p. 285) also note that this is their own interpretation of lean product development, without any justification; surprisingly, all authors that refer to this study have accepted this particular conceptualisation. Moreover, without referring to lean product development at all an in-depth study of cases by Boer and Duing (2001) reveals similar aspects as being crucial to the success of a project for new products (and process innovation). Also in the early 1990s, Henke et al. (1993) and Pinto and Pinto (1990) argue that an important key to successfully developing new products is the degree of cross-functional cooperation. Furthermore, around the same time period, Brown and Eisenhardt (1995) and Clark and Wheelwright (1992) suggested that heavyweight team leaders offer improved communication, strong identification and commitment to project, and a focus on cross-functional problem solving. Moreover, the integration of various functional aspects into each project is discussed by the Project Management Institute (PMI, 1996, p. 39). In addition, Birou and Fawcett (1994, p. 4) state that suppliers have a considerable impact on NPD; they contribute to better resource utilisation, improve the technological expertise and increase network effectiveness. Curiously, Karlsson and Åhlström (1996) have not addressed waste, which is considered by

many to be a core principle of lean product development; that differs from other propositional writings, such as Bauch (2004), Haque and James-Moore (2004a) and Oppenheim (2004), who take this principle as their starting point. Furthermore, the study by Karlsson and Åhlström (1996) has not looked at the principles, tools and metrics, which can be found in other studies about lean product development, for example da Costa et al. (2014), Haque and James-Moore (2004b) and Liker and Morgan (2006). Also, the paper by Karlsson and Åhlström (1996) does not mention set-based concurrent engineering at all. This means that the two most cited papers – Ward et al. (1995) about set-based concurrent engineering and Karlsson and Åhlström (1996) – are incomplete and do not do justice to the heritage beyond lean product development.

[Insert Table 4 about here]

[Insert Figure 6 about here]

Over the course of time, extensions have been proposed to these two conceptualisations of lean product development. Cases in point are the studies by Al-Ashaab, Golob et al. (2013) and Carleysmith et al. (2009), which include set-based concurrent engineering, product life-cycle management and design for six sigma in their approaches. Table 4 lists all these extensions. From a practical point of view, other approaches, particularly the tools they offer, could be integrated without contradicting the core objective of lean – to provide value to customers (Hines et al., 2006, pp. 872–873) and to eliminate waste (Hoppmann et al., 2009, pp. 15–16) (see Figure 6). Obviously, all these extensions over the years by other researchers, such as Carleysmith et al. (2009), Flores et al. (2010), Oehmen and Rebentisch (2010a) and Walton (1999), have moved the approach of lean product development away from its initial focus on eliminating waste and adding value to conceptualisations that cover a wider range of methods, tools and practices. For example, Lee and Chang (2010, p. 425) propose using lean six sigma for aligning business and supply chain strategies; however some of these

researchers (e.g. Fouquet, 2007) have not integrated the analysis of waste as would naturally follow from the principles of lean thinking. Furthermore, the concept might have been adapted because authors thought they were applying lean principles for a specific cause, while not (fully) considering its objectives, principles and methods (in addition its heritage). In this context, it is not yet possible to state that lean product development is a new approach, even with its extensions; perhaps it is only the philosophy of a constant quest to eliminate waste and add value applied to NPD, something we now need to explore.

A most notable extension of conceptualisation in the retrieved papers is the connection of lean thinking to knowledge management and the product life cycle. Whereas knowledge management appears in quite a number of papers, this is mostly linked to reuse of designs at different levels (Gautam et al., 2007), modularisation (Anand and Kodali, 2008; Rossi et al., 2012, p. 6) and standardisation (Dal Forno, Forcelinni and Bornia, 2013; Dal Forno, Forcelinni, de Miranda et al., 2013; Welo and Ringen, 2015, p. 237; Welo et al., 2012, pp. 8–10, 2013, p. 897; Yang and Cai, 2009, p. 87 ff.). This could also be caused by the types of industries, such as the aerospace and automotive industries that are dominant in the studies (see Figure 4); these industries may have more repetitive processes than other types of industries. Such argument is related to the novelty of NPD, which is weakly developed and hardly investigated in the context of lean product development. The additional quest for connecting lean product development to life-cycle management (Dem et al., 2012, pp. 184–189; Dombrowski and Schmidt, 2013; Hines et al., 2006; Maksimovic, 2013; Murman, 2008; Walton, 1999, pp. 16–18) seems mostly embedded in the aerospace industry.

Is Lean Product Development the Only Way?

So far, the concept of lean product development, whatever it covers according to specific authors, has been rooted in preceding approaches and other concepts beyond the principles of

lean thinking; perhaps something more can be derived from its implementation and use. In this respect, many works cite as characteristics for the lean approach to NPD: the need for a heavyweight project manager (for example, Hoppmann et al., 2011, p. 7; Karlsson and Åhlström, 1996, p. 285); the need for parallel activities (e.g. Baines et al., 2006, p. 1545; Karlsson and Åhlström, 1996, p. 289; Nepal et al., 2011, p. 59); the use of multidisciplinary teams, and collaboration and integration between departments to reduce lead time of product development (for instance Karlsson and Åhlström, 1996, p. 283; Liker and Morgan, 2006, p. 13; Nepal et al., 2011, p. 62). However, the question arises whether these features for lean product development are really confined to this approach. These features cannot be considered specific for the approach of lean product development since other concepts for product development, such as multidisciplinary teams (Page, 1993), concurrent engineering (Kusiak and Park, 1990; Miles, 1990) and stage-gate processes (Cooper, 1983), have been related to the same characteristics; also, Boer and During (2001, pp. 104–105), Meybodi (2013, p. 364–365) and Rozenfeld et al. (2006, p. 38) refer to similar characteristics. For those that are interested, concurrent engineering appeared first as simultaneous engineering (Kusiak and Park, 1990, p. 1883). To support this notion Meybodi (2013, p. 373) shows in a statistical study that similarities exist between principles for lean manufacturing and concurrent engineering for a majority of factors. However, it does not account for the characteristics of NPD being iterative, as discussed in beginning of the previous section ‘Examining the Basic Tenets of Lean Product Development’, and, therefore, being more similar to a job shop than a production line or manufacturing cells. One of the flaws in Meybodi’s work is that the two-way communication is identical (for manufacturing one way is the primary process and the other way is control information, whereas for NPD the two-way is about product specifications). Separate from works that are flawed in reasoning, both the implementation and use of lean product development falls back on determinants for

success that are not exclusive – perhaps not even for NPD – and deploys concepts, such as concurrent engineering and stage-gate models, that came about independently.

From the perspective of standardisation and simplification in NPD (Haque and James-Moore, 2004a, pp. 9, 16) the same applies. In this respect, Baines et al. (2006, p. 1546) state that the standardisation of knowledge and information management for the adoption of lean product development has yet to be defined. If we look at companies that use total quality management for all processes, this might bring about the need for standardisation and simplification. Logically, this notion might only apply when the degree of novelty for NPD is relatively low. This is supported by Stockton (1983, p. 16) who indicates the difficulties involved in standardising NPD. Some authors, such as Bertelli and Loureiro (2015, p. 50) and Hines et al. (2004, p. 1007), view total quality management as a technique related to lean thinking in NPD, albeit sometimes somewhat implicitly; but they do not seem to be aware that total quality management was practised well before lean production, and lean product development for that matter. In addition to total quality management, with its drive for standardisation and simplification, some authors (e.g. Liker and Morgan, 2011, p. 16; Powell et al., 2014, p. 574) present modular design as a method associated with lean thinking in NPD. Although modular design might facilitate lean product development, its relevance to product development and manufacturing already appears in the work of Bikker and van der Heyden (1987), Kamarkar and Kubat (1987) and De Toni and Zipponi (1991). Modularity often links to product families consisting of standardised assemblies, components and parts (Dekkers et al., 2013, p. 322); there is a strong relationship with product platforms (Meyer and Utterback, 1993). Modular design, product platforms and standardisation are means to an end for NPD and might facilitate lean product development but are not exclusive to it. Thus, it can be concluded that the discussion about standardisation and simplification applying to NPD dates also back beyond the conception of lean product development.

[Insert Table 5 about here]

When lean product development is compared with other recent approaches (Rozenfeld et al., 2006, p. 33), e.g. design for six sigma, the capability maturity model and product life-cycle management, it can be seen that these are complementary; see Table 5. For example, the focus of design for six sigma is optimisation of design solutions mainly by using statistical tools, which can be used in the lean approach, but with the focus on waste elimination or value aggregation. Similar to product life-cycle management, lean thinking seeks the integration of all stages across the product life cycle, including production and organisational learning (Hines et al., 2006, p. 882). This carries some similarities to the capability maturity model developed in the late 1980s by the Software Engineering Institute; this model is organised into five maturity levels (Paulk, 1993, p. 246; Paulk et al., 1993, p. 21). Nevertheless, when analysing the maturity levels it emerges that some of the principles are similar to lean product development and were created during the 1980s and 1990s with the same objective. However, the union of these approaches brings the idea of increasing the range of tools used to solve NPD problems, which are also not new. Thus, we can infer that lean thinking applied to product development is an evolution of the previous NPD approaches with the inclusion of principles to eliminate waste and to enhance value; however, this does make the concept of lean product development neither unique nor new.

Some Final Thoughts

After looking at the principles, methods and tools of lean product development in relation to other approaches available, the question arises: based on the preceding critical review, what makes lean product development stand apart? In its original conception, dating back to Womack and Jones's (1996) work on the principles of lean thinking, the foremost added value of lean product development is its focus on searching for value and eliminating waste.

Over the course of time, authors have added other methods, tools and principles, increasing its scope but also causing confusion about the delineation of lean product development relative to other approaches. The shifting content and differing interpretations of scope do not allow systematic evaluation of its tenets, thus not meeting the criterion of falsifiability of constructs (see Bacharach, 1989, p. 503) across studies. Even studies themselves have not included the notion of falsifiability, e.g. Khan et al. (2011), Tyagi et al. (2015) and Wang, Ming et al. (2011), not least the original study by Womack and Jones (1996). Neither does such divergent adoption of the concept of lean product development lead to which theoretical question will be addressed, akin to Sutton and Staw's (1995, p. 373) remark. Therefore, our first recommendation is that if studies are undertaken on lean product development, they should clearly identify its principles and its delineation from other approaches; authors doing so should also be clarifying why they have expanded on the original conceptualisation rather than including additional tools and methods without rationale.

Rather, based on these extensions that are put forward with poor or non-reasoning, one cannot come to any other conclusion than that lean product development in its original conception is simply inadequate. If the two main principles of eliminating waste and searching out value for customers would suffice, no extensions and additions need to be proposed. Thus, the mere fact that numerous authors have included other approaches indicates the inadequacy of lean product development as an integral approach. Then it shares the same fate as product life-cycle management, product platforms, stage-gate models, etc.; all describe aspects of NPD but never its entirety. This is exemplified by 22 publications in our sample that refer to other methods for NPD (see Table 6); noteworthy is Bjarnoe's (2006, p. 44) remark that lean product development seems to deploy methods and tools used for the development of the P-51 Mustang fighter during the Second World War. In the set of 22 publications, the only comparative study is the propositional paper by Ćatić and Vielhaber

(2011); this intimates that the 21 other ones have attempted to integrate other approaches into NPD for the purpose of conceptualising of lean product development. Antagonistic to our stance about lean product development that means that the extensions can be useful for managing NPD better, albeit that it may lead to further confusion as to what lean product development is standing for (perhaps even leading to more papers in the future adding to the befogging about its conceptualisation).

[Insert Table 6 about here]

Implications for Practice

All these discussions have implications for how NPD should be managed. NPD should be considered in a broader context that covers the corporate strategy for product development and marketing, including business models, competitive strategy, human resources and process performance (e.g. MacCormack et al., 2012; Sivasubramaniam et al., 2012; Trim and Pan, 2012; Trimi and Berbegal-Mirabent, 2012). In addition, there are many alternative approaches, e.g. sustainable NPD (Gmelin and Seuring, 2014) and Design for X (Meerkamm, 1994), and methods and tools, for example QFD and failure mode effect analysis (Chai and Xin, 2006). So, both arguments allow managers for new product (and service) development to select from a wider pallet of methods and approaches to enhance performance of R&D and to connect better to manufacturing (including supply chains). How lean thinking during NPD benefits overall performance in comparison to other approaches remains elusive; however, the conceptualisation of lean product development could be framed within an integral approach to the rationalisation of NPD (see Figure 7). Therefore, managers will have to rely on their intuition and experience for setting out appropriate approaches to NPD and how lean product development needs to be complemented to arrive at an integral approach based on Figure 7.

[Insert Figure 7 about here]

Perhaps of interest to practitioners is that some studies have mentioned bottleneck management as key to increasing efficiency. By Baines et al. (2007, p. 1599) it is merely touched on in the context of managing workflows; and by Wang, Quesada-Pineda et al. (2011) in an implicit manner. However, studies by Beauregard, Bhuiyan and Thomson (2008, p. 1520) and Beauregard, Thomson and Bhuiyan (2008, pp. 20, 25) take bottleneck management as their starting point for the value stream, albeit limited to certification processes in NPD. Nevertheless, these two studies are less extensive than that by Hinckeldeyn et al. (2014), who examine different bottleneck strategies and their effects on performance of NPD; the mention by Morgan (2002, p. 333) of flexible capacity is only one of the strategies, as is Choothian's (2014, p. 41) reference to queue management for controlling bottlenecks. Consequently, practitioners in product development may benefit from the outcomes of these initial studies into bottleneck management to increase throughput. Nevertheless, the 'lesson' from applying lean thinking to NPD is that of organisational learning. Thus, actions to reduce or eliminate waste and add value during the NPD process should be part of continuous improvement. Such thinking has strong parallels with organisational learning, for example, Adams et al. (1998), Adams and Lamont (2003) and Hoe (2007). Hence, the frameworks for lean product development proposed in the literature and in Figure 7 may assist companies in producing an environment that is adequate for increasing their NPD performance.

Implications for Research

This positive connotation comes along with some profound limitations that have been highlighted during this review. The first is the degree of novelty. The concept of lean product development has not been adequately placed on the dichotomy of incremental versus radical

innovation. Particularly, its reliance on the elimination of waste implies that it only applies to recurrent processes, which can only be found through standardisation and simplification. It is incremental innovation in which this is possible and it rules out the use of lean thinking for radical innovation, though different findings were reported. The same applies to value creation for customers, albeit possibly to a lesser extent. The second limitation is the reasoning for the feasibility of lean thinking for product development. Most writings assume that NPD is similar to the recurrent processes of manufacturing, particularly production lines. We have already demonstrated that NPD resembles more a job shop than line production (see beginning of the section 'Examining the Basic Tenets of Lean Product Development'). The question is then how to extend lean thinking to a job-shop environment. Such a quest should also go beyond oversimplification and incorrect comparisons; Meybodi's (2013) work is a case in point. These two limitations need to be accounted for, which is poorly done in the retrieved papers on lean product development.

Taking these two limitations into account, further research is necessary on comparing lean product development with other approaches regarding the rationalisation of the product development process. Thus, future research to demonstrate the relationships between lean product development and, for example, product platforms, modular design, capability maturity model for NPD may well provide results that show how much is the degree of similarity between lean product development and these approaches as analysed by Meybodi's (2013) work about the approach of concurrent engineering. Also, the framework in Figure 7 could assist in framing future research in the context of rationalisation and performance. Furthermore, more research is necessary to analyse the applicability of production management principles to engineering management, similar to Hinckeldeyn et al. (2015). Since performance measurement applies to NPD irrespective of approach, this research will make it possible to verify the tenets of lean product development.

These implications for research result in agendas for two different groups of researchers in addition to the individual observations and inferences throughout the manuscript; the first group, doctoral students and early career researchers, may benefit from our findings in four ways. First, this review provides insight into which concepts of lean product development have been developed before or in parallel to the application of lean thinking to NPD. Examples are set-based concurrent engineering that preceded the controlled convergence method and the method of value stream mapping that rooted in the ASME process-mapping standard. Such insight will avoid claims that concepts are new, while they have been in existence before under different labels, and they will contribute to a better conceptualisation of lean product development. To this end, our manuscript offers a wide range of sources, including lesser-known sources with differing views on the conceptualisation of new product development, such as the writing by Bjarnoe (2006), so that research projects with a narrow focus can build on relevant extant literature. Second, studies with a clear scope and narrow focus should delineate the conceptualisation of lean product development from other approaches that can be used complementary or conjointed to improve the performance of NPD. This holds also true for specific constructs, such as value, that have a different meaning for manufacturing than for NPD. Third, the specific characteristics of NPD in comparison to manufacturing should be taken into account. These include the degree of novelty, the iterations inherent to NPD, and the necessity for variability in product development in contrast to manufacturing (for part contradicting the quest for increased productivity of NPD). Fourth, integrative studies relating lean product development to complementary approaches for NPD should be welcomed, too. This should include comparative studies vetting lean product development against other specific approaches to NPD. This review, particularly Figure 7, may provide inspiration for this new strand of research. Thus, doctoral students and early career researchers can use this manuscript as a point of reference, have

insight into the historical development of lean product development and delineate the concept from other approaches to new product development.

In addition to these four points for doctoral students and early career researchers, those that are more advanced in their careers or are managing research programmes could take advantage of the following five notions. Whereas our review is confined to product development – see subsection ‘Retrieval of Publications’ about the exclusion criteria – a similar undertaking may be considered for construction projects, new service development and project management in general. In this respect, some literature reviews about lean thinking to other domains already exist; for example, the paper by Jørgensen and Emmitt (2008) already critically reviews the application of lean manufacturing to construction, but does so as a narrative overview (see Green et al. [2006, p. 103] for this classification). Thus, such papers lack a systematic approach to the literature review, which means that not necessarily all relevant sources are covered, and they are not aiming at lean product development or directly related domains. Such reviews would reveal whether findings in this paper are applicable to a broader context. Moreover, a discourse should be started about whether principles of lean product development are confined to the five (adapted) principles of lean thinking (derived from Womack and Jones [1996, pp. 16–26]), the thirteen principles of Liker and Morgan (2006, pp. 10–15) or any other set of principles. This debate could contribute to better delineation of what lean product development constitutes and, therefore, contribute to benchmarking empirical studies with the aim of reaching more definite and more focused inferences about the added value of the conceptualisation of lean product development. Over and above this, attention should be paid to how the analogy from manufacturing can be effectively deployed to NPD in this discourse. As alluded to in the introduction of the section ‘Examining the Basic Tenets of Lean Product Development’ and when discussing the principle of flow, the question could be raised how NPD should be

characterised: as job-shop or as production line? And does the iterative character of these processes, sometimes exacerbated by the degree of novelty, allow this analogy? In this respect it is worth mentioning that Hodgson (1993, pp. 18–20) remarks that playing with metaphors means approaching reality from various perspectives, and recognising that concepts have subjective interpretations as well as inevitably a social and academic history and context. Whereas our review contains a partial account of academic thought and the subjective interpretations resulting in a somewhat skeptic stance, the discussion about how manufacturing and product development compare for the purpose of applying lean thinking has not been settled, yet. Furthermore, systems engineering companies – aerospace and automotive – are considered more immature for implementing lean practices and capabilities for knowledge management (see subsection ‘Descriptive Results of Systematic Literature Review’). This is also indirectly confirmed by Figure 4, which shows the dominant industries investigated are aerospace and automotive. However, an explanation for this phenomenon is missing; is it because systems engineering requires a more rigid approach to NPD, is it because these industries are regulated or is it that organisational hierarchy is more dominant? Not limited to these three questions, further research should shed light on this intriguing finding. Finally, a dialogue should be started about holistic approaches to NPD and how lean product development can be positioned within these. Throughout the paper we came across holistic approaches but these do not capture lean product development and, conversely, papers about lean product development mention sometimes include additional tools, methods and processes but are never complete either. However, practitioners need a holistic view to manage NPD and related processes (for example, Figure 5 and 7). Thus, these five notions aim at stimulating critical discussion about (the delineation of) lean product development and its applications.

Further research is also necessary because of the limited scope of research methods used for the study of lean product development. Most of the retrieved papers are case studies and, in addition, they are mostly descriptive. This does not necessarily lead to insight. In particular, in these case studies the falsifiability of lean product development is not taken into account. This means that it is difficult to discern the tenets of lean product development versus those cases where it is absent (akin to the call for maximum variation case studies by Flyvbjerg [2006, p. 230]). Because of the originally ‘limited scope’ of lean product development it will be even more difficult to distinguish its effects as part of an integral approach for NPD, where other approaches, methods and tools also contribute to overall performance. Multiple methods are necessary to assert the contribution of lean product development, following Weick’s (1995) arguments, albeit that all studies need to contribute collectively to rigorous evidence.

Putting it all together, so far, the concept of lean product development brings little to the table beyond common sense and concepts that already existed at its time of conception and concepts that came about later. In this sense, lean product development is an amalgamation of tools and methods that is neither unique nor complete. Whereas it might have some advantages to bring together more methods and tools than those related to the principles of elimination of waste and searching for value for customers, that should not be presented as lean product development. For these reasons, it becomes necessary that researchers into lean product development demonstrate knowledge about its origins and present appropriately the heritage of all frameworks they use and recognise the extant contributions (it would be helpful if editors and reviewers would stimulate this ‘literature sensitivity’ as [minimal] professional knowledge).

Closing Remarks

This brings us back to the starting point of this paper: why do academics present lean product development as something new or different? Why has this approach been so readily embraced by the 'product development' community? Is it a matter of management fashions, as Abrahamson and Fairchild (1999) contend for generic attitudes of researchers towards managerial concepts? Or is it simply that academics have to 'sell' themselves to practitioners, as Micklethwait and Wooldridge (1996) assert? It is for the reader to decide. However, it is clear from our writing that there is nothing new under the sun for lean product development!

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Appendix

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Table 1: Overview of retrieved publications.

Keyword	EBSCOhost	Google Scholar	Scopus	Total
Lean product development	14	104	93	141
Lean product and process development	7	38	25	39
Lean engineering	10	75	43	83
Subtotal protocol-driven	16	145	111	189
Snowballing				17
Serendipitous searching				1
Total				207

Table 2: *Frequency and combinations of five principles of lean thinking in publications about NPD (n=207).*

Value	Principles of lean thinking				Frequency
	Value stream mapping	Waste	Flow and pull production	Perfection	
119	85	107	75	64	
•	•	•	•	•	27
•					17
•		•			16
•	•	•			9
•	•	•	•		9
		Other combinations			89
		None of five principles			40

Table 3: Comparison between types of waste for new product development and manufacturing

Type of waste	Manufacturing	New product development
Waiting	<ul style="list-style-type: none"> Material and operation parts. Maintenance. Tools. Operators. Queue for further operations. 	<ul style="list-style-type: none"> Available human or machine capacity. Information waiting for people. Waiting for data, answers, requirements, specifications, test results, approvals, decisions, reviews, signatures.
Transport	<ul style="list-style-type: none"> Excessive movement of pieces, materials, pieces and products. Storage movement. Insertion or withdraw of material/product/piece. 	<ul style="list-style-type: none"> Excessive data trade. Back and forth of tasks or interrupted tasks. Inefficient communication.
Unnecessary movement	<ul style="list-style-type: none"> Operators' minimum movements (reach, bend, force). 	<ul style="list-style-type: none"> Remote places. Information search. Direct access lack.
Inadequate processes	<ul style="list-style-type: none"> Over-dimensioning of process, machines and equipment. Unnecessary accuracy of product or process, not meeting customer's real needs. 	<ul style="list-style-type: none"> Unnecessary precision and details. Unnecessary features and processes. Inadequate competence use. Inappropriate use of tools and methods. Excessive accuracy. Excessive transactions.
Inventory	<ul style="list-style-type: none"> Excessive raw-material storage, semi-finished products compared to customer's demands. Waiting lines. Storage among operations. 	<ul style="list-style-type: none"> Excessive data storage. Unnecessary prototype and equipment tests. Waiting lines in critical path.
Over production	<ul style="list-style-type: none"> To produce more than customer's order. To produce before customer's order. 	<ul style="list-style-type: none"> Low synchronism of solicited time and capacity. Low synchronism of considered content. Excessive information dissemination. Task redundancy.
Defects	<ul style="list-style-type: none"> Components, materials, sub-assembling or products that do not have required quality. Production internal defects. Supplying defects. 	<ul style="list-style-type: none"> Information with deficient quality. Wrong database and information. Poor tests and verifications.
Reinvention	Not applicable.	<ul style="list-style-type: none"> Project poor reuse. Knowledge poor reuse.
Lack of discipline	Not applicable.	<ul style="list-style-type: none"> Not well done objectives and goals. Badly defined roles, responsibilities and rights. Badly elaborated rules. Poor dependency definition among activities. Insufficient predisposition to cooperate. Incompetence or poor training.
IT resource limitations	Not applicable.	<ul style="list-style-type: none"> Poor compatibility. Poor capacity. Low capacity.

Sources: Bauch (2004); Salgado et al. (2014).

Table 4: Other principles of lean thinking for NPD.

Principle	Sources
Assessment tool	Sopelana et al. (2012).
Chief engineer/leadership	Baines et al. (2006), Čatić and Vielhaber (2011), Dal Forno and Forcellini (2013), Dem et al. (2012), Dombrowski and Zahn (2011), Khan et al. (2013), Liker and Morgan (2006), Liker and Morgan (2011), Oppenheim (2004), Powell et al. (2014), Ringen and Lodgaard (2009), Rossi et al. (2012), Sobek II et al. (1998), Subramoniam et al. (2009), Swan and Furuhjelm (2010), von Würtemberg et al. (2011) and Wang, Ming et al. (2011).
Culture	Baines et al. (2006), Liker and Morgan (2006), Ringen and Welo (2015), Welo (2011), Welo and Ringen (2015), Welo et al. (2012) and Welo et al. (2013).
Employees/People/ Stakeholders	Dombrowski and Zahn (2011), Powell et al. (2014), Qudrat-Ullah et al. (2012) and Stenholm et al. (2015).
Enablers	Tortorella et al. (2015).
Flexibility	Morgan (2002), Powell et al. (2014) and Reinertsen and Shaeffer (2005).
Heavyweight project manager/Strong project manager/ Heavyweight team structure	Cusumano and Nobeoka (1998), Hille and Eseonu (2015), Hoppmann et al. (2009), Hoppmann et al. (2011), Karlsson and Åhlström (1996) and Schuh et al. (2008).
Just in time	Becker and Wits (2015).
Kaizen/ Improvement culture	Gershenson and Pavnaskar (2003), Hille and Eseonu (2015) and Khan et al. (2013).
Late engineering changes	Ballé and Ballé (2005).
Learning	Powell et al. (2014).
Multi-project organisation	Cusumano and Nobeoka (1998).
Respect for people	Costa et al. (2014), da Costa et al. (2014), Dem et al. (2012), Oehmen and Rebutisch (2010b), Oppenheim et al (2011) and Radeka and Sutton (2007).
Standardisation	Anand et al. (2009), Baines et al. (2007), Cusumano and Nobeoka (1998), Dal Forno and Forcellini (2013), Dal Forno et al. (2011), Dal Forno et al. (2013a), Dal Forno et al. (2013b), Dombrowski and Zahn (2011), Furuhjelm et al. (2011), Gremyr and Fouquet (2012), Hille and Eseonu (2015), Hölttä et al. (2010), Kamath and Liker (1994), Karademir and Cangelir (2013), Kirner et al. (2013), Liker and Morgan (2006), Liker and Morgan (2011), Schuh et al. (2008), Siyam et al. (2013), Sobek II et al. (1998), Swan and Furuhjelm (2010), Wang, Quesada-Pineda et al. (2011), Welo and Ringen (2015), Welo et al. (2012), Welo et al. (2013) and Yang and Cai (2009).
Takt time	Oppenheim (2004).
Transparency	Powell et al. (2014) and Ryan and Reik (2010).
Variability	Reinertsen and Shaeffer (2005).
Visualisation*/visual management/visual planning	Anand et al. (2009), Dal Forno and Forcellini (2013), Dal Forno et al. (2013a), Dal Forno et al. (2013b), Dombrowski and Zahn (2011), Fouquet (2007), Furuhjelm et al. (2011), Gingnell et al. (2012), Gremyr and Fouquet (2012), Hille and Eseonu (2015), Liker and Morgan (2006), Liker and Morgan (2011), Lindlöf and Söderberg (2011), Ringen and Lodgaard (2009), Saad et al. (2013)*, Siyam et al. (2013), Ström et al. (2012), Subramoniam et al. (2009), Swan and Furuhjelm (2010) and von Würtemberg et al. (2011).

* Visualisation by means of A3.

Table 5: Extensions of lean product development.

Conceptualisation	Sources
Axiomatic design	Cabello et al. (2012).
Balanced score card	Flores et al. (2010).
Batch size reduction	Reinertsen (2005) and Reinertsen and Shaeffer (2005).
Bottleneck (management)	Beauregard, Bhuiyan and Thomson (2008), Beauregard, Thomson and Bhuiyan (2008) and Wang et al (2011).
Breakdown of customer value	Browning (2003)*, Khan (2012).
Cadence	Reinertsen (2005).
Cause and effect	El-Sayed (2012).
Communication/visual communication	Fouquet (2007), Kirner et al. (2013) and Liker and Morgan (2006).
Cross-functional team/compact team/ team commitment	Fouquet (2007), Karlsson and Åhlström (1996), Karademir and Cangelir (2013), Kerga et al. (2015), Liker and Morgan (2006), McNeel and Lawrence (2004), Morgan (2002), Ringen and Holtskog (2013) and Sobek II et al. (1998).
Design for Six Sigma (DFSS)	Bertelli and Loureiro (2015), El-Sayed (2012) and Lee and Chang (2010).
Design for X	Dombrowski and Schmidt (2013), Dombrowski et al. (2014) and Haque and James-Moore (2004a).
Design of experiments	Cabello et al. (2012) and Tähemaa et al. (2012).
Design task heijunka/levelling	Gershenson and Pavnaskar (2003) and Swan and Furuhjelm (2010).
DFM and DFA, DFMA	Bertelli and Loureiro (2015), Furian et al. (2013), Khan (2012).
DFQC/target costing/quality and cost production	Ballé and Ballé (2005), Negroni and Trabasso (2009), Tähemaa et al. (2012) and Wasim et al. (2013).
DFV	Cabello et al. (2012).
Early supplier involvement/supplier involvement	Dal Forno and Forcellini (2013), Dal Forno et al. (2011), Dal Forno, Forcellini and Bornia (2013), Dal Forno, Forcellini, de Miranda and Bornia (2013), Gurumurthy and Kodali (2012), Kamath and Liker (1994), Karlsson and Åhlström (1996), Kirner et al. (2013), Liker and Morgan (2006), Radeka and Sutton (2007) and Saunders et al. (2014).
Families of parts	Anand and Kodali (2008).
Feedback loops	Reinertsen and Shaeffer (2005).
Flexibility	Morgan (2002) and Reinertsen and Shaeffer (2005).
FMEA	Bertelli and Loureiro (2015) and Endris et al. (2012).
Frontloading	Dombrowski and Zahn (2011), Gingnell et al. (2012), Liker and Morgan (2006), Mahlamäki et al. (2009) and Radeka and Sutton (2007).
GOLCAD	Gershenson and Pavnaskar (2003).
Human factoring engineering	Institoris and Bligard (2014).
Innovative environment	Wohnhas (2014).
Integrated computer-based solutions	Karademir and Cangelir (2013).
Integrated product team	Rebentisch (2005).
Integration of customers/customers requirement	Ballé and Ballé (2005), Kirner et al. (2013), Liker and Morgan (2006) and Ringen and Holtskog (2013).
Kano model	El-Sayed (2012).
Knowledge-based engineering, systems/ re-use of knowledge/ Re-use of designs/ knowledge management/ knowledge creation	Amin et al. (2010), Flores et al. (2010), Anand and Kodali (2008), Čatić and Sobek II (2013), Čatić and Vielhaber (2011), Dal Forno et al. (2011), Dal Forno, Forcellini and Bornia (2013), Gautam et al. (2007), Harris et al. (2006), Helander et al. (2015), Khan (2012), Khan et al. (2013), Léon and Farris (2011), Lindlöf et al. (2013), Maksimovic (2013), Radeka and Sutton (2007), Ringen and Welo (2015), Rossi et al. (2012), Sorli et al. (2010), Stenholm et al. (2015), Swan and Furuhjelm (2010), von Würtemberg et al. (2011), Wasim et al. (2013), Welo (2011), Welo and Ringen (2015), Welo et al. (2012), Welo et al. (2013), Wohnhas (2014) and Yang and Cai (2009).
Lean knowledge life cycle	Furian et al. (2013).

Learning networks/Organisational learning	Dal Forno and Forcellini (2013) and Liker and Morgan (2006).
Life-cycle management	Dem et al. (2012), Dombrowski and Schmidt (2013), Dombrowski et al. (2014), Hines et al. (2006), Murman (2008), Sorli et al.(2012), Vosgien et al. (2011) and Walton (1999).
Management	Oppenheim (2004).
Machigaiyoke	Gershenson and Pavnaskar (2003).
Modularisation/modular design/modularity	Anand and Kodali (2008), Anand et al. (2009), Cusumano and Nobeoka (1998), Dal Forno and Forcellini (2013), Dal Forno, Forcellini, de Miranda and Bornia (2013), El-Sayed and El-Sayed (2012), Gautam et al. (2007), Powell et al. (2014), Rossi et al. (2012) and Walton (1999).
MOGA	Cabello et al. (2012).
Obeya	Rossi et al. (2012).
Performance	Ringen and Welo (2015).
Platform architecture/platform of products	Bjarnoe (2006), Harland and Uddin (2014) and Rebentisch (2005).
Poka-yoke	Wasim et al. (2013).
Process architecture	Flores et al. (2011) and Flores et al. (2012).
Project portfolio management	Dombrowski and Zahn (2011) and Letens et al. (2011).
QFD/House of quality	Bertelli and Loureiro (2015), Choothian (2014), El-Sayed (2012), Endris et al. (2012), Haque and James-Moore (2004a) and Tähemaa et al. (2012).
Quality management methods	Lee and Chang (2010).
Queue management	Choothian (2014).
Rapid local adjustments	Reinertsen (2005).
RDM	Cabello et al. (2012).
Resources efficiency	Wohnhas (2014).
Reward and motivation process	Haque and James-Moore (2004a).
Risk management	Murman (2008) and Oehmen and Rebentisch (2010a).
Robust Engineering	Bertelli and Loureiro (2015).
Role of prototype	Kamath and Liker (1994).
SE	Dal Forno and Forcellini (2013), Khan et al. (2013), Karlsson and Åhlström (1996) and Kirner et al. (2013).
Single minute exchange of projects	Gershenson and Pavnaskar (2003).
Smart assemblies	Cabello et al. (2012).
Stabilisation	Liker and Morgan (2006), Ringen and Welo (2015), Welo and Ringen (2015), Welo et al. (2012) and Welo et al. (2013).
Stand-up meeting	Choothian (2014).
Strategy	Khan (2012) and Welo (2011).
Structural organisation	Dal Forno and Forcellini (2013).
System perspective	Welo (2011).
Taguchi method	Cabello et al. (2012).
Technology/tools	Powell et al. (2014), Qudrat-Ullah et al. (2012).
TRIZ	Bertelli and Loureiro (2015).
Up-to-date data	Karademir and Cangelir (2013).
Virtual simulation	Dal Forno and Forcellini (2013) and Dal Forno, Forcellini, de Miranda and Bornia (2013).
VRM	Cabello et al. (2012).
Workflow management	Baines et al. (2007), Ballé and Ballé (2005) and Liker and Morgan (2006).

* Either conference proceeding found but substituted by journal publication or conference proceeding identical to journal publication and only latter used.

Table 6: Other methods for new product development.

Conceptual model	Sources
Advanced Product Development (Anderson, 1997).	Walton (1999, p. 12).
Axiomatic design (Suh, 1990).	Pavnaskar and Gershenson (2005, p. 441).
Design concepts (Evans, 1959).	Singer et al. (2009, p. 3).
Innovation funnel (Wheelwright and Clark, 1992).	Morgan (2002), Singer et al. (2009, p. 5) and Walton (1999, pp. 12–13).
Major developmental stages (Clark and Fujimoto, 1991).	Morgan (2002), Saunders et al. (2014, pp. 310, 322) and Walton (1999, pp. 14–15).
Mechanical design process (Ullman, 2009)	Ćatić and Vielhaber (2011, p. 160).
P-51 Mustang development.	Bjarnoe (2006).
Process model for product development (Rauhut, 2011)	Schuh et al. (2014, pp. 394–395)
Pugh matrix, Pugh (1991).	Al-Ashaab, Golob et al. (2013, pp. 8, 12–14), Singer et al. (2009, p. 5) and Ward et al. (1995, p. 48).
Shigley’s model for design processes (Shigley and Mischke, 1989).	Ward et al. (1995).
Stage-gate model for innovation (Rozenfeld et al., 2006).	Wang, Ming et al. (2011).
Stage-gate process (Cooper et al., 2001, p. 272).	Beauregard et al. (2011) and Salgado et al. (2015, p. 31).
Systematic development of products (Baxter, 1995).	El-Sayed (2010, p. 195) and El-Sayed and El-Sayed (2012).
Systematic engineering design and practice (Pahl and Beitz, 2007).	Dombrowski and Schmidt (2013) and Schuh et al. (2014, pp. 394–395).
Ulrich and Eppinger’s (1995, 2000, 2004, 2007, 2008) product design and development process.	Ćatić and Vielhaber (2011, p. 160), Chase (2000, pp. 4–5), Cusumano and Nobeoka (1998), El-Sayed (2010, p. 195; 2012, pp. 2–3), Mayrl et al. (2013, p. 494), Walton (1999, pp. 13–14) and Wang, Ming et al. (2011, p. 7).
VDI guidelines.	Ćatić and Vielhaber (2011, p. 160) and Schuh et al. (2014, pp. 394–395).
Waterfall model (Petersen et al., 2009; Royce, 1970).	Salgado et al. (2015, p. 31).
Wu’s (1994) product development process.	El-Sayed (2010, p. 195).

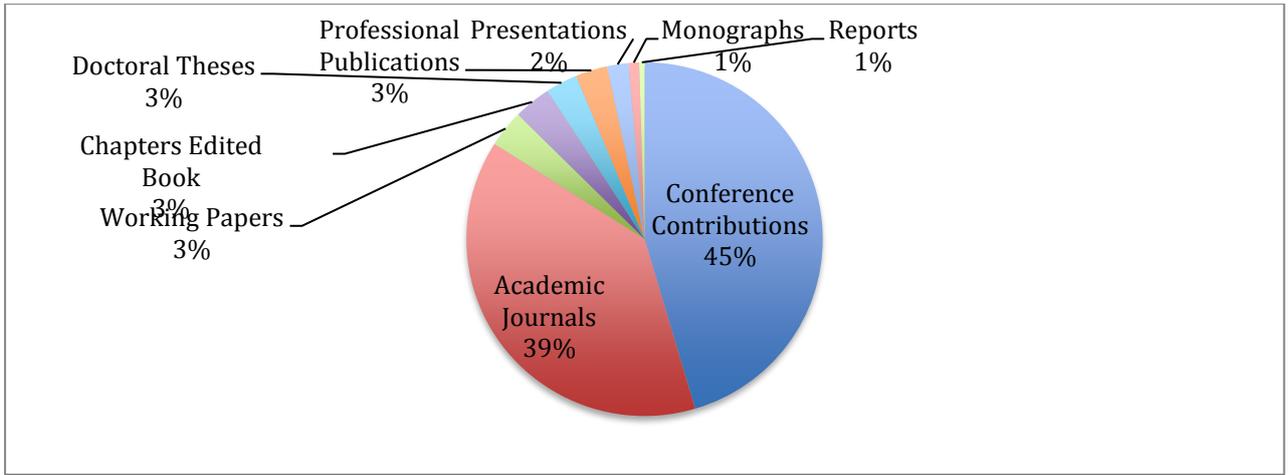


Figure 1: Overview of types of retrieved publications.

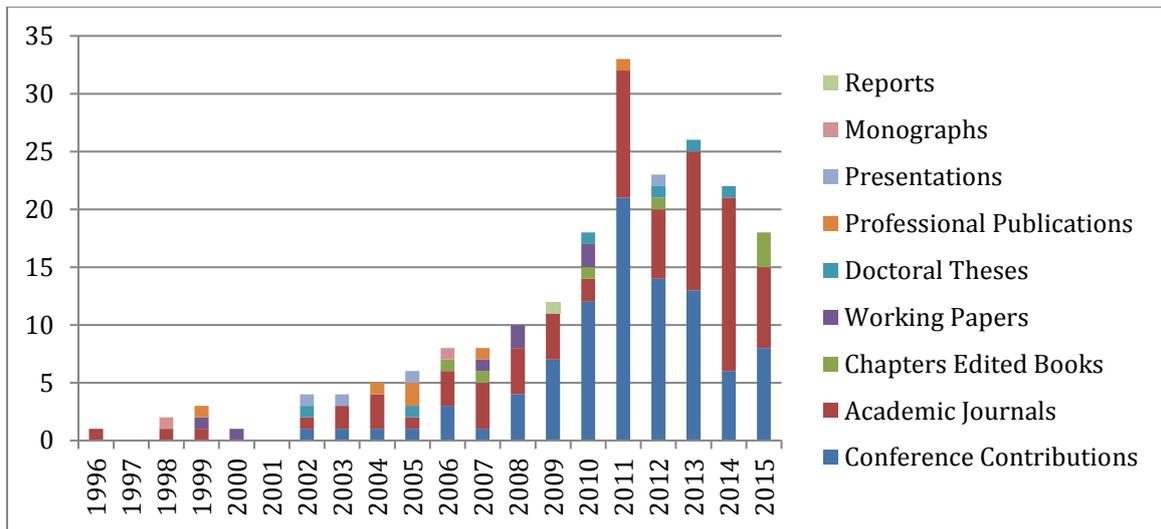


Figure 2: Overview of types of publications by year.

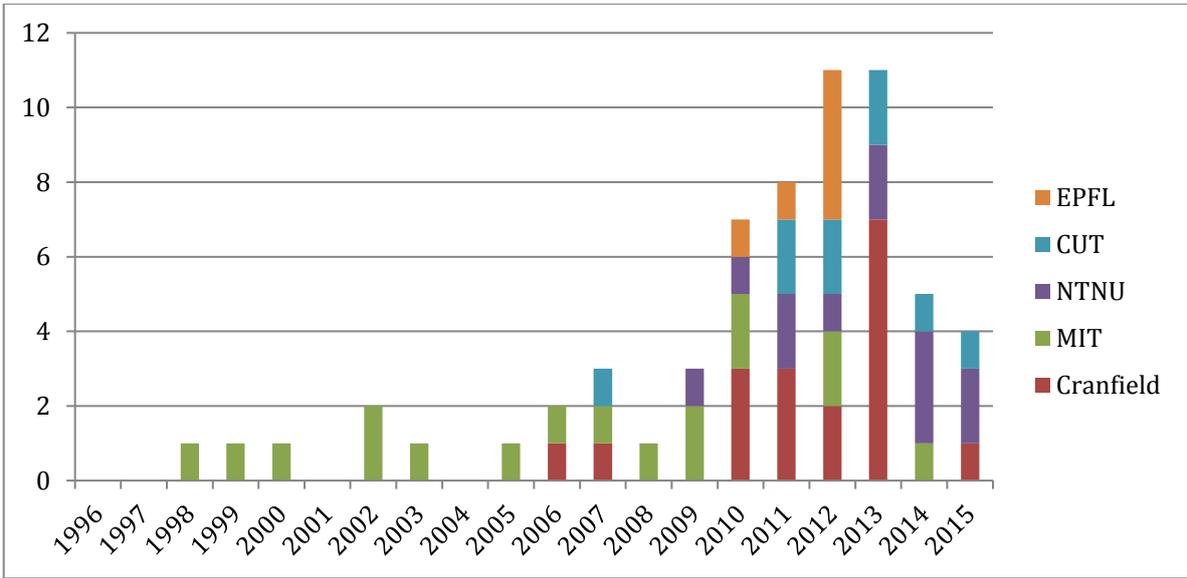


Figure 3: Annual publications per leading institute.

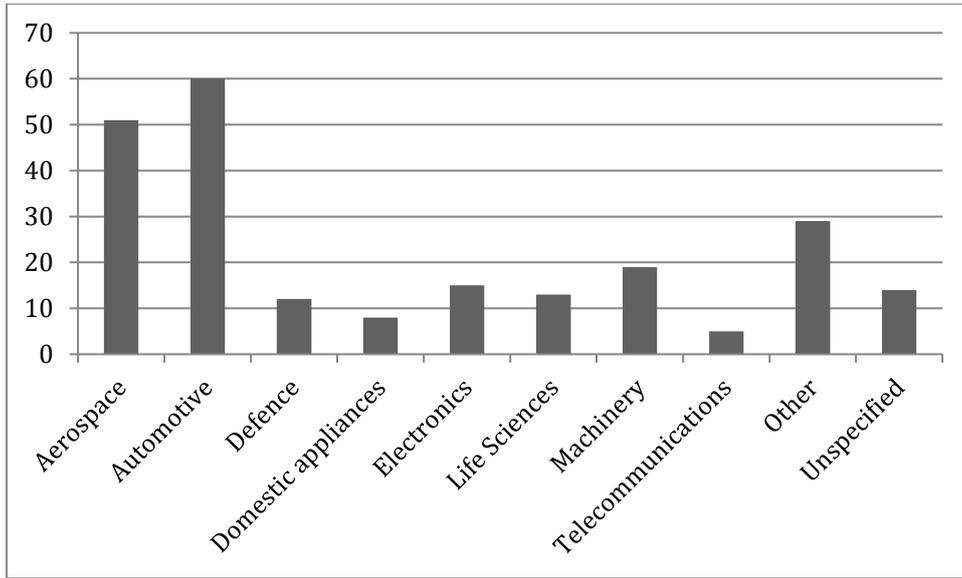


Figure 4: Frequency of industries across publications (excluding propositional papers not directed at a specific industry).

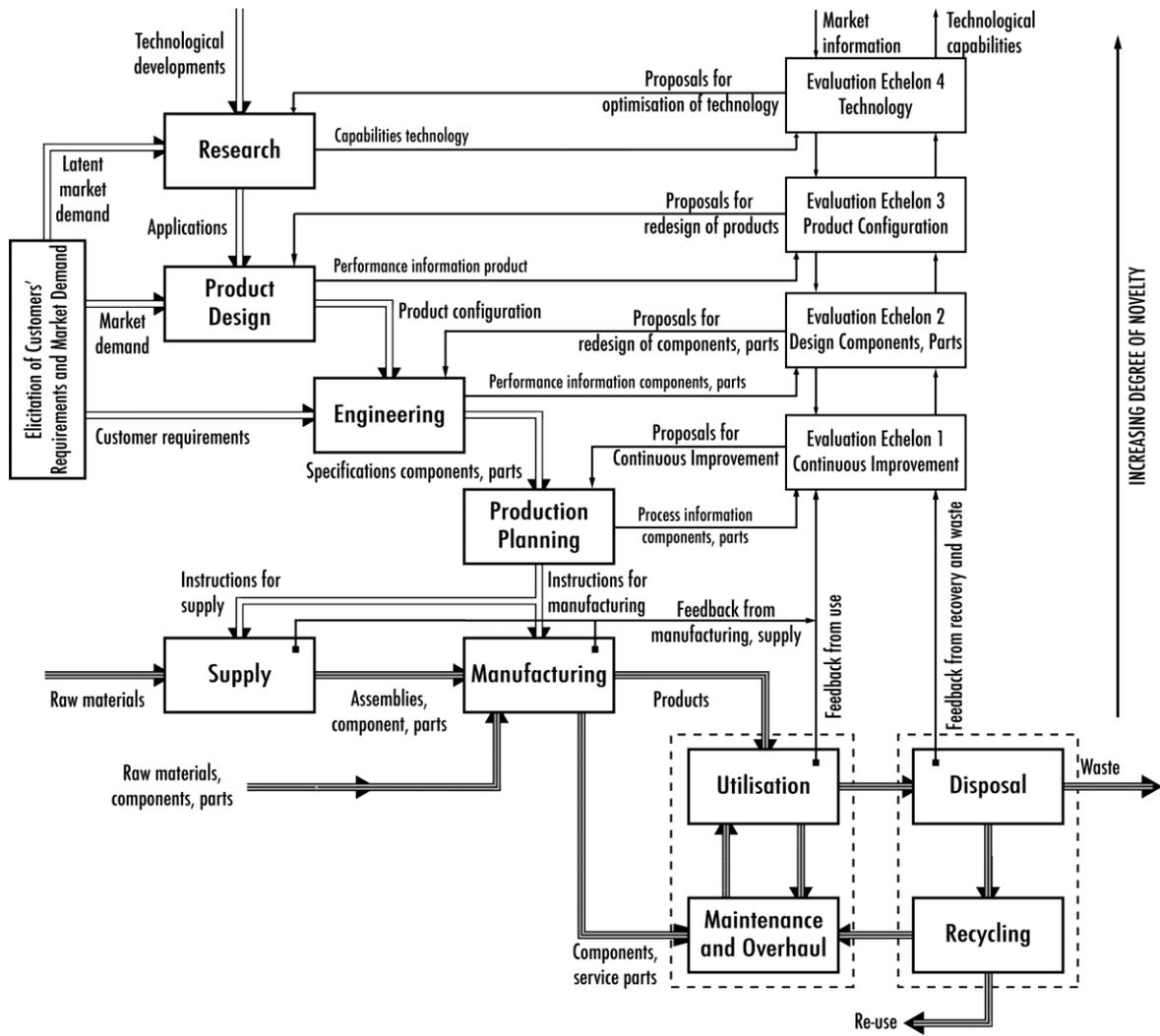


Figure 5: *Generic reference model for engineering, manufacturing and deployment processes (Dekkers et al., 2013, p. 321).*

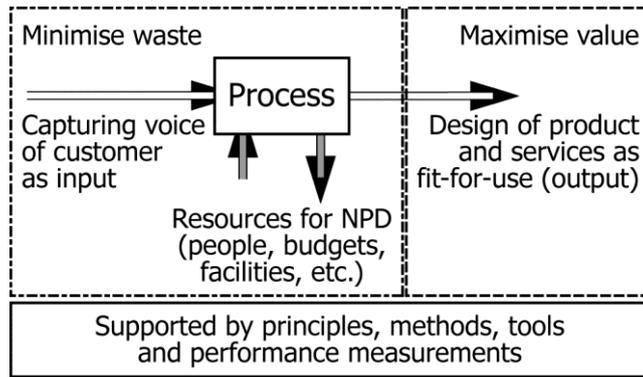


Figure 6: Waste and value in NPD (adapted from Hoppmann [2009, p. 15] by using process modelling from Dekkers [2015, pp. 78– 79]).

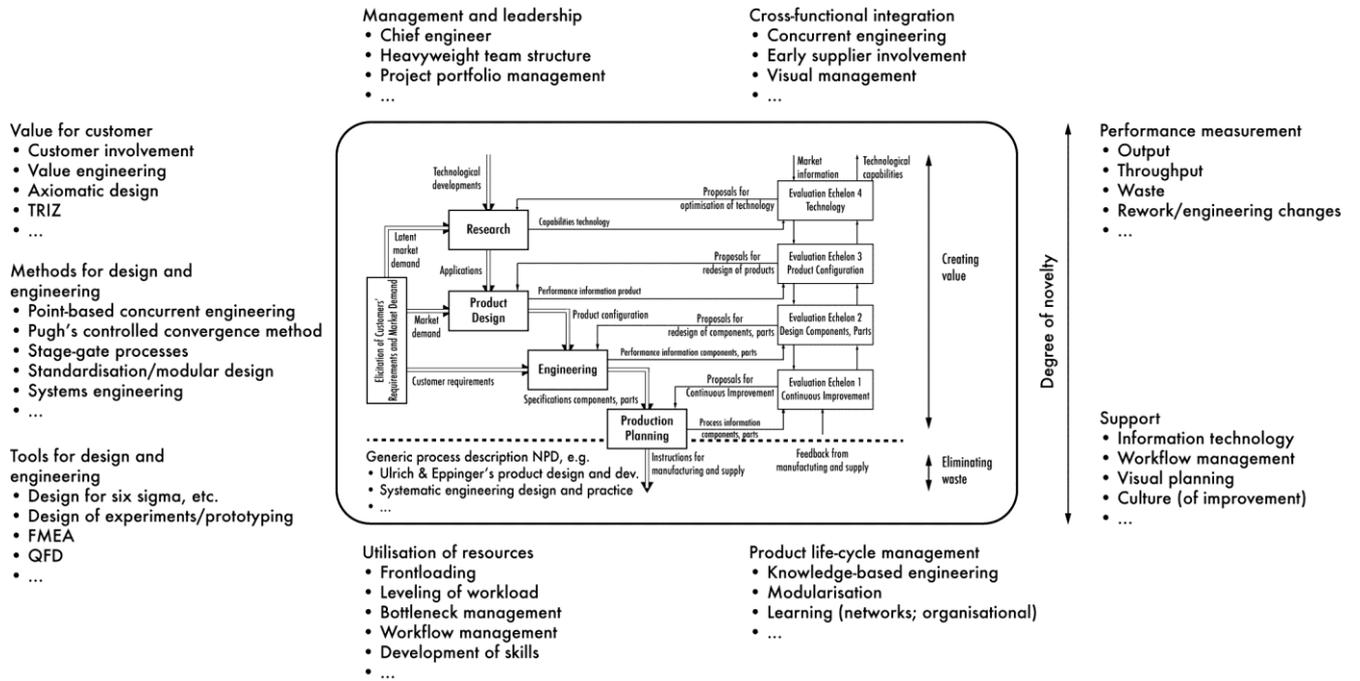


Figure 7: Overview of approaches, methods and tools for new product development.