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Review

Trends and Future Research Direction of Lean Product Development

Ivana Cukor Kirinić * and Miro Hegedić

Department of Industrial Engineering, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, 10000 Zagreb, Croatia; miro.hegedic@fsb.hr

* Correspondence: cukor.ivana@gmail.com

Abstract: The field of product development (PD) has an excellent opportunity to achieve the benefits of lean principles. The literature on lean product development (LPD) is growing and is extensive, but it needs to be more systematic. A distinct, comprehensive, and up-to-date review of LPD literature is necessary. Motivated by studying and understanding contemporary themes and the current trends in the LPD research area, this article reviewed 85 previously published papers across three scientific databases from 2011 to 2022. Using literature review methodology, we determined for every article: research motivation or gap filled, key findings and significant contributions, and suggestions for future research. That helps structure the field of research into nine domains according to the gaps the authors wish to fill. The results indicate that over the past decade, the LPD literature has shown trends towards synergy of LPD with green, sustainability, circular economy, industry 4.0, and digitalisation. Finally, the article proposes six future research directions.

Keywords: lean product development; lean product design; lean engineering; product development; lean thinking; sustainability

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1. Introduction

Dynamic customer requirements in today's highly competitive global markets place continuous pressure on product development (PD), requiring companies to produce new products faster, at reduced cost, and with better quality than their competition [1]. Companies must improve their product development processes to respond to these demands, and Lean Product Development (LPD) offers an effective solution. LPD effectively reduces time to market and improves product innovation while maintaining high quality and cost-effectiveness [2–4].

The field of PD offers an excellent opportunity to achieve the benefits of lean thinking. PD is an integral part of creating value for the customer. It defines the physical look of the final product and the choice of materials to be used, thus significantly limiting the range of manufacturing technologies that can be used to produce it. Therefore, it is usually the case that the influence on cost, quality, and manufacturing lead times is significantly more significant in the PD stage compared to actual production [5]. Almost 80% of a product's cost is decided when designing the product before manufacturing begins [6]. LPD encompasses the entire process, starting with the collection and generation of ideas, followed by the assessment of potential success, concept development and evaluation, elaboration of the product, its testing and development, and culminating in the product transfer for production [7].

In the work of [8], it is stated that LPD is a primary methodology organisations implement to maximise value, enhance quality, reduce lead times, and lower costs for PD processes. Nonetheless, various organisations encounter difficulties when deploying LPD. Stakeholder pressure to apply lean principles to PD processes has recently increased [9], and this has led to a growing literature about LPD [10].

This article presents findings from a systematic review of the literature on LPD covering 2011 to 2022. The literature on LPD is extensive but rather unsystematised. In addition, the only relevant literature review, which exclusively covers Lean Thinking in PD [8], is over a decade old. Article [11] compares LPD with other PD methodologies and does not address LPD as a main topic. A distinct, comprehensive, and up-to-date review of LPD literature is needed to provide an overview of what has been happening in this trendy field over the last decade, current themes and trends, and where the field of LPD is moving.

As [8] is the last available literature review of LPD and the literature about LPD is growing, these articles are motivated to study and understand contemporary themes and the current trends in the LPD research area. Also, we wanted to present the area clearly and systematically, with suggestions for future research.

With a focus on LPD, the following questions will be explored in this review:

1. Can the field of LPD be grouped by research topic?
2. What are the current trends in LPD?
3. What are the main gaps, and where should future research be directed?

This article solves the practical problem of unsystematised literature, making it challenging to explore trends and scientific gaps in the area of LPD and clearly define the opportunities for future research. The novelty of this article is that it provides an overview of the area, with grouped topics and gaps that the authors wanted to cover. Additionally, this literature review recommends future directions for research in the field of LPD according to current trends, suggestions for future research, and unanswered questions from the articles. This comprehensive review aims to assist practitioners in quickly and efficiently finding the desired topics of interest and the answers they seek.

The structure of the article is as follows: Firstly, the research methodology is explained after the introduction, and then the results and the gap analysis are presented and discussed. The article then provides recommendations for future research. The paper discusses the essential findings, contributions, practical implications, and theoretical limitations.

2. State-of-the-Art on Lean Product Development

2.1. Literature Review

The section describes the methodology used to conduct the literature review in this paper and provides a comprehensive analysis of the statistics derived from the literature review.

To investigate the current state of LPD, we employed a systematic literature review (SLR) as our research methodology. Literature reviews are fundamental to various types of research, as they can form the basis for knowledge development, shape guidelines for policy and practice, offer evidence of an effect, and, when well executed, be a source of novel ideas for a specific area. Consequently, they help to lay the foundations for future research and theory [12].

The authors have analysed the research conducted in the LPD research field and identified several research trends. The articles have been categorised to provide an insight into the research area from 2011 to 2022. Also, research gaps have been filled, key findings and future research have been identified, and emerging trends in this area are highlighted. All this served as an introduction and basis for the narrative of LPD's future research direction.

At the beginning, a research protocol was formulated to outline the scope of the research, define the research strategy, and establish the criteria for the selection, categorisation and exclusion of publications.

In order to identify relevant literature with a clear link to LPD only, the search was restricted to papers where the keywords "*Lean product development*", "*Lean product design*", "Lean product engineering" or "Lean engineering design" were present in the title, abstract, or keyword of the paper. Those four words were chosen because the goal was to find articles whose occupation is purely lean in PD. Keyword searches were used across a database, including Web of Science, Scopus, and Science Direct. This corresponds to the

suggestion to consider at least two databases [13]. The search resulted in hundreds of articles, which were then filtered according to the following principles:

- Literature published in the English language.
- The literature search was carried out from January 2011 to December 2022. This time frame was chosen because the authors wanted to cover the area since the last literature review [8] and also to show current publications that were perceived to be most significant for research trends in the field.
- Search results contained only peer-reviewed papers published in academic journals and international conference proceedings because, in the view of [14], these sources are the most helpful and credible for literature reviews.
- Only the engineering domain was relevant (for instance, papers from the fields of medicine, astronomy, and the arts and humanities did not pass this stage).

Another technique that was employed is the snowball sampling technique, in which the reference lists of the selected papers were examined to identify any additional papers that might not have been found in the database searches.

A total of 202 results were generated when searching for LPD papers. The second step was to filter the first search results in order to find out which papers were indeed important for the review. A paper is judged relevant if it has a direct link to the LPD. A "clear link to LPD" is considered if the main topic and occupation of the article are lean in product development and it is not just mentioned incidentally through the article within the framework of some other topic. Relevant or not was decided by analyzing the publication's title and abstract. If these were insufficient for inclusion, the introduction and conclusion were read, and if that was not sufficient for a decision, the full paper was read.

After a brief reading of all the selected papers, a list of 85 LPD papers that were found to be of interest and importance for inclusion in the review was produced.

During the literature review with a focus on LPD, the aim was to summarise the content of each article through the answers to the following five questions:

1. What article type does this article belong to?
2. What was the research motivation and gap filled?
3. What were the main findings and the most important contributions?
4. What were the remaining unanswered questions and suggestions for future research?

During the reading of the article, notes were kept and saved in the form of a table. The contents of columns for each article were answers to questions. After all the articles were read, the notes were analysed and the possibility of grouping the articles according to motivation and gaps was considered. That allows us to organise the articles into nine "filled gap" domains: design guidelines, enablers or components of LPD, framework, implementation issues, industrial application, literature review, people & knowledge, performance metrics, and value or waste identification. The following sections present and explain the review findings. These findings are based on tables available in Appendix B, where each research domain has a corresponding table that provides a detailed overview of the notes for the articles within that domain. The table includes information on the motivation, key findings, and suggestions for future research for each article. Moreover, the table has sorted the articles by their publication year, which makes it easier to identify trends.

The timeline chart shows an overall stable trend in the number of articles published in the area, at least since 2014. (Figure 1). Slightly fewer articles during 2021 and 2022 can be linked to the COVID crisis. Taken alone, the stable number of published works implies continuous interest in the field. With regard to the second variable of evaluation (medium of publication), of the 85 selected works, 48 articles, or 56%, were articles published in journals, and 37 articles, or 44%, were conference papers. Therefore, there is an almost equal distribution of articles by the medium of publication.

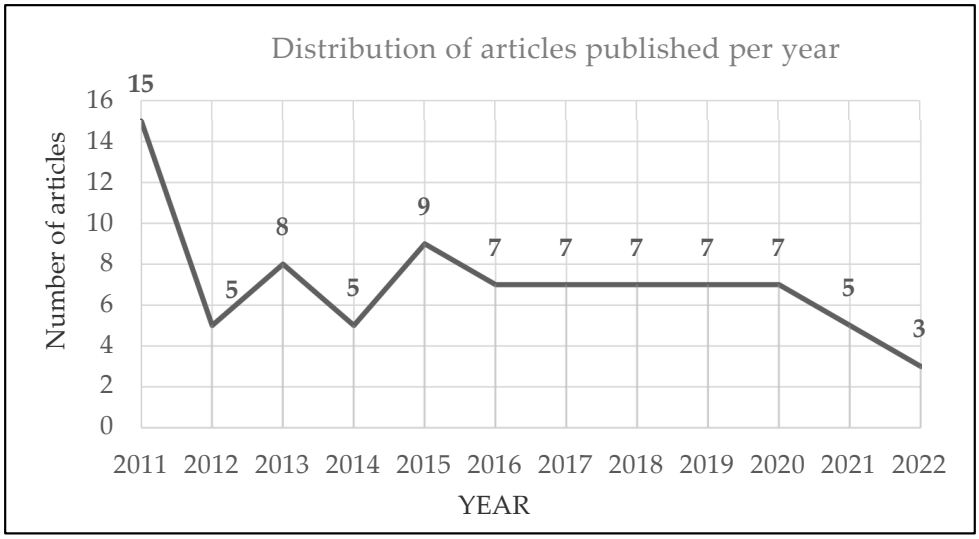

Figure 1. Distribution of articles published per year from 2011 to 2022.

The literature review comprises articles from 31 distinct journals and 16 conference types. All of these journals and conferences cover various topics and research areas. The wide range of publications on LPD indicates how interesting the topic is for researchers from different scientific fields and how much it is related to other areas of research. Tables 1 and 2 show the list of journals and conferences represented.

Table 1. List of represented journals.

No. of Articles per Journal	List of Journals
6	Engineering management journal
3	Int. J. of Computer-Integrated Manufacturing
2	Concurrent Engineering: Research and Applications, Int. J. of Product Development, Int. J. of Lean Six Sigma, Int. J. of Production Economics, Journal of Cleaner Production, Management decision, System engineering, Int. J. of Technology Management, Production Planning & Control, J. of Manufacturing Technology Management
1	Advances in Transdisciplinary Engineering, Benchmarking: An Int. J., Environmental Engineering and Management J., Evolving systems, Int. J. of Production Research, Int. J. of Project Management, Int. J. of production economics, J. of Engineering Design, J. of Engineering, Design and Technology, Tehnički vjesnik, Int. J. of Management Reviews, Journal of business research, Journal of open innovation, Revista de Gestão, Design science, Webology, Int. J. Aerospace System Science and Engineering, Advances in science and technology research journal, R&D management

Articles can be grouped into four main categories: theoretical and conceptual papers, surveys, literature reviews, and case studies. They are grouped according to the author's assessment of which category dominates the articles because some combine categories. A total of 64% (54 articles) of articles published are theoretical and conceptual papers, 9% (8 articles) are literature reviews, 11% (9 articles) are surveys, and 16% (14 articles) are case studies. Table 3 presents a division according to the article type and a rough content description.

Table 2. List of represented conferences.

No. of Articles per Conference	List of Conferences
16	Procedia CIRP
5	IEEE
2	IFIP Int. Conference on Advances in Production Management Systems, Int. conference on engineering design
1	ICoRD 13, Improving Complex Systems Today, Int. Asia Conference on Industrial Engineering and Management Innovation, Int. design conference, Int. Conference on Manufacturing Research, IOP Conference Series: Materials Science and Engineering, Modelling and Management of Engineering Processes, Int. Conference on Concurrent Enterprising, Procedia computer science, Innovative Manufacturing Engineering & Energy International Conference

Table 3. Overview of article types.

Article Type	Article Dominant Type	Content
Case studies	[4]	The most detailed and comprehensive case study
	[15–18]	Use a case study as a confirmation of its own developed model
	[19–26]	Use a case study to investigate potential implementation issues
Literature review	[8,11,27–32]	Pure literature review
Survey articles	[33–35]	The survey is based on a literature review for a specific problem
	[36–41]	Surveys are used for the further development of the conceptual model
Theoretical and conceptual papers	[1,3,9,42–58]	The theory is based on a literature review
	[2,59–66]	The theory is based on a survey
	[7,67–77]	Confirms theory through the case study
	[78–89]	Additional explanation of their own model

An overview of theoretical and conceptual papers and the authors' corresponding models, frameworks, and theoretical treatments can be found in Appendix A—Table A1.

2.2. Results and Discussion

This section presents a review of the 85 works previously selected. By answering the question "*What were the research motivation and gap filled?*", we identify and organise articles into nine "filled gap" domains: design guidelines, enablers or components of LPD, framework, implementation issues, industrial application, literature review, people and knowledge, performance metrics, and value or waste identification. The distribution of articles according to the domain is shown in Table 4.

The answers to the remaining four questions mentioned in Chapter 2.1 will be displayed in the frame of each of the nine domains. Appendix B contains Tables A2–A10 that include a more detailed overview of the notes on the articles in each domain, including information on the motivation, key findings, and suggestions for future research for each article.

Table 4. Filled gap domain.

Filled-Gap Domain	Articles That Belong to the Domain
Design guidelines	[46,79,80]
Enablers or components of LPD	[3,42,45,61,73,89]
Framework	[10,19,41,43,56,60,66,67,72,85,87,88]
Implementation issues	[24,30,38,39,54,58,81,82]
Industrial application	[2,4,15,16,21,23,26,40,51,68,69,75,86]
Literature review	[8,11,27–29,31,32]
People and knowledge	[1,17,22,25,49,52,53,63–65,70]
Performance metrics	[7,9,20,33,35,36,44,47,55,62,74,76–78,83]
Value or waste identification	[18,34,37,48,50,57,59,71,84]

2.2.1. Domain "Design Guidelines"

Research works under the *"Design guidelines"* domain focus on design guidelines for lean design. Dombrowski et al. [46] incorporate the various specific DfX techniques in the holistic design concept, while Rauch et al. [79] use axiomatic design methodology, present a catalogue of generally applicable design guidelines for LPD, and then, in their second work [80], link them with concepts from Industry 4.0. They conclude that LPD and an Industry 4.0-oriented Smart PD are not separate but belong together.

The future direction in this domain is to complete the investigation of DfX approaches regarding their synergies, influences, and more touchable design guidelines. More than a few articles in this domain are needed to observe the trend.

2.2.2. Domain "Enablers or Components of LPD"

Research efforts under the *"Enablers or components of LPD"* domain are primarily motivated by the definition of LPD enablers or components and their influence; however, the most recent work in a decade by Hopmann et al. [42] provides 11 LPD components that depend on each other. Khan et al. [3] proposed five enablers of LPD that make up its building blocks. Schulze and Störmer [89] stated that training that gives lean specialists knowledge of traditional engineering skills (i.e., lean thinking, waste analysis, and standardisation) is a management factor enabler for LPD.

Dombrowski et al. [45] and Tortorella et al. [61] changed efforts from the definition of enablers and tried to describe their influence. A total of 19 LPD elements that influence the effectiveness and efficiency of PD were found in [45], while [61] presented relationships between LPD enablers and problems.

The most recent article by Oliveira et al. [73] reflects a trend (observed in other domains as well, which will be noted later in this article), and that is an attempt to link lean to the modern paradigm. In this case, it is lean and green—they presented 16 lean and green enablers for PD.

Future research in this domain includes the holistic systems perspective, longitudinal studies, and further investigation, which will identify interactions, relationships, industry impact, and a lean/green way of thinking.

2.2.3. Domain "Framework"

Research efforts under the "Framework" are motivated to present some versions of the LPD framework. The applied approach goes in three directions. One group of authors represents frameworks in which LPD connects with other paradigms (LM) [66], eco-principle [55], PSS [43], and sustainability [19]. The second group focuses on more specific cases (small and medium-sized suppliers—[60], OKP environment—[67]. The third group of authors is motivated by creating a framework that facilitates the application of LPD ([41,56,72,85,87,88]).

Meybodi [66] reports a high similarity rate between CENPD (concurrent engineering approach to new PD) and LM factors. The results show that organisations employing LM techniques can create new products with improved quality by 63%, reduced development time by 52%, decreased development cost by 45%, and lowered manufacturing price by 36% compared to conventional companies.

Ref. [41] recommended an adjusted variant of the LPD system to facilitate lean thinking in product engineering within a particular setting. Letens et al. [56] proposed a framework with tools and practices for implementing LPD at all levels (functional, project, and portfolio) and how to manage interactions between them. Furuhjelm et al. [87] and Wang et al. [88] want to present frameworks that can be used in companies that are realistic and feasible. Lermen et al. [72] offers customised guidance on how to adopt the framework from a systematic viewpoint. Khan et al. [85] provides detailed insight into the SBCE process to help organisations initiate and embed it into the PD process.

In [55], the author explores similarities, expected benefits, and potential difficulties in integrating green and lean development perspectives.

The latest articles reflect these trends. The first is outlined in an attempt to integrate lean and circular economy principles [43], or lean and sustainable [19]. The second one is the description of LPD in a specific environment: small and medium-sized (suppliers) [60] or a one-of-a-kind industrial environment [67].

These articles also give directions for future developments in this domain in the form of further investigation of the incorporation of lean and sustainability and lean and circular economy principles.

2.2.4. Domain "Implementation Issues"

Research works under the *"Implementation issues"* domain focus on the relief of the application of LPD in practice.

Rossi et al. [82] state that there is a need for more tools and methods that are easy to understand and present the 5-step methodology for improving an existing design process with lean thinking. [58] The authors noted a need for more methods and tools for synchronising the phases within the Engineer-to-Order (ETO) value chain. They proposed an approach to minimise waste in the entire process. The main result of [38] is that many lean techniques can be introduced rapidly and have excellent potential for improving performance. Also, lean principles and Industry 4.0 methods boost efficiency optimisation in PD. Welo and Lervåg [81] concludes that not only investment in modern technologies is enough to ensure the needed capabilities, but also investment in employee knowledge, competencies, and organisational learning.

Kumar et al. [54] analyses 21 barriers to GLSPD and their relationships. Trying to minimise waste might endanger the innovativeness and quality of the PD process. Oliveira et al. [39] give an interesting comparison between Brazilian and Japanese SMEs in their article. Von Würtemberg et al. [30] conclude that LPD organisations strive toward long-sighted, sustainable goals rather than quick economic profit. Work [24] confirms through a case study that LPD is promising.

Future research suggested by authors from this domain can be found in SME PD and Industry 4.0. (even 5.0) and in further validation of green lean barriers in the industry. From articles [38,39,54], an emerging interest in green and SME can be seen in this domain as well.

2.2.5. Domain "Industrial Application"

Under this domain, the main aim is to present successful implementation or suggest a way to achieve lean transformation.

Al-Ashaab et al. [16,51] show the benefits of using SBCE (Set-based Concurrent Engineering) principles in an industrial area. Gremyr and Fouquet [2] used interviews as a research methodology. It showed that integrating DFSS (Design for Six Sigma) and LPD could provide guidelines on how to structure content improvement activities. The paper [68]

presents the development of the Lean DfX (Design-for-X) design assessment framework in an actual industrial setting, highlighting its holistic approach. Implementation in an engineering department is presented in [15,21,23,26,69,75]. The SMART Readiness Maturity Assessment is presented in [86] and provides insights into how to get over some conditions that restrict the application of LPD practices. Ref. [40] suggests a significant correlation between the development of the lean supply chain and the lean product.

The most comprehensive description of lean transformation is given in article [4]. They suggest achieving massive results and improvements is feasible by making considerable changes in employees, processes, and tools. It is shown through an example at Ford, which continued to use the LPD principles learned from the Toyota study. They consider these principles sufficiently generic to be widely applied in product-process development across organisations and industries.

The authors believe future research in this domain will reflect trends observed in the "Framework "domain. Future descriptions of the industrial application should be linked to lean on one side and current modern trends on the other. These modern trends are reflected in the use of green, sustainability, circular economy, or smart industry principles.

2.2.6. Domain "Literature Review"

In general, the domain of *"Literature review"* focuses on the studies of the LPD area by using the systematic literature review methodology. However, they searched the LPD area for different needs.

Only one pure literature review with an overview of the entire research area is conducted by Martinez and Farris [8], who classified the LPD research area into seven domains of knowledge based on available LPD and PD frameworks. They call for further validation of the proposed methods and theories and confirmation of their adaptability to different industries and scenarios.

Salgado and Dekkers [11] try to answer the question, "Does LPD add value compared to other methods and concepts?" They concluded that it is clear that there is nothing new under the sun for LPD but calls for further comparison of LPD with other approaches for NPD.

Johansson and Sundin [28] and Monteiro et al. [29] research relations between the lean and green PD. Both suggest future research on the integration of lean and green methodologies and the investigation of their relationship in practice.

De Souza and Dekkers [27] stated that more methods and LPD tools are needed to contribute to the sustainability of their use. Only a limited number of tools address the social or even the three dimensions of sustainability altogether. Their suggestion for future research is to research the contribution of LPD methods and tools to each dimension of sustainability and further investigate possible synergies, conflicts, or intersections between LPD and sustainability.

Toche et al. [31] state that SBD (set-based design) has relatively low theoretical development. [32] has conducted a systematic literature review of value perceptions in complex systems PD.

In the *"Literature review"* domain, a noticeable trend is turning the research area of LPD into green and sustainable LPD.

2.2.7. Domain "People & Knowledge"

In the *"People & knowledge"* domain, researchers explored the influence and connection between LPD and an engineer's motivation, learning, creativity, or knowledge transfer. A lot of exciting conclusions have emerged from these studies. One such study is that of Ćatić and Vielhaber [49], which showed that the main differences between LPD and other existing PD models are primarily found in how knowledge is acknowledged and handled. The next thing is how and when decisions are made during the process.

De Oliveira [52] presents the Toyota Kata approach, which minimises development risks and manages knowledge in the LPD environment. Lindlöf et al. [53] conclude that

LPD offers a knowledge transfer that companies with insufficient routines for the transfer of knowledge desire. Ringen and Holtskog [63] found that engineers' motivation and readiness to learn at the team level are remarkably related to customer requirements. Ringen and Welo [64] determine to what extent practices relate to the knowledge component of LPD and suggest that significant differences exist among industrial sectors. Heinzen and Höflinger [65] show that not only human capital resources, such as skills or motivation, have an impact on LPD process performance, but also that certain human resources practices can actively influence these outcomes—research conducted by Helander et al. [70] noted that the main focus of lean in PD is flow-over waste reduction and that solid emphasis is placed on reducing disturbances.

Refs. [1,17,22,25] are articles whose interest is knowledge creation and visualisation.

Although research in this domain has led to many interesting conclusions, future research should include larger populations and different development environments to examine and confirm these conclusions.

Research trends can be seen in the knowledge component of LPD.

2.2.8. Domain "Performance Metrics"

The main focus of research in the *"Performance metrics"* domain is how to evaluate lean practice. This is the domain that most researchers have been interested in in the last decade. The methodology primarily used is a literature review or survey, but some authors continue to use LDfX [7] or SBCE [78], as well as benchmarking [74].

There are three groups of authors. The first group assesses the performance of lean thinking in PD and contributes to the development of new performance metrics [7,9,20,33,35,36,47,62,74,78]. The second group evaluates the impact of LD system implementation on the PD process [44], the impact of LPD practices on LM performance [10], or the overall PD cost [77]. The third group evaluates the effects of product quality, value, development time, and costs on the lean strategy and practice in the PD setting [83].

Future research will test the validity of the models by increasing the research population. There is no increased interest in a particular topic, so that trend was not noticed.

2.2.9. Domain "Value or Waste Identification"

Research in the *"Value or waste identification"* domain focuses on describing value and waste in LPD.

Rossi et al. [59] explain that the list of NPD process wastes (non-value-adding) derived from literature and practice creates a way to systematically identify wastes and find the priority order to eliminate and reduce wastes. Siyam et al. [48,84], Kirner et al. [34], and Schuh et al. [50] analysed value, waste, and their relationship and presented guidelines for eliminating waste when applying value methods. Belvedere et al. [37] conclude that complex projects may be impacted by waste types listed in the LPD publications. Researchers may need help identifying the key priorities for their interventions because they need help separating value-adding from value-destructing activities. Gudem et al. [71] suggest that customers' perception of product value is contingent on their experience, which their momentary requirements can influence. Moreover, it is pointed out that a strong understanding of the value defined by the customer can mean something other than the ability to fulfill this value. According to the reference, [57] states that the LPD must be included in identifying and conceptualising customer value. Ref. [18] describes the most common waste in ETO projects and suggests management strategies about how lean engineering design can reduce waste and enhance the performance of ETO projects.

Future research directions suggested by the authors include a study of different types of industries and empirical validation. There is no increased interest in a particular topic, so that trend was not noticed.

3. Recommendations for Future Research Directions

A significant number of articles (85) and different authors and their aspiration to fill the gaps in the area by looking at various thematic directions confirm that the field of application of lean in PD is exciting and growing. There has to be further validation of the differences in industry-specific, geographical, business context, or enterprise-specific conditions in every domain.

To direct further research, and based on the research above and future research suggested by the authors, we outlined the following directions for further research in the LPD area:

1. Deepen the value and waste domain
2. Performance measurement with accurate data
3. Implementation descriptions with empirical evidence
4. People and knowledge
5. Cross-section and synergy of LPD with other current, cutting-edge fields of research
6. LPD in the SMEs environment

3.1. Deepen the Value and Waste Domain

Lean, which originated at Toyota, is a methodology designed to enhance value for all participants by eliminating waste. Implementing lean begins with identifying value, mapping the value stream, and seeking perfection. In their study, McManus et al. [6] found that only 12% of tasks in engineering processes can be classified as value-added activities, indicating that waste is a significant issue.

Previous studies in this field suggest a need for further investigation ([34,48,50,59,71,84]), but in the past five years, only a few articles have specifically addressed value and waste ([18,37,57]). Despite being central to Lean, value and waste should be addressed lately as research gaps in LPD. Have all types of value and waste within PD already been thoroughly explored? Are there any novel types of waste related to organisations' digitalisation, teams distributed across different countries and time zones, or modern forms of working from home via other digital platforms? Our point of view is that there is still room for further examination across various industries to uncover new sources of waste and value and to determine the generalisability of findings across the industry.

3.2. Performance Measurement with Accurate Data

A total of 14% of the articles in this literature review belong to articles in which the authors attempted to fill the gap associated with the LPD framework, and 18% of the articles in which the authors tried to fill the gap related to the performance measurement of LPD. Many theoretical LPD frameworks and many proposed ways of measuring LPD performance suggest that the LPD research area has yet to come to a consensus and, therefore, is still evolving.

A total of 15% of articles handle the topic of industrial application, and 9% of articles address the topic of implementation issues, but with a variety of performance measurement tools presented in the research area (18%), some questions arise: "What is a successful model of implementation if there is no unique performance measurement?" and "How can we then compare implementations?" or "Is there a general LPD implementation model at all, or does it depend on some factors?" Rossi et al. [36] pointed out these questions and suggested a model that can serve companies in comparison with competitors.

A valuable avenue for future research is to validate existing models through testing in a real-world industrial setting using actual operational performance data [10,47,74]. This will confirm the practicality and effectiveness of the models.

3.3. Implementation Descriptions with Empirical Evidence

Many concept articles (64%) suggest that the number of theoretical frameworks in the research area keeps increasing. Still, several surveys, case studies, and academic and conceptual papers derived from enterprise surveys or case studies show that the theory

discusses implementation (Table 3). Another literature review article [8] also suggests that there is potential in LPD such that focus can be shifted from what types of things should be performed to exactly how to implement the recommendations to enhance processes in PD. Table 3 shows that 12 authors of theoretical papers tried to confirm their theories through the case study, 15% attempted to present the industrial application, and 9% researched implementation issues, which suggests that the authors turned to exploring implementation topics.

Despite numerous efforts, only two articles have documented the transformation of the PD process using Toyota's Lean methodology. Ref. [15] highlights the strategy, experience, and outcomes gathered from successfully implementing Lean thinking within an engineering environment. Ref. [67] provides a comprehensive approach to Lean PD transformation in highly individualised PD, offering valuable insights into the implementation process. The study reported significant savings from redesigning the design process, with a 32% reduction in engineering changes over three years and performance improvements ranging from 25% to 83% across various process indicators.

According to [10], there are still limited reports of successful adoption of LPD outside of Toyota. Ref. [67] also acknowledged the need for more comprehensive coverage of the entire LPD implementation process. This lack of empirical evidence is a concern, and future LPD research should aim to fill this gap by providing more in-depth descriptions and empirical evidence of LPD implementations.

3.4. People and Knowledge

About 14% of the articles research the area of LPD according to issues related to either the exchange and storage of knowledge or people and their skills, motivation, and creativity. Is there a connection between LPD success on one side and people and their knowledge on the other?

Individuals working in development, primarily engineers, have a vital role to fulfill in LPD, as the assets of PD, such as information, knowledge, and ideas, are mainly held in their minds [65]. As LPD is a process based on knowledge, the focus is on gaining and collecting knowledge for current and future products [67]. A supportive knowledge environment is essential for LPD [17]. Ref. [53] also recognises LPD as a valuable tool for knowledge transfer.

We agree with [53] that the relationship between LPD and knowledge management theory deserves further investigation. Further research is needed to explore the LPD's impact on creativity, the improvement of knowledge sharing and management within the PD process, and the influence of engineers on LPD performance.

3.5. Cross-Section and Synergy of LPD with Other Current Cutting-Edge Fields of Research

It is worth mentioning once more that in recent years, authors in the field of LPD have been exploring the intersection and synergy between LPD and current research trends such as Industry 4.0 [20,80], digitalisation [68,75], green thinking [28,29,39,54,73], sustainability [19,27,72], and the circular economy [43]. These emerging trends offer opportunities for future research in LPD and its interaction with a sustainable, green, circular, digital, and smart paradigm.

3.6. LPD in the SME Environment

SMEs have a significant impact on the economic well-being of both high- and low-income economies around the world. Ref. [73] and contribute significantly to economic activity [39].

The significance of SMEs should be noticed. By incorporating lean methodologies within these enterprises' engineering divisions, efficiency may improve, significantly enhancing their impact on innovation [38].

4. Conclusions

This article reviews the literature on LPD from 2011 to 2022. We identified and organised relevant works into nine "gaps filled" domains. The analysis of findings highlights trends and themes in the latest scientific research through research motivation or gaps filled, fundamental discoveries and significant contributions, the remaining unanswered questions, and suggestions for future research. Advancing beyond the pure presentation of the LPD domain, this article provides a theoretical foundation for follow-up research in these areas, providing new perspectives on current trends and guiding future research directions. The discussion presents evidence suggesting that current research trends are in synergy with LPD with industry 4.0, digitalisation, green, sustainability, and the circular economy. In parallel, our contribution to this research area is the identification of six different directions for future research.

The presented systematisation of the LPD area may serve as a source of inspiration for practitioners, enabling them to gain valuable information about the commonly explored LPD topics regarding industrial application and implementation issues. This has practical implications since it would assist them in finding the articles they need to improve their knowledge.

The theoretical limitations of this research come from the sampling used in the literature review. While this review has been carefully carried out to ensure maximum coverage and accuracy, it is subject to certain technical and practical limitations. Initially, the search was limited to three primary databases due to feasibility and practicality constraints. Furthermore, while careful efforts were made, some articles may have been excluded due to restricted or subscription-based access. Also, despite the most dedicated approach, minor human error may have occurred due to the subjective involvement of authors in the selection and categorisation of articles within specific domains.

However, this study investigated only the relationship between lean thinking and PD. It did not explore the relationship between lean principles and other stages of the product lifecycle or the relationship between PD and alternative paradigms, as these were beyond the scope of the study. Nevertheless, the results make a sufficient contribution to the knowledge base in the field of LPD.

Based on the scope of research conducted in the last few years, we believe that the future of LPD lies in creating a holistic approach through the unification of theory, implementation, and performance. In addition, the applicability with regard to the following modern trends: green, sustainability, smart industry, digitalisation, and circular economy must be taken into account. In all of this, it is imperative that we do not lose sight of the fundamental principle of lean thinking-the creation of value and the elimination of waste.

There is no doubt that in the field of LPD, there is still a lot of work to be conducted, as well as areas for research.

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Appendix A

Table A1. An overview of theoretical and conceptual papers and the authors' corresponding models, frameworks, and theoretical treatments.

Authors	Theoretical Suggestion
[1]	A process was developed to generate physics-based ToCs to allow the key SBCE activities of comparing of alternative design options and reducing design choices.
[2]	Discussion of the possible advantages and threats of integrating DFSS and LPD based on industrial experience.
[3,78,85]	Framework for the enablers of LPD, Lean Product and Process Development Performance Measurement Tool SAUCE (Start-Awareness-Unstructured-Continued-Evolved) scale
[7,68]	The LDfX tool was developed taking into account the MSM (Multi-Layer Stream Mapping) concept framework.
[9]	The lean engineering performance measurement (LEPM) model
[10]	This article applies configurational theory to examine the moderating influence of LPD on the impact of LM on quality and inventory performance.
[42]	A Framework for organizing LPD that consists of 11 Lean PD Components
[43]	Circular Lean Product-Service Systems Design framework
[44]	The influence of Lean Development System (LDS) principles on the steps and cross-functions of the PD process
[45]	Lean development elements impact effectiveness and efficiency improvement.
[46]	Theoretical model for incorporating DfX methods into Lean Design
[47,83]	Hybrid fuzzy inference system-conceptual model for evaluating LPD performance
[48,84]	A guideline for eliminating waste when using value methods
[49]	Compare LPD with traditional PD frameworks.
[50]	A method for analysing the performance of product development activities and eliminating waste.
[51]	SBCE process mode
[52]	The Toyota Kata (TK) approach
[53]	Provide a connection between the principle of LPD and the area of knowledge management.
[54]	Hierarchical model of barriers to implementing the GLSPD (green lean six-sigma product development) process
[55]	The similarities, common advantages, and possible difficulties in the integration of green engineering and lean thinking
[56]	A multilevel framework designed to capture key LPD system principles
[57]	value-adding conceptual model for incremental product innovations in LPD
[58]	Lean Enterprise approach aims to eliminate waste by synchronising all activities throughout engineering, production, and the on-site execution phase.
[59,82]	Method to identify process waste in NPD: a five-step methodology for continuous improvement
[60]	A comparative concept specially adapted to the requirements of SMSSes (Small and Medium-Sized Suppliers).
[61]	Instrument for evaluating the adoption of LPD enablers and the occurrence of LPD problems in organisations.
[62]	Engineering change management maturity assessment model

Table A1. *Cont.*

Authors	Theoretical Suggestion
[63]	How intrinsic motivation is influenced by lean enablers
[64]	How companies within the automotive industry rank their performance relative to other sectors in terms of learning and knowledge creation related to NPD practices.
[65]	The significance of engineers' job skills in LPD processes.
[66]	The correlations between LM principles and the concurrent engineering approach to new product development (CENPD).
[67]	LPD process framework in challenging conditions in a one-of-a-kind industrial setting.
[69]	Compact Teams—a Model to Achieve Lean in PD
[70]	Effects of LPD on creativity
[71]	The method for redefining the calculation of functional product value in LPD
[72]	A framework comprising tools and practices to be integrated across the LPD. The framework is customisable and comes with a guide for implementation.
[73]	The procedure for prioritising 16 lean and green enablers for PD makes it useful to set a future improvement agenda.
[74]	The Benchmarking Method to Diagnose How Lean is the PDP at Companies
[75]	Digital LPD
[76]	Measuring the benefits of transformation to LPD via simulation
[77]	Discrete event simulation and integer linear programming models are used to determine the impact of engineering tasks on lean engineering PD performance
[79,80]	Axiomatic Design-Based Guidelines
[81]	Industry 4.0. and LPD
[86],	SMART Readiness Maturity Assessment tool
[87],	Four-field explanatory model of LPD
[88]	Step-by-step framework for achieving an effective LPD
[89]	How to eliminate waste in NPD through various management factors

Appendix B

Table A2. "*Design guidelines*" notes overview.

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2014	[46]	-DfX's qualitative design guidelines	-integrate the different specific DfX techniques into the overall Lean design concept.	-complete the examination of current DfX methods regarding design guidelines, identification of compromises and synergies between them, the impact of design guidelines at various phases, and the consideration of enterprise-specific conditions.
2015, 2016	[79,80]	-missing design-guidelines for Lean Product/Service Development processes	-catalogue of generally applicable design guidelines for LPD and linked them with Industry 4.0 concepts in engineering	-explain the identified fundamental LPD guidelines into more tangible design solutions.

Table A3. "*Enablers or components of LPD*" notes overview.

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2011	[42]	-constituent elements of LPD systems	-integrated existing approaches into a unique framework of 11 LPD components that are interdependent in many ways.	-LPD, which assumes a holistic systems perspective; existing experience of implementing an LPD system besides that of Toyota
2011	[3]	-definition of LPD and its enablers	-proposed five enablers of LPD, which serve as the basis for the LPD building blocks.	-the impact of the individual LPD enablers; the consideration of organisational, human resource, and cultural factors
2012	[89]	-Management factors as enablers for the removal of waste in the setting of NPD	-management factors: training that gives lean specialist knowledge (i.e., lean thinking, waste analysis, standardisation) of conventional engineering skills aids in enhancing the identification and elimination of waste.	-attempting to determine more influential management factors; consideration of the effects of introducing flow or pull; further investigation of other industries
2012	[45]	-the impact of LD elements on enhancing effectiveness and efficiency.	-found 19 LPD elements that are good to very good at influencing the effectiveness and efficiency of PD.	
2015	[61]	-assessment of LPD enabler acceptance and the incidence of LPD issues in organisations.	-presented relationships between LPD enablers and problems; this identification may help determine the circumstances in which problems are likely to arise.	-a comprehensive outlook on the issue by recognizing the relationship between LPD enablers and their impact on LPD issues.
2018	[73]	-enablers that drive lean and green inclusion in NPD operations in the context of SMEs	-presented 16 lean and green enablers for PD.	-explore the relationships among the 16 elements by conducting longitudinal studies and surveys to assess the enabling factors for lean and green practices.

Table A4. "*Framework*" notes overview.

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2011	[56]	-lack of understanding of the interactions between organisational levels of LPD systems and the effective means of managing them.	-Core principles of LPD systems at the functional, project, and portfolio levels; practices and tools for implementation of the principles; strategies for managing how the levels interact	-to validate further and use the framework.
2011	[85]	-description of the SBCE methodology in detail	-provide an insight into Set-Based Concurrent Engineering (SBCE) in detail.	-longitudinal studies are currently underway in the automotive, home appliance and aerospace industries to explore the needs of individual organisations.
2011	[87]	-framework that is applicable to companies that want to implement lean practices in their PD	-presented framework of four essential lean principles	-discussed and interconnected other principles in the same way as we have conducted in this paper.
2011	[88]	-framework has realistic aspects and feasibility and combines more existing best practices in the industry.	-gave a detailed framework for step-by-step implementation to achieve an effective LPD.	-tested the framework approaches in a number of different environments.

Table A4. *Cont.*

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2013	[66]	-relationship between lean manufacturing (LM) principles and the CE approach	-high rate of similarity between CENPD (concurrent engineering approach to new PD) and LM factors	-focus on specific industries
2015	[55]	-investigation of the integration of LPD and eco-design principles	-similarities and common benefits, while also considering the potential difficulties with the integration of green engineering and lean thinking.	-obtain a more articulated view of the integrated approach; investigate factors that would support the implementation of an integrated approach
2015	[41]	-implementation of LPD principles in automotive PD within South African companies	-significant potential for enhancing the integration of lean principles in product engineering practices.	-
2017	[60]	-design of LD for small and medium-sized suppliers	-highlighted the differences regarding the design of an LPD for the requirements of small and medium-sized suppliers.	-identification of novel tools and methods within the framework of Interface Management and Synchronisation; validation of findings in a business context
2018	[72]	-Lean practices in PD stages with a systemic vision of the process	-offer customised guidance on how to adopt the framework with practices and tools throughout the LPD.	-dissemination and replication of knowledge both within the agro-industry and in the education of Lean methods
2018	[19]	-benefits of lean and sustainability when applied as an integrated system	-explain how lean and sustainability can benefit the innovation process when applied as an integrated system.	-Lean and Sustainability integration into the design of new products
2019	[43]	-integration of "lean" into PSS design	-proposed circular lean product-service system (CLPSS) Design Framework, which integrated PSS, circular economy, and lean.	-deeper look into the benefits that CLPSSs can provide to organisations and their implementation in other sectors of the industry.
2020	[67]	-lean implementation process in the specific one-of-a-kind (OKP) industrial environment	-presented an original framework for the LPD procedure under the challenging conditions of a special OKP industrial environment.	-the possibility and usefulness of a broader use of the suggested procedure in the field of OKP

Table A5. "Implementation issues" notes overview.

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2011	[30]	-clarification of the expectations that a company that just started to implement LPD can have of the concept.	-Organisations that successfully implement LPD seek long-sighted, sustainable goals rather than quick economic profit.	-how the principles should be used in practice to obtain the desired results
2012	[82]	-a shortage of tools and methods that are easy to understand and use to achieve a more agile process of design.	-showing how the 5-step methodology can improve each type of process, i.e., how to enhance an actual process from a lean perspective.	-future improvements depend on decreasing the subjective nature of qualitative analysis using quantitative tools and KPIs.
2015	[58]	-aligning all activities across engineering, production, and on-site execution phases	A shortage of methods and tools for synchronizing the phases within the Engineer-to-Order (ETO) value chain has been noted.	-

Table A5. *Cont.*

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2016	[54]	-Barriers in the green, lean, six-sigma PD process (GLSPD)	-analysed 21 barriers to the GLSPD process and their relationships.	-further validation of actual problems in the industry.
2016	[81]	-improving the organization's capability to support the changes needed to transform to Industry 4.0.?	-concluded that not only investment in modern technologies is enough to ensure the needed capabilities, but also investment in employee knowledge, competences, and organisational learning.	-
2017	[38]	-evaluating the usability, the benefits, and the crucial elements of Lean in SME PD.	-numerous lean methods can be implemented rapidly with great potential for improvement; Lean methods and Industry 4.0 techniques give a boost to efficiency optimisation in PD.	-a widened questionnaire covering a greater number of lean methods and a larger amount of internationally distributed SMEs
2022	[39]	-explore the mature state of Lean-Green approaches to the PD process for SMEs in Brazil and Japan.	-identification of lean-green enablers with greatest adherence in a bi-national setting	-investigate 'lean-green enablers' using longitudinal research and replication of the model in other national contexts.
2022	[24]	-investigate the application of new practices towards achieving a more lean PD process.	-the introduction of novel practices in PD aimed at reducing capability gaps in LPD shows encouraging results.	

Table A6. *"Industrial application"* notes overview.

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2011	[4]	-detailed study of the lean transformation of one major automotive system	-it is feasible to achieve huge improvements in results by making huge changes in employees, processes, and tools. For example, Ford stayed true to the LPD principles that were based on the Toyota study.	-collaborative research is preferable to building on ideas.
2011	[21]	-a reflective case study of an LPD transformation framework.	-presented LPD transformation framework by integrating Six Sigma and project management tools (like the DSM and the cause-and-effect matrix).	-formulating strategies and standard operating procedures
2012	[2]	-benefits and risks of combining LPD and DFSS on the basis of industrial experience	-a possible integration of LPD and DFSS (Design for Six Sigma) could provide guidance on how to structure and improve content.	-lean Six Sigma merges with LPD.
2012	[86]	-use the SMART tool to assess industry practices for applying lean.	-The SMART assessment tool provides information on how to overcome some of the conditions that can constrain the usability of LPD practices.	-investigation of other sectors of the industry.
2013	[16]	-presented the principles of SBCE embedded in an existing PD model.	-show benefits of using SBCE principles in an industrial area.	-implementation of SBCE at sub-system and component levels.

Table A6. *Cont.*

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2013	[69]	-successful application of LPD in the industry	-report one successful application of LPD in the industry using the CT (Compact teams) model.	-how to expand the model to global and dispersed teams rather than collocated teams
2017	[51]	-benefits of using SBCE	-show the benefits of using SBCE principles in an industrial area.	-developing the business case for the SBCE application
2017	[26]	-optimizing the PD process through the integration of Lean Engineering principles.	-development of a project management model and its implementation in a PLM tool.	-
2019	[15]	-successful implementation in an engineering department	-describes the success of implementation at an engineering unit of a railway vehicle producer.	-
2019	[68]	-current state of Lean DfX evolution	-presents the evolution of the holistic Lean DfX (Design-for-X) design assessment framework in a real industrial application	-generate libraries of typical variables for each domain, digitalise Lean DfX integration, and use
2019	[23]	-application potential of LPD and APM in the construction industry during the design phase.	-the main challenges are the functional organisation's structures, customer-supplier relations, and the resistance of the internal culture to changes.	-quantitative research
2020	[75]	-digitalisation of LPD approaches	-to effectively apply lean management principles to distributed teams, tools, methods, and strategies should be digitalised.	-offer industry specialists easily manageable guidelines and toolkits
2021	[40]	-impact of the practices and tools of the LP on the lean supply chain	-significant correlation between the development of the lean supply chain and the lean product	-identification of more LPD practices and tools to support the supply chain

Table A7. *"Literature review"* notes overview.

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2011	[8]	-better understand the theoretical content of LPD research.	-LPD research has been approached from various viewpoints, which, using the available LPD and PD frameworks, can be grouped into seven domains of knowledge. The field is apparently characterised by explorative instead of confirmative studies and by studies with small sample sizes.	-By further developing theoretical work and academic research in this area, the LPD knowledge base will be deepened so that it can be easily adapted and applied in different types of industries.
2014	[28]	-lack of insights regarding the relationships between the concepts of lean and green PD	-9 Proposals for cross-field learning between LPD and GPD	-implementing LPD and GPD in practical settings, preferably when both concepts are combined.
2015	[32]	-value ideas relating to lean in complex systems (PD)	-helps clarify the value delivery process and puts value-based methods in relation to it.	-elaborating the cause and effect that connects the various components of value creation

Table A7. *Cont.*

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2017	[11]	-How LPD adds value compared to other methods and concepts.	-concluded that it is evident from their writing that there is no new information regarding LPD. This review assesses the conceptualisation of LPD, outlines its advantageous contributions to organisations, contrasts it with other approaches to NPD, and suggests a number of research implications.	-further comparing LPD with other approaches regarding the rationalisation of the PD process. -How should NPD be labeled? Is it more like a job shop or a manufacturing line?
2019	[27]	-find existing methods and tools for LPD that contribute to sustainability.	-stated that there is no shortage of LPD tools and methods that contribute to sustainability, but that only a limited number of tools address the social or even the three dimensions of sustainability altogether.	-how methods and tools can contribute to each dimension of sustainability; further investigation of possible synergies, conflicts, or intersections between LPD and sustainability.
2019	[29]	-uncover the intersection of lean and green with PD issues.	-provides a deeper understanding of the LPD and GPD paradigms and their potential relationships.	-evaluate the empirical relationship between Lean and Green paradigms, investigate the differences between their practices, and propose ways to resolve these issues.
2020	[31]	-principles underlying LPD and SBCE	-SBD (set-based design) has a relatively low theoretical development	-methodologies for the practical implementation

Table A8. *"People & knowledge"* notes overview.

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2011	[49]	-whether LPD contains elements that complement the existing PD models	-showed that the main differences between LPD and other existing PD models are primarily found in how knowledge is acknowledged and handled. The next thing is how and when decisions are made during the process.	-investigate LPD with regard to engineering time, costs, and quality.
2011	[63]	-how lean performance enablers affect the motivation and willingness to learn of product developers and engineers at the team level.	-suggests that only customer variable requirements are significantly connected to engineer motivation.	-how do experts match the important principles recognized in LPD?
2013	[53]	-analysing if and how LPD can enhance knowledge exchange in PD	-concluded that LPD offers a way of transferring knowledge that covers both explicit and tacit knowledge., which companies with insufficient routines for the transfer of knowledge desire.	-The connection between LPD and knowledge management theory
2015	[70]	-the effects of LPD on creativity	-noted that the main focus of lean in PD is flow over waste reduction and that strong emphasis is placed on reducing disturbances.	-further research should strive to increase the size of the sample, in terms of both the number of organisations and the number of interviewees per organisation.

Table A8. *Cont.*

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2016	[64]	-determination of the extent to which R&D-intensive manufacturing organisations relate their methods to the knowledge element of the LPD.	-there appear to be important differences across industries in terms of learning and knowledge outcomes.	-larger number of respondents and in-depth analysis
2017	[65]	-influence of skilled and motivated engineers on the performance of LPD processes	-show that not only human capital resources, such as skills or motivation, have an impact on LPD process performance, but also that these outcomes can be actively influenced by certain human resources practices	-LPD measurement model needs to be tested in other countries.
2018	[52]	-How to effectively handle uncertainties, involve developers, and ensure that knowledge sharing is maximised and its loss minimised in an LPD context.	-The Toyota Kata concept provides a management structure that allows for developer alignment, inclusion, development risk reduction, and knowledge management in the LPD context.	-applying the Toyota Kata approach in other steps of the LPD and in different development environments.
2020	[25]	-investigate through empirical research how Obeya is applied to the creation of knowledge.	-Obeya is a useful tool to enable knowledge creation inside an organisation.	-investigation into the potential applications of the Obeya methodology across various sectors.
2021	[17]	-precise and visible knowledge environment generated from trade-off curves (ToCs)	-importance of trade-off curves and the appropriate knowledge environment in the early phase of LPD	-
2022	[22]	-in an LPD environment, in what way does knowledge visualisation assist in the development of a portfolio optimising task??	-empirical results provide evidence for why and how knowledge visualisations can be utilised to support knowledge transfer and exchange between persons and from persons to groups.	
2022	[1]	-providing a structured way of creating and applying trade-off curves.	-physics-based ToCs provide valuable and efficient means for facilitating essential set-based concurrent engineering tasks.	

Table A9. *"Performance metrics"* notes overview.

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2011	[77]	-uniform engineering task classification	-systematic categorisation of engineering tasks, facilitating the assessment of their individual performance within the lean value stream.	-developing models to determine the ideal size of product development tasks to improve information flow and minimise the overall cost of product development.
2013	[78]	The need for a novel tool that can measure current PD processes and assess them against the best-case lean scenario.	-tool to evaluate the performance of the Lean Thinking deployment in PD comprises sets of questions that reflect the key enablers.	
2013	[36]	-global model for assessing NPD as a whole	-the suggested method provides organisations with the chance to evaluate themselves and benchmark themselves against their competition.	-applying this approach to as many companies as needed to check the relevance of the model.

Table A9. *Cont.*

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2014	[44]	-the effect of the LDS principles on the development process	-an evaluation of the impact of the LD System principles on the phases and cross-functionalities of the PD process	
2014	[35]	-metrics most often used in R&D by program managers	-there is still potential for new metrics to be proposed, particularly those related to the people category and leading insights metrics.	-definition of specialised metrics to satisfy LPD needs and objectives.
2015	[33]	-identification of similarities and divergences between various industries in terms of lean methods and capabilities.	-Systems engineering firms are typically more immature when it comes to lean practices and capabilities, particularly when contrasted with their automotive industry colleagues.	-increase the population of research
2016	[20]	-novel tool introduced to evaluate lean capability at the project team level.	-The implementation has been used to map the process for assessment of LPD capabilities with the aim of reaching agreed enhancement initiatives.	-redo the assessment to compare the situations before and after the improvement initiatives were introduced. -identify factors that may have an impact on LPD gaps.
2016	[47]	-evaluation of LPD performances	-conceptional model for LPD performance evaluation through the identification and analysis of available key LPD enablers.	-The conceptual model developed in this study is currently unfinished and needs validation within an industrial setting.
2016	[74]	-present the Benchmarking method to diagnose how Lean is the PD process in companies.	-creating questions that assess how lean the PD process is in an organised manner and with the right theoretical grounding.	-use this method in other countries and compare the results with those of Brazilian companies.
2018	[7]	-quantitative metrics for analysing and comparing different approaches and product designs	-assessment of the effectiveness and efficiency of a particular product concept	-The potential capabilities of the Lean Design-for-X method should be further explored with regard to their design indicators.
2018	[10]	-function of LPD in the impact of LM on inventory and quality performance	-LPD methods positively mitigate the LM impact on quality performance.	-investigate whether similar relations appear when applying other performance measures, for instance, productivity or unit cost.
2018	[62]	-assessing the maturity level of ECM-engineering change management, incorporating lean criteria	-engineering change management maturity assessment model with lean criteria for the automotive supply chain	-Efficient knowledge capture and integration in the ECM process in a usability-driven way
2019	[76]	-measuring the benefits of transformation to LPD via simulation	-the results of the simulation indicate that the proposed LPD model is effective in improving the utilisation rate, the overall time in the system, the waiting time, the value-added time, the work-in-process time, and the overall number of resources consumed.	-
2019	[83]	-assessment of the effects of product quality, value, development time, and costs on lean strategies and practices	-assessment of the impacts of product quality, value, development time, and costs on lean strategies and practices in PD settings	-Automatic processing of information

Table A9. *Cont.*

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2020	[9]	-performance measurement model	-model for quantitatively measuring performance at different organisational levels	-relationship between alternative scheduling algorithms and lean engineering performance; implement a model across industries

Table A10. "*Value or waste identification*" notes overview.

Year	Articles	Motivation/Gap Filled	Key Findings and Major Contributions	Future Research
2011	[59]	-practical method for identifying waste in the NPD process	-tool for systematically identifying wastes in order to find a priority order by which to eliminate and reduce waste.	-The model is used by other companies in order to collect more sources of waste that enable the creation of a complete library of waste in NPD.
2012 2013	[34,48]	-lack of relation between value methods and waste types of information	-guideline to eliminate waste when applying value methods is presented, along with insight into industrial practice in defining value and waste.	-further investigation of the relationship, measurements, and impact of value and waste on information based on specific phases in the PDP
2013	[71]	-redefining the functional product value calculation of the product in LPD	-pointed out that a strong understanding of the value defined by the customer may not be accompanied by the ability to deliver on that value.	-study in different types of industries
2014	[50]	-generic actions to systematically eliminate waste in PD operations	-a novel method to evaluate the implementation of PD activities, which can be evaluated utilizing a VSA.	-the validation of the generic actions described in this paper can be empirically verified through a comprehensive study across various organisations.
2015	[84]	-expand the understanding of how value is generated and delivered in different contexts and stages of the product life cycle.	-the significance of understanding value within a specific context and stage of a product's life cycle.	-further exploration is needed on the definitions, generation and delivery of value.
2019	[37]	-types of waste in complex projects	-Complex projects may be impacted by the waste types listed in the LPD publications.	-Replication of this work in other similar organisations and in other industries
2019	[57]	-proposing a value-adding concept model for product incremental innovation in the LPD	-LPD needs to be included in identification and consumer value creation activities.	-the application and validation of the conceptual customer value model in LDP via empirical research
2021	[18]	-large waste in ETO PD projects	-general overview of waste detected in ETO projects	-case comparison analysis, allowing the linkage of waste to particular cases.

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