European Research Studies Journal
Volume XXIV, Special Issue 2, 2021

pp. 291-300

From Lean to Sustainable Manufacturing – An Overview

Submitted 02/03/21, 1st revision 07/04/21, 2nd revision 25/05/21, accepted 15/06/21

Małgorzata Jasiulewicz - Kaczmarek[1], Katarzyna Antosz[2], Arkadiusz Gola[3]

Abstract:

Purpose: *The purpose of the research is to present the comparison and connection between three manufacturing paradigms, Lean, Green, and Sustainable Manufacturing.*
Design/Methodology/Approach: *The methodology of the research is based on the literature review of three paradigms, including, definitions, methods and tools, as well as main challenges.*
Findings: *Transition towards Sustainable Manufacturing has been taking place in an evolutionary way and may be traced in the context of changes in production paradigms. The production paradigms presented in paper do not cover all examples of paradigms classification contained in the literature, since, they only indicate the way to learn the theories and challenges that the scientific community and economic practitioners must face.*
Practical Implications: *Lean and green methods and tools support the realization of sustainable manufacturing processes challenges.*
Originality/Value: *The paper presents synergy between every production paradigms. Every new paradigm generally considers the objectives and approaches of the previous one, so integrating the lean and green approach is a natural consequence. The combination of these two concepts enables achieving a synergetic effect even if a trade-off and balance of divergent goals. The shift from conventional manufacturing practices to more sustainable practices has led to better compliance with regulations and standards in order to enhance the corporate and brand image while pursuing economic benefits and environmental and societal responsibility.*

Keywords: *Lean Manufacturing, Green Manufacturing, Sustainable Manufacturing.*

JEL codes: *L23, L60.*

Paper Type: *Research Paper.*

[1]*Faculty of Management Engineering, Poznan University of Technology, Poznań, Poland, malgorzata.jasiulewicz – kaczmarek@put.poznan.pl*
[2]*Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology, Rzeszów, Poland, katarzyna.antosz@prz.edu.pl*
[3]*Faculty of Mechanical Engineering, Lublin University of Technology, Poland, a.gola@pollub.pl*

1. Introduction

Since the end of the 1980s, when 'Our common future' report was published by the World Environment and Development Committee (1987), politics, economy and science have been dominated by the term 'Sustainable Development'. In the report, sustainable development was defined as a process of change, in which exploitation of resources, new investments, orientation on technology development and institutional changes are focused on the current and future needs of society. To support companies in their transition towards sustainable development, the term 'Sustainable Manufacturing' (SM) was introduced during the UN Conference in Rio de Janeiro in 1992.

In 1997, however, Elkington tried to transform the general concept of sustainable development to fit it into a business context. Borrowing the term 'bottom line' from accounting, which means profit or loss, Elkington (1997) defined the triple bottom line (TBL) as 'Profit, Planet, and People' – '3P'. Transition towards Sustainable Manufacturing has been taking place in an evolutionary way and may be traced in the context of changes in production paradigms. Transition towards Sustainable Manufacturing has been taking place in an evolutionary way and may be traced in the context of changes in production paradigms. A new paradigm does not always exclude the previous one; it can develop and improve, for example, by acquiring new information (Table 1).

Table 1. *Manufacturing paradigm over the years*

Source	Evolution of manufacturing paradigms
Javahir and Dillon, 2007	Traditional production (craft production and mass production), Lean Production, Green Production, Sustainable Production
Koren, 2010	Mass Production, Lean Manufacturing, Mass Customization, Reconfigurable Manufacturing, Sustainable Manufacturing
Mourtzis and Doukas, 2014	Craft Production, American Production, Mass Production, Lean Production, Mass Customization, Global Manufacturing

Source: *Own creation.*

The concepts presented in Table 1 do not cover all examples of production paradigm classification contained in the literature; they only indicate the way to learn the theories and challenges that the scientific community and economic practitioners must face. The main goal of the paper is the review and description of manufacturing management concepts from Lean to Sustainable.

2. Lean Manufacturing

The concept of Lean Production first appeared formally in the article 'Triumph of the lean production system', by Krafcik (1988), and became popular through the book 'The Machine That Changed the World' by Womack and Jones in 1990. There

is no consensus on the definition of Lean Production among authors in the literature. Examples of different definitions are presented in Table 2.

Table 2. *Examples of definitions of Lean Production / Lean Manufacturing.*

Author/s	Definition
Ohno, 1998	Lean manufacturing consists of a work management philosophy that meets customer demands in the shortest possible time at the highest quality and the lowest cost.
Womack *et al*., 2007	A system which aimed to perform production with minimum manpower, by using the minimum production area, by consuming minimum resources, by holding inventories at the minimum level, by making minimum defects, by producing products at the shortest time, and by minimizing customer dissatisfaction.
Shah and Ward, 2007	An integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer and internal variability.

Source: *Own creation.*

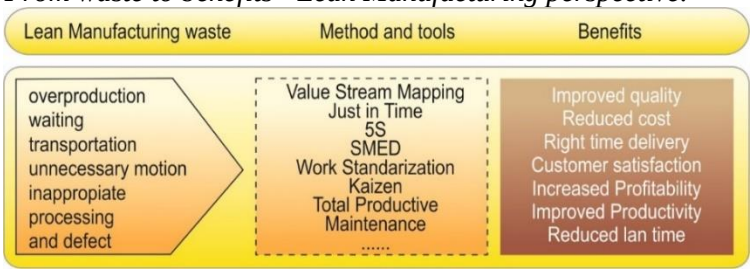
However, regardless of the defining approach, the main challenge of Lean Manufacturing (LM) is to maximize customer value while minimizing waste. In the work of Womack *et al.* (2007) waste is defined as any human activity which absorbs resources but creates no value. The seven types of waste are overproduction, waiting, transportation, unnecessary motion, inappropriate processing and defect as are identified by Ohno (1998). But later, the eighth waste was added to Ohno's original list by other authors, namely "unused employee creativity" Liker (2004).

Lean can be considered from both a philosophical perspective, as guiding principles or overriding goals, and from a practical perspective, as a set of management practices, tools, or techniques that can be observed directly (Shah and Ward, 2007). Lean from an operational perspective involves implementing a set of shop floor tools and techniques aimed at reducing waste within the plant and along the supply chain. Such tools and techniques include, for example, kaizen (i.e., continuous improvement), visual displays (e.g., 5S), Kanban, Value Stream Mapping (VSM), Single Minute Exchange of Die (SMED), Total Productive Maintenance (TPM), just-in-time supply systems (Figure 1). Lean philosophy assumes the interrelationship of practices in order to improve overall levels of quality, productivity, integration, and waste reduction, in functional areas such as R&D, maintenance, and along the supply chain (Tiwari, *et al.*, 2020; Psomas, 2021).

From the standpoint of the sustainable management paradigm challenges, various levels of the Lean implementation may have an impact (both positive and negative) on one or more TBL pillars (Helmold, 2020; Dey *et al*., 2020). The beneficial effect of the LM practices implementation on the improvement of MS results concerns, among others:

- Economic dimension - scraps and reworks, cost, lead time, product quality, inventory reduction (Bortolotti *et al.*, 2015; Negrão *et al.*, 2017).
- Environmental dimension - resource consumption, pollution control, energy efficiency, environmental awareness (Resta *et al*., 2017).
- Social dimension - multifunctional teams, health and safety, continuous improvement, employee satisfaction (Resta *et al.*, 2017).

Figure 1. *From waste to benefits - Lean Manufacturing perspective.*



Source: *Own creation.*

Nevertheless, the literature research proves that the implementation of LM practices may have a negative impact:

- Economic dimension - long-time implementation, misallocation of resources, administrative cost (Čiarnienė and Vienažindienė, 2014).
- Environmental dimension - waste disposal, pollution, trade-offs with operational performance (Resta *et al.*, 2017).
- Social dimension - routine operation, employee mistrust, trade-offs with operational performance (Čiarnienė and Vienažindienė, 2014; Resta *et al*., 2017).

This positive as well as negative impact of Lean Manufacturing practices on each of the TBL pillars results from necessity to make trade-offs between sustainability pillars in order to continue making performance gains in a given dimension. On the basis of business practice observations, it can be noticed that many enterprises implement socio-environmental practices "as long as they pay off" and which they exclude in a situation with deteriorating financial results.

3. Green Manufacturing

In the 1990s, the classic conflict between three parameters, cost, quality and time were extended by yet another element, namely by "environmentally friendly products". Enterprises faced the requirement of taking responsibility for the whole life cycle of the product (pre-manufacturing, manufacturing, use and post-use), including recycling and utilization, the so-called 3Rs principle, Reduce, Reuse and Recycle. The term Green Manufacturing (GM) was coined to reflect a new manufacturing paradigm that employs various green strategies and techniques to become more eco-efficient. Similar

to Lean Manufacturing, the term 'Green Manufacturing' is defined in many ways, as presented in Table 3.

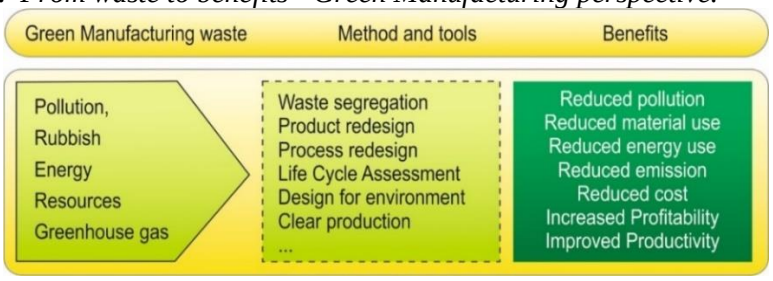
***Table 3**. Examples of 'Green Manufacturing' definitions.*

Authors	Definition
Melnyk and Smith, 1996.	A system that integrates product and process design issues with issues of manufacturing planning and control in such a manner as to identify, quantify, assess, and manage the flow of environmental waste with the goal of reducing and ultimately minimizing environmental impact while also trying to maximize resource efficiency.
Deif, 2011	A sustainable approach to the design and engineering activities involved in product development and/or system operation to minimize environmental impact.
Baines, 2012	The application of environmentally and socially sensitive practices to reduce the negative impact of manufacturing activities while, at the same time, harmonizing the pursuit of economic benefits.

***Source:** Own creation.*

Characterizing management as 'Green' reflects enterprises' awareness concerning the influence of planning, implementation and control of activities and their result (the product) on the environment and natural resources, as well as the need to identify related waste. Environmental wastes can occur when companies use resources to provide products or services to customers, and/or when customers use and dispose of products. Environmental wastes include 1) energy, water, or raw materials consumed in excess which is necessary to meet customer needs; 2) pollutants and material wastes released into the environment, such as air emissions, wastewater discharges, hazardous wastes and solid wastes (trash or discarded scraps); 3) hazardous substances that adversely affect human health or the environment during their use in production or their presence in products. In order to eliminate or at least limit these wastes, several methods and tools have been proposed to support enterprises in meeting GM's challenges. In general, methods/tools can be classified as assessment oriented or improvement oriented (Figure 2).

***Figure 2.** From waste to benefits - Green Manufacturing perspective.*



***Source:** Own creation.*

4. Lean and Green Manufacturing

Every new production paradigm generally considers the objectives and approaches of the previous one, so integrating the lean and green approach is a natural consequence. LM and GM have a common goal of eliminating waste, although the categories of "waste" in each of the paradigms are different. LM defines waste from the point of view of cost and time in the first place, while GM focuses on environmental aspects, defining waste as unnecessary or excessive use of resources, emissions to the atmosphere, water, etc., potentially endangering human health and polluting the environment (Amrutha and Geetha, 2020). Due to the growing interest in the integration of LM and GM in recent years, many authors (Pampanelli *et al.*, 2013) focused their attention on this issue (Table 4).

***Table 4**. Impact of L&G manufacturing on cost & environment performance.*

	Contribution	Criteria	Result
Rothenberg *et al.*, 2001	Relationship between LM practice & green performance	Buffer, work & Human Resources Management vs. water & energy use	Trade-off between lean and environment performance
Miller *et al*., 2010	Impact of integrated lean tools and DES modeling on the environment and financial performance	Cell vs. lead time vs. environment performance, recycling vs. profit & environment performance	LM and GM reduce waste and increase profitability
Pampanelli, *et al*., 2013	Lean model for managing environmental aspects	Kaizen vs. environment & operational performance	LM & GM reduce energy, materials, waste, and cost

***Source:** Own creation.*

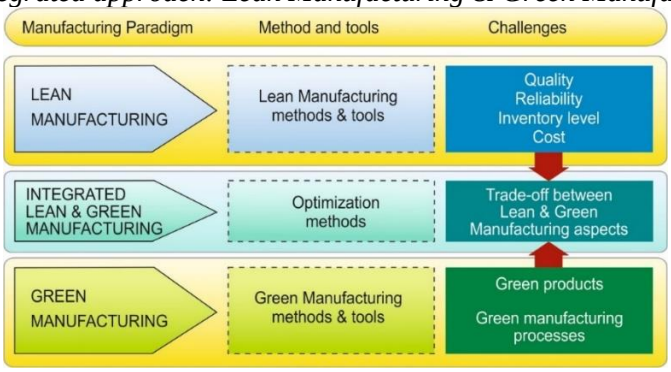
According to Kuo and Lin (2020) the combination of these two concepts enables achieving a synergetic effect even if a trade-off and balance of divergent goals is required (Figure 3). As in any of the previous manufacturing paradigms (e.g., Lean Manufacturing or Green Manufacturing), the next manufacturing paradigm is an outcome of market and technological drivers. Society continuously demands products and processes to satisfy its needs. Limited resources increase the need to use renewable materials and preserve the non-renewable ones. The shift from conventional manufacturing practices to more sustainable practices has led to better compliance with regulations and standards in order to enhance the corporate and brand image while pursuing economic benefits and environmental and societal responsibility (Wu, *et al.,* 2015; Abualfaraa, *et al*., 2020).

5. Sustainable Manufacturing

Sustainable Manufacturing is perceived in the literature as a paradigm, strategy, set of technologies or a system. According to the definition provided by the Department of Commerce in the US, Sustainable Manufacturing (SM) is ‘the creation of

manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers, and are economically sound'.

Figure 3. *Integrated approach: Lean Manufacturing & Green Manufacturing.*



Source: *Own creation.*

Javahir and Dillon (2007) describe SM as a process that leads to: (1) increased friendliness to the environment, (2) decreased cost, (3) decreased energy consumption, (4) decreased waste generation, (5) increased operational safety, and (6) improved health of employees. Examples of the 'Sustainable manufacturing' definitions are shown in Table 4.

Table 4*. Examples of 'Sustainable manufacturing" definitions.*

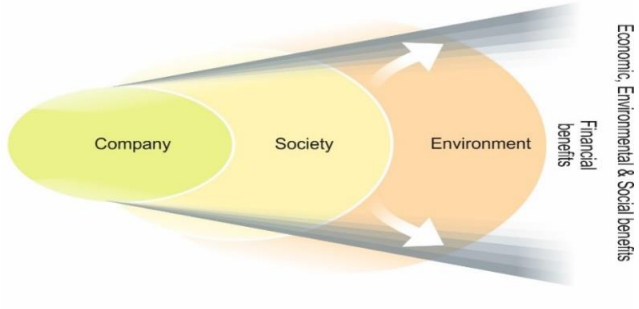
Authors	Definition
Lowell Center for Sustainable Production, 1998	Creation of goods and services using processes and systems that are non-polluting; conserving of energy and natural resources; economically viable; safe and healthful for employees, communities and consumers; and socially and creatively rewarding for all working people.
United States Department of Commerce, 2008	Creation of a manufactured product with processes that have minimal negative impact on the environment, conserve energy and natural resources, are safe for employees and communities, and are economically sound.
Moldavska and Martinsen, 2018	A complex behavior pattern to which any manufacturing organization should tend to evolve.

Source: *Own creation.*

The goal of sustainable manufacturing is to obtain balance between environmental, social and economic dimensions in order to meet stakeholder requirements and achieve a competitive advantage (Kannegiesser and Günther, 2014). Molamohamadi and Ismail (2013) believe that apart from TBL factors, technology, education, ethicsand responsibility are the key factors enabling sustainable manufacturing. According to Veleva and Ellenbecker (2001), six main aspects of sustainable production are: energy and material use (resources), natural environment (sinks),

social justice and community development, economic performance, workers, and products. According to Despeisse and Vladimirova (2014), transition to sustainable manufacturing requires changes in thinking and decision-making from the traditional approach to a more holistic one (Figure 4).

Figure 4*. Decision-making system for sustainable manufacturing*



Source: *Based on Despeisse and Vladimirova, 2014.*

This holistic approach should, (1) integrate the multiple dimensions of sustainability into manufacturing decision-making in a more balanced manner, (2) consider the benefits and implications of today's actions in the long term (trade-off), and (3) expand the scope of decision-making.

6. Conclusions

The concepts presented in paper do not cover all examples of production paradigm classification contained in the literature; they only indicate the way to learn the theories and challenges that the scientific community and economic practitioners must face. Despite the fact that the literature provides numerous strategies and practices supporting the implementation of sustainability in manufacturing it is difficult to combine three dimensions of sustainability for decision-making. As a result, decision-making is still dominated by financial metrics and short-term thinking, which do not adequately account for qualitative benefits.

The manufacturing industry needs more 'useful' information for sustainability decision-making that widens and specifies options to enable better results from implementation and to achieve desired objectives. The challenge, which manufacturers are facing, is to monetize the benefits of long-term innovative sustainable solutions, such as clear production practices, closed loop and resilient industrial systems, organizational learning, etc.

References:

Abualfaraa, W., Salonitis, K., Al-Ashaab, A., Ala'raj, M. 2020. Lean-green manufacturing practices and their link with sustainability: a critical review. Sustainability, 12(3), 981.

Amrutha, V.N., Geetha S.N. 2020. A systematic review on green human resource management: Implications for social sustainability. Journal of Cleaner Production, 247, 119131.

Baines, T., Brown, S., Benedettini, O., Ball, P. 2012. Examining green production and its role within the competitive strategy of manufacturers. Journal of Industrial Engineering and Management, 5(1), 53-87.

Bortolotti, T., Danese, P., Romano, P. 2012. Assessing the impact of just-in-time on operational performance at varying degrees of repetitiveness. International Journal of Production Research, 51(4), 1117-1130.

Čiarnienė, R., Vienažindienė, M. 2014. How to facilitate implementation of lean concept? Mediterranean Journal of Social Sciences, 5(13), 177-183.

Deif, A.M. 2011. A system model for green manufacturing. Journal of Clear Production, 19(14), 1553-1559.

Despeisse, M., Vladimirova, D. 2014. Decision Making for Sustainability: Review and Research Agenda, In: Grabot, B., *et al.* (Eds.), IFIP International Conference on Advances in Production Management Systems (APMS), Sept 2014, Ajaccio, France. Springer, IFIP Advances in Information and Communication Technology, AICT-439 (Part II), 146-153.

Despeisse, M., Ball, P., Evans S. 2012. Modelling and Tactics for Sustainable Manufacturing: An Improvement Methodology, In: Seliger, G. (eds.). Sustainable Manufacturing. Berlin, Heidelberg: Springer, 9-16.

Dey, P.K., Malesios, C., De, D., Chowdhury, S., Abdelaziz, F.B. 2020. The impact of Lean management practices and sustainably-oriented innovation on sustainability performance of small and medium-sized enterprises: empirical evidence from the UK. British. Journal of Management, 31(1), 141-161.

Elkington, J. 1997. Cannibals with forks: the triple bottom line of twenty-first century business. Oxford: Capstone.

Helmold, M. 2020. Sustainability and Lean Management. In Lean Management and Kaizen. Cham: Springer, 139-143.

Jawahir, I.S., Dillon, O.W. 2007. Sustainable Manufacturing Processes: New challenges for developing predictive models and optimization techniques. Proceedings of First International Conference on Sustainable Manufacturing, Montreal, Canada, 1-19.

Jones, DT., Roos, D., Womack, J.P. 1990. Machine that Changed the World. New York: Simon and Schuster.

Kannegiesser, M., Günther, H.O. 2014. Sustainable development of global supply chains-part 1: sustainability optimization framework. Flexible Services and Manufacturing Journal, 26(1-2), 24-47.

Koren, Y. 2010. The Global Manufacturing Revolution: Product-Process-Business Integration and Reconfigurable Systems. New Jersey: John Wiley & Sons.

Krafcik, J.F. 1988. Triumph of the Lean Production System. Sloan Management Review, 30(1), 41-52.

Kuo, S.Y., Lin, P.C. 2020. Determinants of green performance in container terminal operations: A lean management. Journal of Cleaner Production, 275, 123105.

Liker, J.K. 2004. The Toyota Way: 14 Management Principles from The World's Greatest Manufacturer. New York: McGraw-Hill.

Lowell Center for Sustainable Production. 1998. Sustainable Production: A Working Definition. Informal Meeting of the Committee Members.

Melnyk, S.A., Smith, R.T. 1996. Green Manufacturing. Society for Manufacturing Engineering, Dearborn, MI.

Miller, G., Pawloski, J., Standridge, C.R. 2010. A case study of Lean, sustainable manufacturing. Journal of Industrial Engineering and Management, 3(1), 11-32.

Molamohamadi, Z., Ismail, N. 2013. Developing a new scheme for sustainable manufacturing. International Journal of Materials, Mechanics and Manufacturing, 1(1), 1-5.

Moldavska, A., Martinsen, K. 2018. Defining sustainable manufacturing using a concept of attractor as a metaphor. Procedia CIRP, 67, 93-97.

Mourtzis, D., Doukas, M. 2014. The evolution on Manufacturing systems: From Craftsmanship to the era of Customization, In: V. Modrak, P. Semenco (Eds.), Handbook of Research and Design and Management of Lean Production Systems. Business Science Reference book series Advances in Logistics, Operations, and Management Science. USA: Hersley, 1-30.

Negrão, L.L.L., Filho, M.G., Marodin, G. 2017. Lean practices and their effect on performance: a literature review. Production Planning & Control, 28(1), 33-56.

Ohno, T. 1998. Toyota Production System. Cambridge: Productivity Press.

Pampanelli, A.B., Found, P., Bernardes, A.M. 2013. A Lean & Green Model for a production cell. Journal of Cleaner Production, 85, 19-30.

Psomas, E. 2021. Future research methodologies of Lean manufacturing: a systematic literature review. International Journal of Lean Six Sigma. https://doi.org/10.1108/IJLSS-06-2020-0082.

Resta, B., Dotti, S., Gaiardelli, P., Boffelli, A. 2017. How Lean manufacturing affects the creation of sustainable value: an integrated model. International Journal Automation Technology, 11, 542-551.

Rothenberg, S., Pil, F.K., Maxwell, J. 2001. Lean, green, and the quest for superior environmental performance. Production and operations management, 10(3), 228-243.

Shah, R., Ward, P. 2003. Lean manufacturing: context, practice bundles, and performance. Journal of Operations Management, 21, 129-149.

Tiwari, P., Sadeghi, J.K., Eseonu, C. 2020. A sustainable lean production framework with a case implementation: Practice-based view theory. Journal of Cleaner Production, 277, 123078.

Veleva, V., Ellenbecker, M. 2001. Indicators of sustainable production: framework and methodology. Journal of Cleaner Production, 9, 519-549.

Womack, J.P., Jones, D.T., Roos, D. 2007. The machine that changed the World: The Story of Lean Production-Toyota's Secret Weapon in the Global Car Wars That Is the Machine That Changed the World- Now Revolutionizing World Industry. New York: Rawson Macmillan.

Wu, L., Subramanian, N., Abdulrahman, M.D., Liu, C., Lai, K.H., Pawar, K.S. 2015. The Impact of Integrated Practices of Lean, Green, and Social Management Systems on Firm Sustainability Performance - Evidence from Chinese Fashion AutoParts. Sustainability, 7, 3838-3858.