Lenses of Lean in Non-repetitive Manufacturing: Systematic Literature Review

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Abstract. Hopp & Spearman proposed a construct consisting of four lenses of lean in their attempt to guide research and implementation of lean. Authors claim that their proposition could introduce much needed systematicity into the field. In order to test if the proposed construct is useful for researching and practicing lean in non-repetitive manufacturing, authors propose a systematic literature review of 126 articles published in 72 peer-reviewed international journals. The analysis results show that lenses are addressed with different levels of attention, where Process and Flow lens dominate the literature. The construct covers some important topics for non-repetitive manufacturing, such as the context of waste, waste propagation, variability, buffering, and complexities, deeming it suitable as a foundation for considering lean in non-repetitive manufacturing. On the other hand, the construct has some fallacies which should be recognized, in general, and within the context of non-repetitive manufacturing, such as a strong focus on efficiency, disregard of some important lean topics such as responsiveness, flexibility, strategic aspects of lean, management commitment, people development, and change management.

Keywords: Lean manufacturing · Non-repetitive manufacturing · Lenses of lean · Literature review

1 Introduction

Since its inception, lean has become widely spread manufacturing paradigm used by companies around the world, and is considered by several authors as one of the most significant developments in the field of operations management [2, 33, 34]. It was devised in Toyota over the course of several decades, in practice, through constant experimentation and trial and error attempts. Traditionally, lean has been developed and primarily used in repetitive manufacturing of high volumes of products with limited amounts of variability [15, 31, 41, 58]. However, reducing lean to repetitive manufacturing is arbitrary [36], and recent research has shown increased interest in lean in non-repetitive manufacturing [43, 67, 80, 81]. And while lean is often asserted to be universally applicable [44, 45, 84], both research and implementation do not fully account for specificities of non-repetitive manufacturing and are often plagued by the burden of repetition [79]. Traditionally, lean is aimed at reducing variability through both product and process

M. Mihić et al. (Eds.): SymOrg 2022, LNNS 562, pp. 490–508, 2023.
https://doi.org/10.1007/978-3-031-18645-5_31

standardization, while non-repetitive manufacturing creates value through design and manufacturing of non-standard products, which strategically introduces variability into the production system [56]. Because of this, the applicability and relevance of lean in non-repetitive manufacturing has been debated in the past. While some authors claim that lean is inapplicable or irrelevant to specific nature of non-repetitive manufacturing [4, 20, 60], others stress the possibilities and potential benefits lean can have in this environment [33, 42, 49, 83]. Still, the literature on lean in non-repetitive manufacturing remains limited, and conclusions are draws from a limited number of sources, which causes confusion among practitioners and researchers [22, 55 61, 62, 67].

Lean research (both early and recent) is considered to be phenomenon-driven rather than theory-driven [21]. Since practice mainly comes from case-specific reports, it is hard to distil common theory and knowledge [10, 31]. This gap between practice and theory makes both research and implementation difficult. There is still no consensus on what is lean and what it takes for a company to be lean. The lack of general theory that fully describes lean adds to the confusion and frustration and often causes the lean implementation to fail [10, 31, 73]. This confusion is deepened when lean research and implementation is considered in non-repetitive manufacturing, as the environment differs significantly from the one lean was devised in and for. It has been noted that both research and practice (of lean in general, but specifically in non-repetitive manufacturing) is hampered by the lack of clear definition of lean on which most scholars could agree [36]. Several recent attempts have proposed and clarified the definition of lean [2, 17]. One of these attempts is made by Hopp & Spearman, who propose a construct based on four lenses of lean: process lens, flow lens, network lens, and organizational lens [36]. The construct is based on some fundamental theories from operations management and social sciences, and is aimed at helping researchers regarding what to study, and practitioners regarding how to implement. The proposition has been discussed by some authors [17, 21], with construct being criticized for its' incomprehensiveness in an attempt to define lean. On the other hand, authors stress the importance of Hopp & Spearman's initiative to redefine lean and agree that the construct can facilitate both implementation and research by introducing some rigour. Hopp & Spearman claim that their proposition is based on fundamental science, tool agnostic, and as such applicable regardless of environment. In order to test these claims, it has been decided to analyze the existing literature on lean in non-repetitive manufacturing, and see how these lenses are addressed in the existing body of knowledge, and if the proposition could resolve some ambiguities and introduce clarity into lean research and practice in non-repetitive manufacturing.

The remainder of the paper is organized as follows: Sect. 2 discusses the theoretical background of the research; Sect. 3 describes the method used in this research; Sect. 4 presents the results of the analysis; Sect. 5 furthers the discussion of the results and presents the conclusion, research implications and research limitations.

2 Theoretical Background

2.1 Lean in Non-repetitive Manufacturing

Non-repetitive manufacturing indicates a complex, to-order manufacturing systems with generic production processes, characterized by uncertain demand for a wide variety of non-standardized products produced in low volumes [7, 51]. As non-repetitive manufacturers often have long lead-times, lean has become interesting topic, as one of its main goals is shortening customer delivery time [56, 57]. The relevance of lean in non-repetitive manufacturing has been debated, as the reality of non-repetitive manufacturing does not match the context in which lean was devised. Cooney claims that only a limited number of lean practices is relevant or achievable in non-repetitive manufacturing, deeming lean unachievable [20]. Olhager & Prajogo argue that, in its pursuit for greater efficiency, lean is irrelevant for non-repetitive manufacturers, as they rarely compete through efficiency [60]. Azadegan et al. claim that lean's ability to improve performance in non-repetitive manufacturing is limited, mainly due to unpredictability and instability inherent to this type of operations [4]. On the other hand, the interest in lean in non-repetitive manufacturing is on the rise, and various research shows that non-repetitive manufacturers experience shorter lead times [13, 43, 70], reduced costs of production [11, 49], improved quality [37, 65], and increase in output [32, 53, 54] after lean implementation.

Tomašević et al. present the results of a systematic literature review on lean in non-repetitive manufacturing [81]. The authors state that there is a rising interest in this area, but that the current research has some major drawbacks, such as low maturity of the research, lack of theoretical research regarding the context of lean in non-repetitive manufacturing, strong focus on lean tools, or addressing rather narrow niche of non-repetitive manufacturers that have at least some characteristics of repetitive manufacturing, which disregards specificities of non-repetitive manufacturing.

2.2 Lenses of Lean

Lenses of lean appeared as a proposition to (re)define lean and resolve at least some ambiguities regarding lean in literature and practice [36]. It presents a noteworthy attempt to standardize lean knowledge and is an addition to other efforts aimed at achieving the same goal [2, 17, 21]. As claimed by the authors, the goal of describing four lenses of lean was to bridge the gap between the trial-and-error approach of practical approach to lean implementation and the conceptual view based on basic research in the mathematical, physical and social sciences. The result should describe the fundamentals of multifaceted concept such as lean.

The construct consists of four 'lenses', which in turn stem from various conceptual definitions of lean: Process lens, aimed at eliminating process-level waste; Flow lens, aimed at revealing/reducing flow variability; Network lens, aimed at rationalization of flow network; and Organizational lens, aimed at helping in organizational transformation. According to the authors, the construct is based on generic terms and formal concepts of operations management and is primarily equated with efficiency management. The lenses are designed around fundamental 'laws', such as the law of variability and buffers, and laws of bottlenecks. The organizational lens adds insights from psychology to complete the definition of lean. The lenses are aimed to guide both lean implementation and research, although authors claim that the first lens offers limited possibilities for research [36]. In addition, from the practitioner's point of view, for lenses to achieve best results, they are to be implemented in a specific order, starting with a Network lens, over Flow lens, ending with Process lean.

Although fairly recent, the article has already spurred interesting debate in the operations management community about the proposed construct and lean theory and practice in general. In a recent article by Åhlström et al. it is evident that there is still great divergence among researchers when it comes to defining lean [2]. Browning & de Treville urge for the joint effort of researchers to define a list of formal concepts that describe what Toyota has done to improve their operations, which will be broadly defined enough to be universally applicable [17]. They argue that lenses of lean present a good starting point in reconciling different approaches and definitions of lean [17]. Cusumano et al. criticize the construct for the sole focus on efficiency, the restriction of the domain of lean only to operations management (especially when it comes to research), and the lack of context (e.g. the influence of digitalization or COVID-19 pandemic) [21]. However, the authors agree that the proposition presents a worthy effort to conceptualise lean and reminds researchers of lean's importance.

3 Research Methodology

For this research, articles that research the implementation of lean in non-repetitive manufacturing have been selected and retrieved. To do this, a systematic procedure was followed, as proposed by Tranfield et al. [82]. The procedure includes four stages: research question formulation, article sourcing, article screening, and article analysis. A brief description of the procedure used in the research is given in Fig. 1.

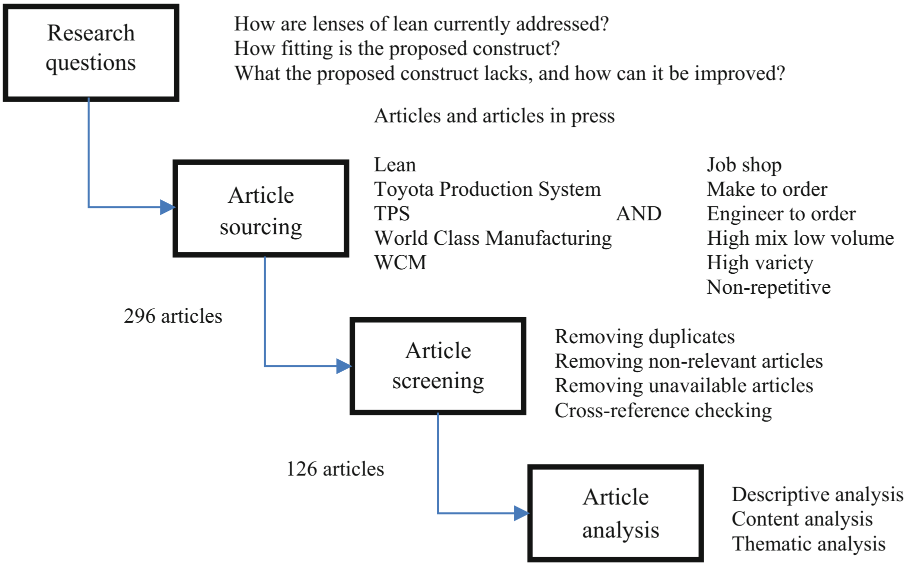

Fig. 1. Research procedure

Subsections 3.1 to 3.4 give overview of the mentioned stages. Subsection 3.5 summarizes the characteristics of the sample used in this research.

3.1 Research Questions

The following research questions were formulated at the beginning of the research:

- How are lenses of lean currently addressed in the state-of-the-art literature dealing with lean in non-repetitive manufacturing?
- How fitting is the proposed construct for practising and researching lean in non-repetitive manufacturing?
- What the proposed construct lacks, and how can it be improved

3.2 Article Sourcing

In order to take into account the heterogeneity of lean and non-repetitive manufacturing, two sets of keywords were chosen for the search. First set was used to capture lean, and included the following terms: 'lean', 'Toyota Production System', 'TPS', 'World Class Manufacturing', and 'WMC'. Second set was used to capture non-repetitive manufacturing, and included the following terms: 'job shop', 'make to order', 'engineer to order', 'high mix low volume', 'high variety', and 'non-repetitive'. Finally, the terms from both sets were combined through 'AND' association (e.g. 'lean' AND 'non-repetitive').

The search was restricted to article title, abstract, and keywords, from the scope of articles and articles in press in peer-reviewed journals, written in English language. Scopus and Web of Science abstract and citation databases have been searched for articles, as they provide broad coverage through different full-text databases [6, 79]. Conference papers were not analyzed due to limited availability of the material and possible quality issues. The search resulted in 296 articles, all included in the original sample.

3.3 Article Screening

The original sample was reduced to 139 articles by removing duplicates and irrelevant articles. Relevancy was checked through abstract screening by both researchers, first independently and then together. In situations where there was no consensus regarding the article's relevancy, the tendency was to include it in the final sample. The sample was further reduced by excluding articles that are not available, leaving 120 articles in the database. The final sample was supplemented with 6 additional articles, obtained through the snowballing procedure using articles' references, tallying 126 articles altogether.

3.4 Article Analysis

The remaining articles were examined in detail. For the analysis, a two-dimensional matrix was designed in Excel sheet to gather the information relevant for the research. For each paper, the following information were extracted: Are the authors academicians or practitioners? What research methodology was used in the research? What lenses are addressed in the research (if any; one article could address more than one lens)? In what way were the lenses addressed? Both researchers analysed all articles, and all issues were resolved through discussion until reaching consensus.

3.5 Sample Characteristics

Figure 2 and Tables 1, 2 and 3 summarize basic characteristics of the final sample. Figure 2 shows that there's an increase in interest in lean in non-repetitive manufacturing. The number of papers is on the rise, with peak being reached in 2017 and 2018. Low number of articles in 2022 (compared to previous years) is due to the date database was completed (April 2022).

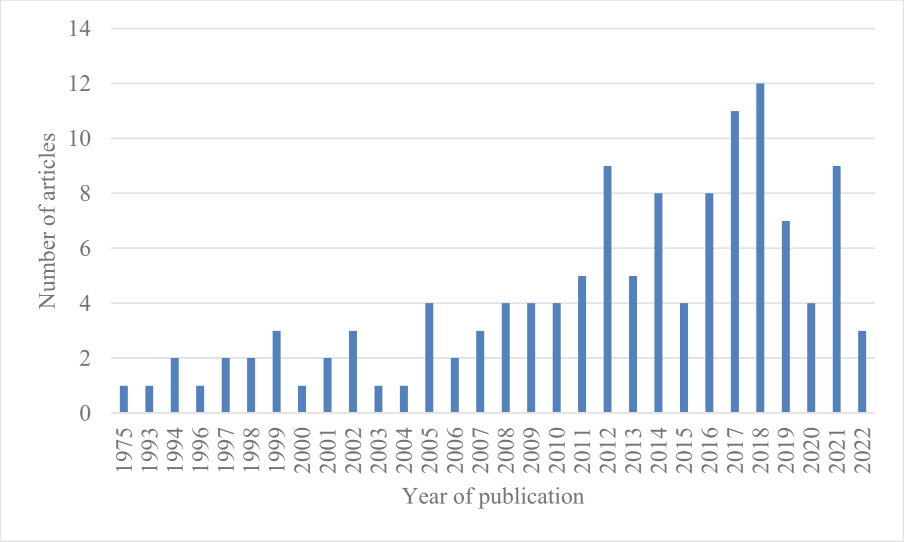

Fig. 2. Distribution of articles per year of publication

Table 1 shows journals that have published articles on lean in non-repetitive manufacturing. Large number of leading Operations Management journal confirms that the final sample contains articles of high quality, and that the review is representative of the literature.

Table 1. Journals publishing the articles

Journal	No. of articles (%)
International journal of production research	13 (10.32%)
Production planning and control	9 (7.14%)
International journal of production economics	7 (5.56%)
Journal of manufacturing technology management	6 (4.76%)
International journal of operations and production management	4 (3.17%)
IFAC-PapersOnLine	3 (2.38%)

(*continued*)

Table 1. (*continued*)

Journal	No. of articles (%)
International journal of advanced manufacturing technology	3 (2.38%)
Journal of manufacturing systems	3 (2.38%)
Omega	3 (2.38%)
Procedia CIRP	3 (2.38%)
Automation in construction	2 (1.59%)
Computers and industrial engineering	2 (1.59%)
European journal of operational research	2 (1.59%)
International journal of computer integrated manufacturing	2 (1.59%)
International journal of lean six sigma	2 (1.59%)
International journal of services and operations management	2 (1.59%)
Journal of advanced manufacturing technology	2 (1.59%)
Journal of construction engineering and management	2 (1.59%)
Production and operations management	2 (1.59%)
Applied sciences (Switzerland)	2 (1.59%)
Other (one article per journal)	52 (41.27%)
Total	126 (100%)

Table 2 shows that most authors (121) have a background in academia, with only 2 articles authored exclusively by people from practice. Additional 3 articles have academicians and practitioners as co-authors.

Table 2. Profile of author(s)

Profile of author(s)	Number of articles
Academician	121
Practitioner	2
Both	3
Total	126

Table 3 shows that empirical methods have been mostly used in researching lean in non-repetitive manufacturing, which makes low participation of practitioners among the authors unexpected.

Table 3. Distribution of research methods used in articles

Research method used in the article	Number of articles (%)
Single case study	44 (34.92%)
Simulation	22 (17.46%)
Multiple case study	15 (11.9%)
Modeling	13 (10.32%)
Action research	9 (7.14%)
Conceptual/theoretical	8 (6.35%)
Survey	8 (6.35%)
Literature review	5 (3.97%)
Design science research	1 (0.79%)
Field research	1 (0.79%)
Total	126 (100%)

Other measures (e.g. distribution of articles per university, country, etc.) are not presented here, as they are deemed irrelevant for this research.

4 Research Results

Table 3 shows how lenses of lean are addressed in the articles that were analyzed. It is evident that some articles address more than one lens of lean, which suggests more systematic approach to lean implementation. However, the number of these articles is not that great, and lenses of lean are primarily addressed in isolation. The results also show that there is also a reasonably large number of articles (27 or 21.43%) where it is not clear which lens of lean is explicitly addressed.

Table 4. The way lenses of lean are addressed in the final sample

Lean lens	Number of papers (%)
Process lens	48 (38.1%)
not clear	27 (21.43%)
Flow lens	22 (17.46%)
Process lens and Flow lens	12 (9.52%)
Process lens, Flow lens, and Network lens	7 (5.56%)
Flow lens and Network lens	3 (2.38%)

(*continued*)

Table 4. (*continued*)

Lean lens	Number of papers (%)
Process lens and Network lens	2 (1.59%)
Process lens and Organizational lens	2 (1.59%)
Process lens, Flow lens, and Organizational lens	1 (0.79%)
Network lens	1 (0.79%)
Organizational lens	1 (0.79%)
Total	**126 (100%)**

Figure 3 shows the distribution of lean lenses among articles in the final sample, as there are articles discussing more than one lens. Corresponding to the Table 4, Process lens is discussed the most, covered in more than half of the articles, followed by the Flow lens.

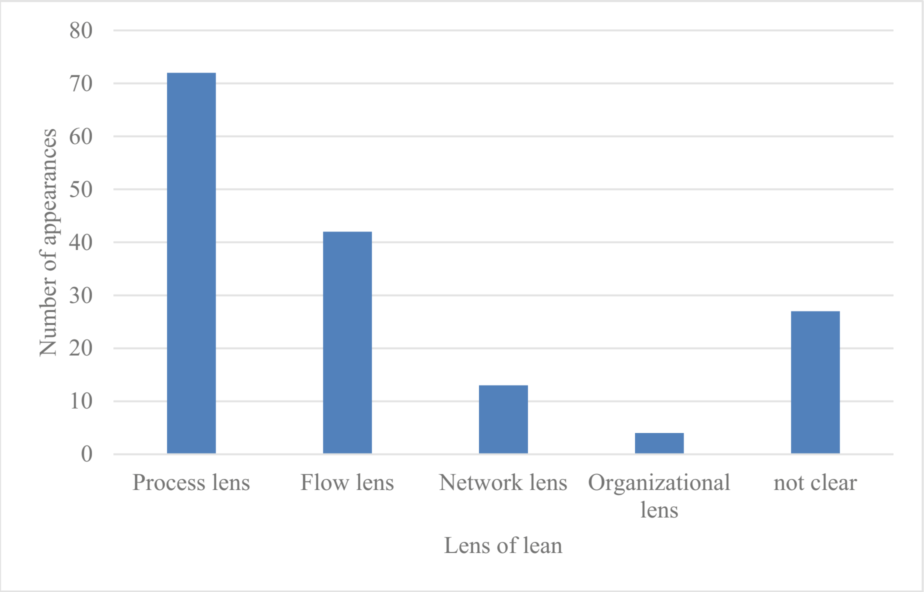

Fig. 3. Distribution of lenses of lean in the final sample

4.1 Process Lens in Non-repetitive Manufacturing

The analysis results show that Process lens is discussed the most in the contest of non-repetitive manufacturing. Additionally, Process lens is most frequently combined with other lenses of lean. This is not surprising, as reductionist view of lean (i.e. elimination of waste) is still dominant in practice [16], and many articles that discuss lean in non-repetitive manufacturing define lean in terms of waste elimination [81].

Waste is often discussed in the 'traditional' manufacturing context, e.g. seven wastes (overproduction, overprocessing, excess inventory, excess motion, transportation, defects, and waiting) [18, 38, 48], or as a negation of value to the customer [19, 25, 70]. Most waste elimination is focused solely of the shop-floor. Some authors consider a combination of Process lens and Flow lens, as waste is seen as an obstacle to efficient flow, suggesting that waste elimination maximizes flow [60, 69, 70].

A handful of authors discuss waste elimination beyond shop-floor. Birkie et al. state that the sustainability of lean in turbulent manufacturing environments might be better sustained if waste elimination is extended to transactional processes [11]. Bäckstrand & Powell support this claim, stating that waste identification beyond manufacturing might be difficult, e.g. if there is a larger amount of documentation in the engineering department of engineering-to-order operations [5]. Bertolini et al. acknowledge the fact that waste propagates through both internal and external supply chain, and propose a matrix for analyzing the cause-effect relationship between wastes in different stages of the supply chain [8]. Rauch et al. argue that extending the focus to entire supply chain can play important role in waste elimination and consequently lead time reduction [66].

4.2 Flow Lens in Non-repetitive Manufacturing

Flow lens is considered a key component of lean manufacturing aiming at revealing/reducing flow variability, as the variability has a strong negative effect on company's performance [85]. As variability is inherent to complex manufacturing environments, this lens presents great potential for both lean research and implementation. However, the number of articles that explicitly address variability is fairly low.

Authors often discuss external variability (e.g. demand variability), debating whether it should be curbed in some ways or not. Bertolini et al. argue that some of the demand variability could be mitigated through the reduction of the product mix [9], while Powel et al. claim that a wide product mix is an asset of non-repetitive manufacturers and that it should be retained and managed through e.g. customer enquiry management [64, 76, 77]. Bortolotti et al. state that demand variability can negatively impact responsiveness, while efficiency remains largely unaffected [14]. Internal variability is discussed to a lesser extent, with just general suggestions that it should be addressed through waste elimination and continuous improvement [86].

Strategic variability is a source of competitive advantage in non-repetitive manufacturing, and should be buffered and/or exploited to a company's benefit [35, 74]. Nonetheless, the topic of variability buffering is not properly addressed in the literature. Thürer et al. argue that lead-time and capacity buffers could be controlled through customer enquiry management by matching the demand with the available capacity [77]. White & Prybutok state that inventory buffers are often present in the form of a high level of in-process inventory [83], mainly due to poor shop-floor management [81]. WIP reduction has a positive impact on material flow [26], and is often obtained through the implementation of pull manufacturing, either through Kanban and its variants [50, 63], or other alternatives better suited for complex environments, such as Workload control (WLC) [76, 77], CONWIP [13], Drum-Buffer-Rope (DBR) [29], or Paired-cell Overlapping Loops Cards with Authorization (POLCA) [28].

Some authors consider flows that go beyond manufacturing by extending it to sales [76, 77] or other parts of the internal supply chain [8, 11, 72], as this approach can help in obtaining more sustainable results of lean implementation.

4.3 Network Lens in Non-repetitive Manufacturing

Part of the complexity of non-repetitive operations comes from the fact they often consist of many interrelating routings, where products compete for the same resources [3, 7]. Hopp & Spearman state that there are two ways of addressing complex flows: (i) reducing the complexity of flows and then applying Process or Flow lens; or (ii) more dynamic representation of complex networks in order to identify and analyze improvement options [36]. The analysis results show that most authors choose the first way by assimilating the complexities of non-repetitive manufacturing to resemble more to repetitive manufacturing. This is why this lens is often combined with either Process lens, Flow lens, or both, as shown Table 2.

The assimilation is often obtained through identification of dominant product families (so-called runners) [37, 42, 47], which increases the ability for some ‘traditional’ lean tools to be applied, such as cell manufacturing [12, 39, 40], raw material and parts standardization [42], or supplier consolidation [24, 59] However, authors often disregard that this assimilation is often unfeasible (e.g. it requires resource duplication) or even undesirable (e.g. it requires the reduction of product mix which negatively affects competitive advantage of the company, or reduction of supplier variety which negatively affects product variety).

Bertolini et al. stress the importance of considering complex routings when considering lean implementation, as they are often encountered in non-repetitive manufacturing [9]. However, this issue remains largely unaddressed in the existing literature.

4.4 Organizational Lens in Non-repetitive Manufacturing

Organizational lens is by far the least addresses component of lean in the literature, as only four articles explicitly consider this issue, in isolation or in combination with other lenses. Abd & Othman argue that lean implementation in non-repetitive manufacturing is feasible, but results deteriorate over time, and one of the main reasons is a lack of organizational engagement [1]. Schulze & Dallasega also recognized organizational barriers in lean implementation in engineering-to-order operations, such as insufficient organizational structure, and people’s unwillingness to engage in lean transformation, often due to fear of the unknown, fear of failure and complacency, and fear of losing job [69]. Powel et al. propose a new set of lean principles adapted to the needs of engineer-to-order operations, stressing the importance of leadership, people, and learning [64]. Bäckstrand & Powell argue that one of the main features of lean transformation is an organisation’s ability to learn, and that the learning opportunities exist regardless of the level of manufacturing repetition [5].

5 Discussion

5.1 How Are Lenses of Lean Currently Addressed in Non-repetitive Manufacturing Literature?

Hopp & Spearman devised their proposal to guide research and help implementation in a comprehensive way, stressing the importance of specific order lenses that need to be addressed [36]. Cusumano et al. believe that this interpretation of lean manufacturing would be pleasing to lean fathers (i.e. Ohno), and praises the content and sequencing of lenses [21]. However, the analysis results show that state-of-the-art literature on lean implementation in non-repetitive manufacturing does not reflect these lenses correctly and comprehensively, neither in content nor arrangement of lenses. Different lenses are addressed with different levels of attention and detail. As expected, Process lens is addressed the most, which is in line with broader lean literature dominated by the reductionist view of lean. This approach has been criticized as it stresses the importance of waste elimination by eliminating non-value adding activities over the overall system view of interrelated routes [17]. This is why the sequence of lens implementation (as a consequence of different priorities and attention) seems to be reversed in non-repetitive manufacturing. The results show a strong focus on Process and Flow lenses, which can be detrimental to lean in non-repetitive manufacturing, as this approach addresses only a small subset of non-repetitive operations that are comparable to repetitive operations. By focusing of pure waste elimination and flow efficiency, authors assume that non-repetitive manufacturing are either simple enough to be improved by addressing pure waste and flow inefficiencies or that the complexities can be reduced and system can be simplified. Both of these assumptions are flawed and can be even dangerous, as this simplification might negatively affect competitive advantage of a non-repetitive manufacturer [77]. Even when Process and Flow lenses are considered, authors often opt for well-established lean tools devised for repetitive manufacturing, e.g. Kanban, VSM, takt. This leads to the conclusion that authors are pursuing form rather than exploring context of lean in non-repetitive manufacturing. In addition to partially addressing the whole construct, the research lacks rigidity, as evidence is obtained through case-specific reports, which makes it hard to distil common ground on how lenses of lean are addressed in the literature.

5.2 Are Lenses of Lean Useful for Practicing and Researching Lean in Non-repetitive Manufacturing?

The proposed lenses offer a good starting point in introducing rigidity in lean research and practice in general, but they also offer interesting insight in the multifaceted nature of lean that can be highly valuable for non-repetitive manufacturing. In addition, the construct is parsimonious, as it excludes noise coming from care-specific reports by focusing on fundamental laws and theory. While the first lens offers limited opportunities for research [36], it does propose important guidelines for practice. Waste elimination is considered to be straightforward and understandable to all. However, recent research shows that there may be many ambiguities in waste definition and elimination [78]. Hopp & Spearman claim that the usual categorizations of waste are not precise or valuable. The lens addresses what is often called ‘obvious’ waste, i.e. waste that can be eliminated without creating other waste [76]. But this waste has to be contextualized to reflect the needs of non-repetitive manufacturing, as wasteful things in repetitive manufacturing (e.g. non-standardized product mix) can be considered an asset in situations when flexibility is important. Authors consider that the ‘traditional’ approach to waste reduction (e.g. focus on seven wastes) provides few guidelines to remove waste successfully, and suggest that everything that hinders the efficient matching of supply and demand just-in-time should be considered wasteful, and consequently removed [2, 36, 78]. Although this view of waste might be too broad, it is useful for non-repetitive operations, as it promotes focus of problem-solving rather than focusing on practices made for different contexts and different goals. It suggests that the term ‘waste’ can and should be contextualized, and adapted to specific need of complex manufacturing environments. Authors also acknowledge the fact that waste propagated through the connection of Process waste (symptoms) with Flow and Network lens (cases). This is of great importance within the context of non-repetitive manufacturing, as whole supply chains is engaged when a customer order arrives, and waste created in one step of supply chain can case waste in subsequent stages where its’ effect can be amplified.

Lean implementation pursues variability reduction, as it is considered the main waste source. This is acknowledged through second lens of lean, Flow lens. As variability is inherent, stressing the importance of variability reduction and buffering plays an important role in non-repetitive manufacturing. However, the context and the goals of non-repetitive operations have to be taken into account in order to avoid extremes in variability reduction, which can in turn put at stake some of order-winning characteristics of non-repetitive manufacturers [27, 64, 77]. Suri differentiates between dysfunctional and strategic variability, and argues that lean attempts to eliminate both, while suggesting that strategic (and dysfunctional, at least to some extent) variability needs to be exploited [74]. The exploitation requires that variability be retained, which means that it must be buffered. Variability buffering plays significant part in the Flow lens, as capacity buffers were used to obtain some of Toyota’s early success in lowering inventory.

On the other hand, Toyota continuously pursues lowering of buffers, and early definition of lean manufacturing indicates that it is considered to be un-buffered production system [46]. Avoiding extremes is also key here, as inherent variability needs to be buffered, while lowering buffers too much might have negative effect on performance [26]. Buffers should be chosen wisely and according to context. For example, while raw material and finished inventories are common in repetitive manufacturing, they are rare in non-repetitive manufacturing. On the other hand, excess capacity is considered a source of flexibility in non-repetitive manufacturing, while repetitive operations are often seen as a waste [71].

In their definition of Network lens, Hopp & Spearman argue that many production systems consist of many different routings, where products often share the same resources. Although this lens is under-researched in the literature, this description (possibly involuntarily) matches the one of non-repetitive operation [3, 7], and puts focus on the complexities of a specific manufacturing environment. Authors claim that assimilating non-repetitive operations to repetitive ones, while appealing, might be difficult but also undesirable. This suggests that opportunities for improvement should be contextualized, and tailored to the specificities of the environment while relying on fundamental lean principles.

Organizational lens is rather generic, and extends focus beyond technical sub-system, and takes people into account. As such, suggestions are equally useful to repetitive and non-repetitive manufacturers.

5.3 What Do Lenses of Lean Lack in the Context of Non-repetitive Manufacturing

Many authors discussed the 'what' of lean, but consensus is far from being reached [10, 31]. Hopp & Spearman equate lean with efficiency, which could be problematic in the context of non-repetitive manufacturing [36]. The construct does not address effectiveness, which is integral part of lean manufacturing in general. Thürer states that lean explains the law of just-in-time, which states that process will have the highest level of efficiency and effectiveness (although it may not have the lowest cost) if it synchronizes demand, transformed resources (e.g. materials), and transforming resources (e.g. capacity) just when it is needed [2]. He continues that lean is a theory that tries to explain efficiency and effectiveness as they are both part of the value created for the customer, and that it is not possible to attain highest levels of process efficiency and effectiveness (which is ideal state), as there are deviations and trade-offs which appear in terms of waste and buffers [2]. Non-repetitive operations often don't compete through efficiency [60], which means that they are willing to sacrifice efficiency to attain greater levels of effectiveness and possibly create what is considered waste, while still creating value to the customer. Bortolotti et al. argue that pursuit of efficiency can adversely impact responsiveness and flexibility [14], while Tomašević et al. claim that non-repetitive manufacturers should pursue higher levels of efficiency, but only to a point where flexibility is not affected [81]. Going after higher levels of efficiency is often reserved for mature phases of product-process life cycle, which is hard to attain in non-repetitive manufacturing, as it requires fair amount of repetition, which could be achieved only at the cost of flexibility.

With a narrow focus on operations management techniques for efficiency improvement, the proposed construct overlooks other aspects of management that are considered integral to lean. For example, strategy deployment is key in lean implementation regardless of the environment [75]. Furthermore, uncertainty and strategic variability are considered to be strategic assets in non-repetitive manufacturing, and lean programs should acknowledge this when designed in order to avoid losing competitive advantage [23, 27, 76, 77]. Beyond this ascertainment, strategic level of lean remains under-researched [81]. This is not peculiar for non-repetitive manufacturing, as lack of strategic considerations of lean are recognized in broader literature, although it is important for sustaining the effects of lean initiatives [33]. Still, strategic could be incorporated in lenses of lean (and vice versa) is completely unaddressed in the proposition by Hopp & Spearman.

Organizational lens plays a significant role in the proposed construct, as it permeates other three lenses. Authors claim that all business systems include people and that organizational culture should be designed to support lean transformation [36]. Furthermore, although many aspects of organizational perspective are recognized (e.g. organizational learning, motivation, training, communication), the lens is reduced to making decisions and psychological bias. Some traditional lean practices, such as cross-functional employees, are unpractical in volatile environments such as non-repetitive operations, as it is not certain when newly learned skills might be needed [52]. In addition, so called 'craftsmanship pride' often encountered among workers in non-repetitive manufacturing can present an obstacle to learning, knowledge sharing, and overall readiness of workers to change things [52], which is why it presents an important contextual factor when lean in non-repetitive manufacturing is considered.

Finally, the results show that with one-fifth of the papers from the final sample it is not clear which part of the construct is explicitly addressed. This suggests that some lean research and implementation topics, such as e.g. measurement of leanness, lean scheduling, lean strategy, management commitment, lean 4.0, etc., remain unaddressed by proposed lenses.

6 Conclusion

In their attempt to redefine lean, Hopp & Spearman developed a construct consisting of four lenses of lean, aimed at guiding lean research and implementation. In order to tackle the fit of the proposed construct for research and implementation of lean in non-repetitive manufacturing, this article has presented the results of a systematic literature review, where articles were analyzed through lenses of lean. The results show that different lenses are addressed to a different extent, with a dominant attention to Process and Flow lenses. The analysis showed that the proposed construct presents a good base for both research and practice, as it considers important aspects of lean that are highly relevant for non-repetitive operations, such as e.g. context of waste, propagation of waste, variability, buffering, complexities of routing etc. On the other hand, the construct is not without flaws, as with its strong focus on efficiency, it fails to address other aspects of lean that are very important in non-repetitive manufacturing, such as effectiveness, responsiveness, and flexibility. In addition, the construct overlooks some aspects of lean in general, such as strategy deployment, people development, design of organizational culture, and change management.

This study comes with several limitations. First is subjectivity inherent to the literature review. Second is using just two citation databases, although they provide wide coverage. Third is the focus on articles published in peer-reviewed journals, which means that some important evidence from conference papers, case reports, or books might be overlooked. Future research could be designed to include these sources. In addition, it would be beneficial to test the proposed construct in more detail through longitudinal studies that will include implementing lean in non-repetitive manufacturing through all four lenses.

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