State of art perspectives of lean and sustainable manufacturing

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Abstract

Purpose – The contemporary manufacturing organizations recognize the importance of lean manufacturing as a tool to eliminate wastes, streamline processes and improve value addition. On the other hand, such organizations also focus on the development of ecofriendly products and processes. In this context, lean manufacturing concepts provide a pathway for attaining sustainable benefits. This paper aims to present the state of art review on lean and sustainable manufacturing.

Design/methodology/approach – A total of 80 research papers on lean and sustainable manufacturing from various perspectives have been reviewed and their contributions are being presented. The perspectives include origin, definition, decision-making, performance measurement, product development and application for both lean and sustainable manufacturing.

Findings – Findings from the literature prove that both lean and sustainable manufacturing systems aim at improving the organizational performance and provide both operational and sustainable benefits. Also based on the studies, it has been found that integrated lean sustainable manufacturing system can be defined as a system that creates value for the customers by eliminating wastes consistently and adopting processes that are ecofriendly, economically viable and safe for the employees to produce green products that enhance the social performance.

Research limitations/implications – The present review considers the papers on lean and sustainable manufacturing based on certain perspectives. Peer-reviewed journal articles, and books are only being considered and reviewed. Articles and information from dissertation thesis, unpublished working papers and conference proceedings were excluded. In future, the study can be enhanced by considering more such perspectives that reflect the ideology and applicability of the selected themes. The practical perspectives of lean and sustainable manufacturing and their integration are also being presented.

Originality/value – This paper presents a review of lean and sustainable manufacturing and provides insights from different perspectives. The scope for their integration is also discussed. The contributions are original.

Keywords Lean manufacturing, Value addition, Sustainable manufacturing, Ecofriendly process, Waste elimination

Paper type Literature review

1. Introduction

The modern manufacturing systems are focusing on the implementation of lean and sustainable manufacturing for ensuring waste elimination and development of ecofriendly processes and products, respectively. Lean manufacturing focuses on consistent elimination of wastes. It is defined as a system that uses less from viewpoint of all inputs to generate similar deliverables as facilated by a conventional mass production system, with more variants for the customer (Womack *et al.*, 1990). Lean manufacturing aims at minimizing wastes and maximizing activities that add value from customer's view point (Shingo, 1989; Jones and Roos, 1990; Duarte and Cruz-Machado, 2013; R. Jadhav *et al.*, 2014). Value is defined as anything that induces the customer's willingness to pay. Hence, waste elimination is considered as the basic

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principle of lean manufacturing. The vital objective of a lean manufacturing is to manufacture products of greater quality at a lower possible cost and with least available time by elimination of wastes (Liker, 2004; Stone, 2012; Hu *et al.*, 2015). Liker (2004) explained about 14 key management principles that Toyota implemented from the leadership levels on down to create a better organization for serving customers while remaining flexible to crises. These 14 principles emphasize more on continuous improvement and respect for people in designing a system that makes people to continually improve their work standards. Recently, underutilization of creativity of workforce has been considered as the eighth waste (Vinodh and Chintha, 2011). Lean strategy also has the potential to benefit the environment by reducing the environmental wastes such as excess energy or water use, hazardous waste or solid waste. There exists a need to include environmental waste as ninth waste alongside other lean wastes, as it aligns organizational practices with strategic objectives for reducing environmental wastes. Inclusion of environmental waste as lean waste directly influences the sustainable performance of a firm as it addresses the environmental dimension. Sustainable manufacturing is focused on the creation of products that use processes that minimize negative environmental impacts, conserve energy and natural resources. The World Commission on Environment and Development (WCED) defines sustainable development as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987; Hult, 2011; Thomas *et al.*, 2016). Sustainable manufacturing has triple dimensions, namely, environment, economy and society, and aims at proving triple bottom line benefits (Jayal *et al.*, 2010; Garbie, 2013). The principles of sustainable manufacturing aim at improvising the three dimensions of sustainability. In addition, they are economically safe for employees, communities and consumers. Also, there exists vital need to extend lean manufacturing concepts to ensure sustainable benefits. Over the past, various studies have been conducted on analyzing the literature pertaining to lean manufacturing and few studies on sustainable manufacturing. However, a study that analyzes the literature of both lean and sustainable manufacturing from different perspectives and investigating the scope of its integration has not been developed yet. This paper presents the review of 80 articles on lean, sustainable and integrated lean–sustainable manufacturing. The inferences derived from the review are being presented in the forthcoming sections. The insights derived from the conduct of review are being presented in the conclusion section. The research objectives addressed in the present study include:

- to analyze the existing literature on lean and sustainable manufacturing from different perspectives and to gather their insights; and
- to investigate the studies on integration of lean and sustainable manufacturing and to analyze the possibility of their integration.

The focus of this research is to consolidate the insights available on literature pertaining to selected topics on lean and sustainable manufacturing. The review also highlights the critical inferences to researchers and practitioners seeking to attain knowledge on the discussed topics and to help in deriving directions for future research. The paper is structured in a way such that it starts with a brief introduction about the lean and sustainable manufacturing concepts. The next section explains methodological approach used to perform the systematic literature review and data collected are being analyzed. Finally, a critical discussion of the results with suggestions for future research is presented.

2. Review methodology

The present article is based on the systematic review on lean and sustainable manufacturing. A systematic review is a structured approach used to study about the background literature, which aims at avoiding potential pitfalls that arises from a purely narrative analysis (Crossan and Apaydin, 2010). It consists of three phases, namely, review planning, review execution and reporting (Kitchenham *et al.*, 2009). The review plan was prepared based on the research purpose and scope of the article. Details regarding Nature of analysis, unit of analysis, inclusion factor, exclusion factor, search limitations and time frame of analysis were discussed in the review planning phase. Selecting and segregating the articles based on the identified perspectives were performed during the review execution phase. Finally, reporting of the selected articles is being performed and findings are being tabulated. Research articles were searched and collected from standard citation databases. Relevant data and information were extracted from the selected articles and were documented. The extracted data were summarized in a table form. This research article reviews lean and sustainable manufacturing in a broader perspective and would help in providing a better understanding of lean and sustainable manufacturing practices and their applications. Over 350 research papers on lean and sustainable manufacturing were collected and on thorough review of all the articles, 80 research articles pertaining to the main research topic were selected as target papers and an intensive literature review was carried out and their key findings were summarized according to the earliest date of publication for each subgroup of lean and sustainable manufacturing. The articles that are in close relation with the perspectives and have more citations were selected and reviewed. Later an introduction to the integrated lean and sustainable manufacturing approach was provided. Literature review for integrated lean sustainable manufacturing was conducted and its future potential was also discussed. The deliverable of the reviews is the extraction of a set of key findings, compiled and grouped as different perspectives for providing a better understanding. The review is presented in a tabulated form to provide information in a crisp and lucid manner to the readers. Tabulation is done based on the information pertaining to description of the work, attainable outcomes and its future scope. The key findings based on the review are presented at the end. The summary of the review methodology is depicted in Table I.

Table I.
Summary of review methodology

Nature of analysis	Qualitative
Review planning	
Unit of analysis	Research articles that are frequently cited in the literature on lean and sustainable manufacturing was the main constituent
Inclusion factor	Articles were collected from peer-reviewed journals, books
Exclusion factor	Articles and information from unpublished working papers, dissertation thesis and conference proceedings were excluded
Search limitations	The search was limited to research articles on lean and sustainable manufacturing pertaining only to manufacturing sectors
Time frame of analysis	1950-2017
Review execution	
Search tools used	ScienceDirect (Elsevier), Taylor and Francis database, Emerald Insight, Scopus, Springer link, Scopus, IEEE Explore, Inderscience, Google Scholar and ISI Web of knowledge
Perspectives	Origin, definition, principles, tools and techniques, decision-making, conceptual models, performance measurement, product development and applications

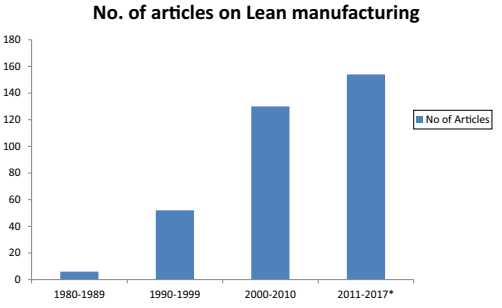
2.1 Literature trends

The search for the research articles was performed through renowned academic journals in the field of LSS that are published in leading journal databases. The databases include Elsevier, Taylor and Francis, Emerald Insight, Springer, IEEE Xplore and Inderscience. Major journals that contribute articles pertaining to lean manufacturing include *Journal of Operations Mangement*, *Production Planning and Control*, *Intenational Journal of Advanced Manufacturing Technology*, *International Journal of Production Research*, *International Journal of Production Economics, Journal of Manufacturing Systems, Journal of Manufacturing Technology Management, International Journal of Lean Six Sigma, Journal of Industrial Engineering, International Journal of Services and Operations Management, The TQM Journal*, etc. Journals that have more articles on sustainable manufacturing include *Journal of Cleaner Production, Clean Technologies and Environmental Policy, Environmental Impact Assessment, Ecological Indicators, International Journal of Sustainable Engineering, International Journal of Sustainable Manufacturing, Stochastic Environmental Research and Risk Assessment*, etc. On analyzing the articles pertaining to lean manufacturing, it is found that very few articles were published over the early and mid-1980s and have increased considerably toward the end of the millennium year. An increase in quantity of publications on lean manufacturing is being witnessed post 2000s and has been gradually increasing over the years. Figure 1 depicts the apportionment of the collected research articles on lean manufacturing over the four decades.

On analyzing the literature on sustainable manufacturing, it is to be known that reports, namely, International Union for Conservation of Nature (1969), World Commission on Environment and Development (WCED) (1987) and Brundtland (1987), dealt with the usage of terms like sustainability and ecofriendly manufacturing. While over the beginning of the 1990s, publications on sustainable manufacturing started to feature in journals and retained a substantial level until the early 2000s. Later, more number of research articles and special issues were published on renowned journal databases and have been on an increasing note till date. This shows the wide acceptance and scope for research on the topic. Figure 2 shows the distribution of the research articles on sustainable manufacturing over the three decades.

3. Lean manufacturing

The lean manufacturing research is presented in the following subsections.



Note: *Data includes articles collected as on July 2017

Figure 1.
Distribution of the collected research articles on lean manufacturing

3.1 Origin of lean manufacturing

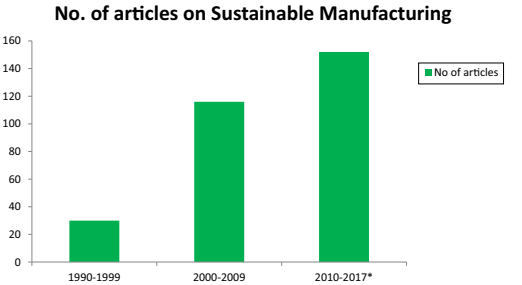
The term lean manufacturing has its origin from Toyota Production System, which focuses on continuous elimination of wastes prevailing in manufacturing environment. The origin of lean manufacturing was discussed by various researchers in literature and this section compiles a set of discussion on the origin of lean manufacturing as mentioned by the researchers. The research insights on origin of lean manufacturing is shown in Table II.

3.2 Definition of lean manufacturing

Lean manufacturing is defined as the process of consistent elimination of wastes. In the literature, there are various definitions available for lean manufacturing. Table III presents the set of definitions of lean manufacturing contributed by various researchers in their perspectives.

3.3 Tools and techniques of lean manufacturing system

Lean manufacturing comprises various tools and techniques for its successful implementation. Lean manufacturing tools help and support waste elimination



Note: *Data includes articles collected as on July 2017

Figure 2.
Distribution of the collected research articles on sustainable manufacturing

Research study	Research insights
Ohno (1988)	A system was developed to make Toyota corporation to compete with American automakers to achieve long production runs that Toyota did not have. The developed approach was referred to the "Toyota Production System", which was framed to produce goods as in a continuous flow
Shingo (1989)	Indicated that after World War II, Japanese manufacturing were facing a situation of shortage of material, financial, and human resources. To overcome these conditions, they developed a system which focuses on eliminating the wastes and this resulted in the birth of lean manufacturing concept
Holweg (2007)	Detailed a historical information of the research that lead to the development of lean production formerly referred as JIT. Developed a timeline that relates the key events and major publications which contributed towards the development of lean production system over the years
Womack *et al.* (2008)	Defined the concept and working philosophy of lean manufacturing which was pioneered by a Japanese automotive company, Toyota
Bhaskaran (2012)	Presented the popularity of lean manufacturing which was little known outside Japan until 1970s. Britain learned about the concepts of lean manufacturing from the establishments of firms like Toyota, Nissan and Honda after their inception in UK

Table II.
Research studies on origin of lean manufacturing

process and facilitate the organizations to achieve operational excellence. Various lean manufacturing tools and techniques described by the authors are shown in Table IV.

3.4 Performance measurement of lean manufacturing system

The performance of lean system must be assessed to track its benefits after successful implementation. It is important to practice and sustain lean manufacturing practices so as to attain organizational goals. The performance measurement and assessment models help in assessing the lean systems and also help in improvising the organization's performance. The research insights of various performance measurement systems of lean manufacturing are shown in Table V.

Research study	Definition
Womack *et al.* (1990)	A system that uses minimal of all inputs, to generate the same outputs as produced with a traditional mass production system with focus on enhanced varieties for end customer
Shingo (1992)	Strongly advocated the elimination of waste and put forth the idea, "don't accept waste as unavoidable". The basis of lean manufacturing is waste elimination
Womack and Jones (1996)	Lean is as a process that consists of five steps: the steps are defining customer value, defining value stream, making it "flow", establish pull, and aiming at excellence
Bhasin and Burcher (2006)	A philosophy that when deployed reduces the time from customer order to delivery by eliminating waste sources in the production flow

Table III.
Research findings on definition of lean manufacturing

Research study	Research insights
Pavnaskar *et al.* (2003)	Created a classification scheme that systematically links the manufacturing wastes with the lean tools. They organized 101 lean manufacturing tools and metrics using this classification scheme which would help the firm in solving the manufacturing problems
Herron and Hicks (2008)	Discussed the lean tools, such as statistical process control, Single Minute Exchange of Dies (SMED), Failure Mode and Effect Analysis (FMEA) , fool proofing, process mapping and also briefed about the practical implications of deployment of such tools
Krishnan and Parveen (2013)	Compared lean tools used in manufacturing and service sectors and detailed how the application changes from a manufacturing firm to a service firm. The compared lean tools included JIT, total quality management (TQM), six sigma, kaizen, total productive maintenance (TPM), statistical process control (SPC), Kanban, job reengineering, work teams, benchmarking, organizational restructuring and business process reengineering
Belekoukias *et al.* (2014)	Investigated the impact of five crucial lean tools namely JIT, kaizen, autonomation, TPM and value stream mapping (VSM). The results showed that JIT and autonomation possess highest influence on operational performance while TPM, VSM and kaizen generates lesser impact
Ståhl *et al.* (2015)	Performed a study to investigate the effect of lean tools on organizational performance by using decision latitude which enables a climate for innovative learning. Multilevel linear regression analyses were used to evaluate the performance of different lean tools
Burch V and Smith (2017)	Developed a simulation-based model to teach lean methodologies to provide better understanding about lean methodologies to the workplace employees. The study also discussed about how the benefits of simulation training for Lean differs from all employees in the workplace versus employees born between 1979 and 2000

Table IV.
Tools and techniques of lean manufacturing system

Research study	Research insights
Wan and Frank Chen (2008)	Contributed a unit invariant leanness evaluation approach based on data envelopment analysis (DEA) with self-contained benchmarking technique to measure leanness level. The proposed approach extracted the value adding investments of a manufacturing process to find the benchmark enabler
Vinodh *et al.* (2011)	Conceptualized a leanness measurement model which uses multi-grade fuzzy approach for computing leanness index. After computing the leanness index, the potential scope for improving the leanness index were identified and subsequently implemented
Behrouzi and Wong (2011)	Developed an approach which uses the application of fuzzy membership functions to measure the lean performance. They explained about the basic concept of fuzzy logic and proposed a measurement model comprising lean attributes, categories and metrics
Bhasin (2011)	Framed a performance score card template and collected data from small, medium and large manufacturing organizations. The results proved that larger organizations which adopted lean philosophy obtained better score compared to medium- and small-scale manufacturing organizations
Aziz and Hafez (2013)	Designed a dynamic conceptual model for evaluation of a lean production system and defined areas for improvement based on lean approach principles. The model evaluates the system and defines scope for improvising the operational efficiency of manufacturing system
Ali and Deif (2014)	Developed a model which uses dynamics approach to find the leanness score of manufacturing systems. Based on three metrics, namely, overall equipment effectiveness (OEE), overall service level (OSL), overall work in process efficiency (OWE) and the leanness score of the manufacturing system was calculated
Sharma *et al.* (2015)	Developed a framework to investigate the effect of lean production practices on performance measures in machine tool industries. The criteria that has significant positive impact on lean performance were also identified

Table V.
Research findings on performance measurement of lean manufacturing system

3.5 Decision-making for lean manufacturing

The literature analysis provides various frameworks and decision-making models used for selecting the best possible tools, techniques and implementation models. Various lean decision-making models proposed by the researchers which are used for facilitating better decisions are discussed in Table VI.

3.6 Lean product development

Lean product development uses lean philosophy and principles during product development stages and eliminates unnecessary wastes that exist in every product development stage. Table VII shows the research insights on lean product development discussed by various researchers.

3.7 Applications of lean manufacturing

Lean manufacturing principles, tools and techniques are deployed in several industrial settings to achieve waste elimination, attain operational excellence and improve the firm's business performance. Table VIII shows the research contribution on applying lean manufacturing concepts in different organizations.

4. Sustainable manufacturing

The literature analyses on sustainable manufacturing are presented in the following perspectives.

Research study	Research insights
AlDurgham and Barghash (2008)	Developed a model named simulation application framework for manufacturing (SAFM) that analyses the nature of relations between different decision areas and makes the task of using simulation to support decisions more systematically. The developed tool can be used as a continuous improvement tool and supports decision-making
Huang *et al.* (2010)	Developed a lean model which creates an algorithm for feature selection and act as an intelligent assessment method. This lean model reduces time consumption for tool selection and greatly improves the efficiency of manufacturing system
Vinodh *et al.* (2011)	Designed and developed a decision support system (DSS) for leanness measurement which uses fuzzy logic approach to compute leanness index. The developed DSS is also used as a test kit to evaluate the manufacturing firm's lean performance
Ramesh and Kodali (2012)	Modeled a decision framework which integrates preemptive goal programming (PGP) and analytical hierarchy process (AHP) which helps the decision-makers to arrive at the optimum implementation sequence of a chosen set of VSM tools to identify and reduce all wastes present in the system which maximizes organizational performance in the shortest timeframe
Shamah (2013)	Developed a model to examine the nature of the relationship between lean thinking and value creation to enhance customer satisfaction and performance. The developed model is based on a questionnaire and addresses the impact of lean thinking in improvising the value chain of the entire process
Wu *et al.* (2015)	Developed a group decision-making model named multi-attribute group decision-making (MAGDM) model to assess the leanness of manufacturing firms. The developed model was based on triangular fuzzy numbers and help in obtaining a crisp evaluation
Sharma *et al.* (2015)	Developed a conceptual model for studying the interaction among major lean manufacturing criteria in a machine tool industry. interpretive structural modeling (ISM) technique was used to prioritize the criteria and to understand the mutual influences based on their driving and dependence powers

Table VI.
Contributions on decision-making for lean manufacturing

4.1 Origin of sustainable manufacturing

This section describes the origin of sustainable manufacturing as mentioned by various researchers. A very few literature is available which reports the origin of sustainable manufacturing. Table IX shows the insights on the origin of sustainable manufacturing.

4.2 Definition of sustainable manufacturing

Sustainable manufacturing is widely termed the development of manufactured products that use processes that are non-polluting, conserve energy and natural resources, have economical benefits and are safer for employees, communities and consumers (Jayal *et al.*, 2010). Various definitions of sustainable manufacturing reported in the literature are shown in Table X.

4.3 Tools of sustainable manufacturing

Sustainable manufacturing tools support manufacturing organizations to make their system, process and product sustainable. This section describes various sustainability tools and their applications and discusses how sustainability tools helps in making the process and product sustainable. Table XI shows the research insights on sustainable manufacturing tools as described by various researchers.

Research study	Research insights
Mcmanus and Millard (2002)	Explored the effect of value stream analysis and mapping when applied to product development. They developed a new approach called PD VSAM (product development value stream analysis mapping) which applies lean tools during different stages of product development which correlates process improvement
Oppenheim (2004)	Developed a generic holistic framework based on lean principles, namely, lean product development flow (LPDF) for organizing engineering stages of product development. This approach achieved the traditional goals of system engineering by assuring quality and reduced program cost by radical reduction of wastes
Gautam and Singh (2008)	Contributed a mathematical model to identify the value of a product and to capture optimized design changes with cost implications. The developed model helped in enhancing change benefits by acquiring the highest possible customer perceived value in product using the given set of budgetary constraints
Taylor *et al.* (2013)	Developed a conceptual lean product and process development model which uses the application of knowledge-based environment, continuous improvement culture, value-focused planning and development, and set-based concurrent engineering process for achieving value focused product development
Dal Forno *et al.* (2016)	Developed a diagnosis based benchmarking model for manufacturing organizations to minimize its development time from a lean perspective. A set of measurable indicators were used to evaluate the practices in a structured way. The model helped in reduction of time-to-market, improvement in quality of the product and decreased the development costs

Table VII.
Insights on lean product development

4.4 Performance measurement of sustainable manufacturing system

From the literature, it is found that authors propose different sustainability evaluation and performance measurement methods based on its application. Various sustainability performance measurement techniques widely used in the literature are discussed in Table XII.

4.5 Decision-making for sustainable manufacturing

Sustainability-based decision-making models help the decision-makers to take decisions under complex and uncertain situations. Most of the sustainable decision-making models help in improving the sustainability performance and also provide managerial implications. Various sustainable decision-making models are discussed in Table XIII and their unique aspects are emphasized.

4.6 Sustainable product development

Sustainable product development incorporates sustainability aspects and concepts during initial stages of product development. Various research studies on sustainable product development and their insights are shown in Table XIV.

4.7 Applications of sustainable manufacturing

This section discusses about the application of sustainable manufacturing principles, tools and techniques adapted in various industries. Application of sustainable manufacturing concepts in various industries and their insights are discussed in Table XV.

5. Integrated lean sustainable manufacturing

As lean manufacturing focuses on elimination of wastes and sustainable manufacturing enhances environmental, economic and societal performance of a firm, an integrated lean

Research study	Research insights
Gunasekaran and Nath (1997)	Conducted a study to apply lean concepts in a manufacturing firm, Training was provided for workers and 5S tool was implemented to improve security in the workplace, quality of products and production status of the company. They replaced traditionally adopted push system with a pull system for obtaining a smooth and synchronized system, so that products were to be produced at right time and in right quantity
Abdulmalek and Rajgopal (2007)	Carried out a study where lean concepts are adopted for implementation in a large integrated steel mill. VSM was deployed to recognize the scope of several lean techniques. They contributed a simulation model to illustrate the potential benefits that will be experienced in the future scenario
Shah *et al.* (2008)	Implemented kaizen approach to find the solution to the problem of "part mismatching"' in the assembly line of an automobile company. Kaizen approach was used to eliminate problems step by step by collection of data, analysis of root causes, determination and selection of best solution from various possible solutions, implementation and proper documentation
Wong *et al.* (2009)	Analyzed the implementation of lean principles in an electrical and electronics industry. The author also conducted a survey based on a questionnaire that explores 14 key lean areas, namely, material handling, scheduling, inventory, work processes, quality, equipment, suppliers, employees, layout, customers, safety, product design and ergonomics, management and culture
Bergenwall *et al.* (2012)	Performed a study to investigate about the differences in seven Toyota Way principles linked with process design between American automakers and Toyota . The methodology used structured interviews with line managers and logistics coordinators in two assembly plants to create continuous process flow and leveled work flow
Jasti and Sharma (2014)	Demonstrated a study to implement the applicability of VSM and other lean tools in an automotive manufacturing firm. Study revealed that VSM creates a positive effect on parameters like talk time, process inventory level, process ratio total lead and process time, line speed and lesser man power
Vinodh *et al.* (2017)	Contributed a framework for lean concepts deployment in large-scale manufacturing industries. The framework was validated based on a study performed in a welding fabrication firm. Results suggested that lean principles facilitated weld defect reduction and provided substantial financial savings

Table VIII.
Research contribution on applications of lean manufacturing

sustainable system helps the firm in achieving operational excellence and also improves their green performance. The research work done by various researchers on integrating lean and sustainable manufacturing principles are shown in Table XVI.

On basis of the literature review, it is obvious that the integrated lean sustainable manufacturing system enhances the firm's business performance. Few studies are reported on the integration of lean and sustainable manufacturing principles. The integrated lean sustainable system helps the firm to improve its green performance and also helps in achieving operational excellence.

6. Results and discussions

The findings based on the review are being presented in the following three subsections.

6.1 Lean manufacturing

Based on the conducted review on lean manufacturing, the following insights were derived:

- As discussed by the researchers, it is clear that lean manufacturing was originated from Toyota Production System with a focus on waste elimination that occurs

Research study	Research insights
Hart and Ahuja (1996)	With the beginning of new millennium, several frontier firms in the USA, Europe and Japan are reacting to the advancements of global population growth and environmental pressures with an assurance to sustainability. As a result, it lead to the development of a new concept called sustainability
Kiernan and Martin (1998)	In 1969, a group of US companies including DuPont and General Motors networked in coordinating a high-visibility National Town Meeting on Sustainability. The recent research illustrated that pursuit of sustainability not only ends in environmental improvements and societal benefits but also enhance firm's economic value
Moffatt and Hanley (2001)	As a part of Earth Summit meeting held in Rio de Janeiro in 1992, many national governments pledged them to ensure development sustainable by making the manufacturing system to support eco-socio aspects and this led to the development of sustainability models
Miller *et al.* (2010)	Sustainability originates from the ideology that was initially developed by Green Party, a political party in Australia in early 1970's whose political agenda rapidly disseminate around the world. The developed ideology created a greener manufacturing system which supports sustainability aids

Table IX.
Origin of sustainable manufacturing

Research study	Definition
International Union for Conservation of Nature (1969)	Achieving economic growth and industrialization without environmental damage
WCED (1987)	Development that fulfills the needs of the present without the compromise of ability of future generation to fulfill their own requirements
Brundtland (1987)	Meet the needs of the present without compromising the ability of future generations to meet their own needs
de Ron (1998)	Sustainability means rearrangement of technological, scientific, environmental, economic and social resources in such a way that the resulting heterogonous system can be maintained in the state of temporal and spatial equilibrium
Feng and Joung (2009)	Sustainable development implies ability to advance its economic state without compromise of natural environment and social equity that facilitate the quality of life for all community residents, present or future

Table X.
Definitions of sustainable manufacturing

during manufacturing process. After the birth of lean manufacturing concept, the manufacturing firms experienced a paradigm shift from traditional and craft manufacturing system to batch and queue type manufacturing system.

- Though there are different definitions available for lean manufacturing as defined by the researchers, all definitions focus on the core area of eliminating wastes in the organization and providing products/services to the customers at right quantity, quality and during right time.
- The authors have classified and detailed the available lean manufacturing tools and also discussed how each tool helps in waste elimination and support in improvising the business performance. Apart from the discussed tools, there are also certain advanced lean tools which are under development which integrates the developed system with

Research study	Research insights
Hauschild *et al.* (2005)	Developed an analytical tool for lifecycle assessment based on different design for environment (DFE) tools developed in the past. The developed tool was used for LCA and results proved that LCA not only include eco-efficiency but also product's environmental justification and company's ethics to make the product sustainable
Seliger (2007)	Listed 11 sustainability tools often used by manufacturing industries. The discussed tools include lifecycle management, extended producer responsibility, lean manufacturing, Six Sigma quality, eco efficiency, cleaner production, ecological foot printing, IS0 14001, eco redesign, industrial ecology and green purchase programs
Zorpas (2010)	Presented the necessity for deployment of environmental management system (EMS) as a sustainable tool to track the production of waste from manufacturing firms. They also discussed the benefits, disadvantages, motivation, in implementing EMS
Huertas *et al.* (2013)	Developed a simulation based sustainability evaluation tool used for the manufacturing processes. The developed tool supports the optimization of process and product design in advanced production runs to support the "right first time" approach to manufacturing
Faulkner and Badurdeen (2014)	Developed a sustainable value stream map by recognizing appropriate metrics and methods to pictorially represent them. The approach was validated through an application case study in an industry opportunities for further improvement were discussed

Table XI.
Tools of sustainable manufacturing

Research study	Research insights
Culaba and Purvis (1999)	Described a methodology for assessing the impacts created by environment on manufacturing process using decision-making potential and flexibility of a knowledge-based system. They created a model with reference to knowledge engineering for sustainability assessment and validated the model in a paper manufacturing industry
Veleva *et al.* (2001)	Designed a tool named indicators for sustainable production (ISP) to quantify sustainability with supplemental and core indicators to improvise the performance and decision-making. They emphasized that how ISP can assist ISO 14001 program to evaluate environmental and financial performance and to ensure strategic benefits
Schwarz *et al.* (2002)	Developed a set of indicators of sustainability that includes energy intensity, toxic emissions, material intensity, water consumption, and pollutant emissions. The developed metrics that support decision-making with a mechanism to benchmark performance and generate strategies for improvement
Todorov and Marinova (2009)	Classified the available sustainability models as visualization models, quantitative models, physical models and conceptual models. They emphasized the importance of inclusion of role of humans and utilization of concepts of information technology in creating sustainability assessment models to meet global standards
Vinodh *et al.* (2013)	Developed a system approach by integrating various sustainability assessment models currently used to find the sustainability level of the manufacturing organizations. The integrated approach helped in finding current sustainability level of the manufacturing organization and facilitate effective decision-making

Table XII.
Performance measurement of sustainable manufacturing system

computers and act as a tool to assist in waste elimination process. In future, more such tools will be developed to enhance the performance of lean practices.

- Various lean performance measurement and evaluation system are being described by the researchers. The main objective of the developed models is to assess and

Table XIII.
Research findings on decision-making for sustainable manufacturing

Research study	Research insights
York (2009)	Developed a methodology based on American pragmatism to provide an architecture for businesses which focuses on innovation and experimentation. Using the developed approach, the alternative for sustainability becomes obvious which best fits business excellence
Hwang *et al.* (2013)	Developed a new data envelopment analysis (DEA) model for evaluation of design for environment (DfE) performance. The proposed model helps in establishing a benchmark with lower undesirable outputs for inefficient decision-making unit (DMU)
Singh *et al.* (2014)	Contributed a fuzzy inference system-based model for the assessment of manufacturing sustainability of SME's. The proposed model served as a technique to assist decision-makers in evaluating several dimensions of sustainability of manufacturing SMEs
Zhu *et al.* (2015)	Developed an approach using low dynamic programming which provides an optimized structure for two different cost functions namely cost savings and energy efficiency. This approach helped in decision-making by using specific performance criteria to efficiently manage energy and overall sustainability of production environment
Orji and Wei (2015)	Developed a decision-making model for integrating information on supplier behavior in fuzzy environment with sustainable simulation modeling technique. A multi-criteria decision-making model was formulated to compare results from the system dynamics model to find the best supplier with sustainable behavior

evaluate the current performance of lean system and help the manufacturing firms to identify its potential weak areas and provide measures to improve them. The performance measurement models being discussed may differ in their approach but satisfy the objective by measuring the performance of lean manufacturing system.

- Decision-making models help the decision-makers in selecting the appropriate lean tools, techniques and deployment models that relate to particular application and business environment. It is also evident that majority of the existing lean decision-making models and framework are applied as performance evaluation models and decision support systems to improve the performance of manufacturing organizations.
- Lean product development methodology enables to reduce product development cycle time and development costs and supports to fulfill customer's requirements in terms of innovation and quality. It uses techniques like set based concurrent engineering, visual management and reusable knowledge during different stages of product development. Applying lean product development methodology helps in eliminating wastes that occur during various stages of product development and helps in increasing the value of product.

With reference to the above discussion, it is clear that the application of lean manufacturing principles is pertaining not only to manufacturing firms but also to all sectors considering their needs and business requirements.

6.2 Sustainable manufacturing

Based on the review on sustainable manufacturing, the following insights were gathered.

- It is understood that the manufacturing firms necessitate an environmentally safe and economically stable system to meet the emerging challenges. As a result, the concept of sustainability was developed and practiced. Most of the literature state

Research study	Research insights
Hanssen (1999)	Summarized the results from six case studies in sustainable product development, based on a method developed for environmentally sound product development. Based on the results, the researcher proposed that eco effectiveness can be used as a measure for environmental improvement of product systems as an alternative to ecoefficiency
Kaebernick *et al.* (2003)	Discussed the scope for inducing environmental needs into new product design and development of new products. They framed a methodology for sustainable product development and implemented in an industry. They also described some of the sustainable tools, which have been developed by prior researchers for individual stages of the product development process
Klöpffer (2003)	Explained the need for sustainability in product development and briefed how lifecycle methods like environmental lifecycle assessment (LCA), economic lifecycle costing (LCC) and social lifecycle assessment (SLCA) create impact on each stages of product development
Byggeth and Hochschorner (2006)	Developed a method for sustainable product development by integrating ecological and social aspects of sustainability from strategic business view point in product development. A modular system based on sustainability principles and product lifecycle for sustainable product development was developed and the results proved that the developed system provides better flexibility in designing and developing the sustainable products
Gremyr *et al.* (2014)	Explored how efforts based on robust design methodology would contribute in designing sustainable products. Also discussed about eco design indicators and described how the methodology meets the key aspects of eco design and lifecycle approach in making a product sustainable
Gmelin and Seuring (2014)	Developed a framework which integrates sustainability and new product development with a product focused lifecycle approach. Results proved that it is important to involve lifecycle management concepts while designing a sustainable product to reduce the complexity and to attain process harmonization by proper utilization of technologies

Table XIV.
Research insights on sustainable product development

that the concept of sustainability was developed in 1969 by a group of companies in the USA to enhance the environment and economic value of the manufacturing firms and this contributed to the origin of sustainable manufacturing

- Although there are different definitions for sustainable manufacturing as quoted by the researchers, the definition for sustainable manufacturing defined by World Commission on Environment and Development as "Development that meet the needs of the present without compromising the ability of future generations to meet their own needs" is widely followed and emphasized by most of the researchers.
- Various sustainable manufacturing tools and indicators are discussed by the researchers to fulfill the sustainability needs of organizations using different approaches. Most of the discussed sustainability tools deal with enhancing the environmental performance of organization and very few tools support social and economic impact.
- It is vital to evaluate the performance of sustainable manufacturing system to assess whether the system meets sustainability needs and also to upgrade the system to global sustainability standards. Researchers discussed various sustainable performance measurements models that use different assessment approaches in evaluating the system's performance. The measurement models help the firms to evaluate its sustainable performance and provide scope for further performance enhancement.

Research study	Research insights
Ren *et al.* (2006)	Analyzed the environmental impacts of an automotive industry by assessing the environmental impacts of automobile raw materials in production, consumer use stage, and in disposal stage. The study revealed that on proper adoption of the sustainable principles production of automobiles will increase rapidly by saving energy, reducing pollution, and creating a sustainable automotive environment
Fore and Mbohwa (2010)	Demonstrated a case of applying of cleaner production concept to include environmental protection into business performance. A case was conducted at a foundry that had negative impact on environmental performance. Study revealed that cleaner production approach provides clear guidance and managerial decision-making in environmental policy formulation
Miller *et al.* (2010)	Applied the principles of sustainability on a furniture production company with the aid of discrete event simulation modeling and analysis and mathematical optimization to create a positive effect on the environment, society and its own financial success. The results found that sustainable manufacturing has more significant and positive impact on multiple measures of operational performance on parallel deployment
Chuang and Yang (2014)	Proposed a three-layer assessment model to evaluate the performance of a green-manufacturing system (GMS) and identified key success factors for successful implementation. The proposed model was demonstrated by evaluating three companies that produce similar products and share similar business models
Alkaya and Demirer (2014)	Investigated the applicability of sustainable production measures and their impact on environmental and economic performance of a fabric manufacturing firm. After implementing the sustainability measures, the firm experienced reduction in water and energy consumption, greenhouse gas emissions and salt consumption. It also helped the firm to produce high quality textile products thus achieving an environmentally benign production

Table XV.
Reported applications of sustainable manufacturing

- Majority of the discussed sustainable decision-making models enable the improvement of the sustainability performance of the firm and also provide managerial implications. The developed decision-making models and frameworks helped the decision-makers in finding the most influential factors that affect sustainability performance and also help in selecting the best possible model for improving green performance and sustainability aspects.
- As the demand for green products increase considerably, there exists a need for product developers to generate sustainable products, which satisfy both ecological and social needs. Sustainable product development also improves firm's competitive performance by developing and producing green products and adopting sustainability aspects in their manufacturing processes.
- Sustainability principles are applied in various types of industries and sectors based on their application. Based on the applications discussed by the researchers, it is evident that the implementation of sustainability principles enhances environmental, social and economic performance of the firm and the concepts can be deployed in varied sectors to yield sustainable benefits.

6.3 Insights on integrated lean sustainable manufacturing

- Based on the above discussions and research studies reported by the researchers, the integrated lean sustainable manufacturing system can be defined as a system that creates value for the customers by eliminating wastes consistently and by

Research study	Research insights
Larson and Greenwood (2004)	Discussed briefly about the principles of lean and sustainable manufacturing. Also, discussed how sustainable manufacturing approach help in lean production and also emphasized the advantages of an integrated lean eco-sustainable manufacturing system
Langenwalter (2006)	Extended the concepts and principles of lean manufacturing into sustainable manufacturing in a broader perspective and described how lean principles satisfy sustainability needs. Developed a strategy on deciding whether to implement or not to implement sustainability based on firm's cost, paybacks and risks
Dakov and Novkov (2007)	Developed a set of indicators to evaluate the lean production impact on sustainable industrial enterprise development. The developed indicators respond to modern trends of performance measurement system and provided right measures for lean production effect on sustainability
Herrmann *et al.* (2008)	Investigated the relationship among lean manufacturing practices, environment management system and business performance. Study revealed that lean manufacturing experiences are positively associated with environmental management system with good business performance out comes
Koranda *et al.* (2012)	Explored the application of lean and sustainability principles in a construction project. They identified the sources of wastes that exists in a construction project and described how sustainability concepts would help in reducing the wastes. They concluded that wastes can be reduced considerably by integrating lean concepts with sustainability principles and also the integrated approach improves environmental performance of construction projects
Kováčová (2013)	Discussed the differences and similarities between lean and sustainable manufacturing principles. They analyzed the gradual extension of lean concepts to sustainability and also discussed how lean tools such as 5S, SMED and Kanban can improvise the environmental performance of the organizations
Verrier *et al.* (2014)	Proposed a framework that includes a set of green intention indicators, green performance indicators and lean indicators that includes environmental and social dimensions to the consideration of economic benefits generated through lean concepts. This framework helped in finding the best lean and green practices to make the firm more competitive
Chiarini (2014)	Developed a general model for lean production which emphasizes greening of the production processes. The environmental impacts of the production processes of five organizations were observed before and after the deployment of five lean tools namely SMED, 5S, cellular manufacturing VSM and TPM. Results proved that the companies experienced better environmental performance after implementing the lean tools. It also had a positive impact on electricity consumption, standardization of activities and worker behavior
Prasad *et al.* (2016)	Investigated the applicability of lean and sustainability practices to foundry industry for improving productivity and eliminating waste by incorporating sustainability into business performance measures. Results proved that lean practices are positively and moderately interrelated with sustainability practices and improves both organizational and green performance of foundry industries

Table XVI.
Research studies on integrated lean sustainable manufacturing

adopting processes that are ecofriendly, economically viable and safe for the employees to produce green products that enhance the social performance thus facilitating flow.

- Though there are separate tools and techniques existing for deploying lean and sustainable manufacturing principles, researchers discussed certain dedicated tools that are needed for implementing an integrated lean sustainable manufacturing system. Based on the recommendations and studies reported by the researchers, tools needed for an integrated lean sustainability system include lifecycle management, product design and development, facilities management, poka-yoke,

design for environment, 5 why analysis, eco-efficiency analysis, autonomation, lifecycle assessment, integrated product policy, 7S, sustainable VSM, green layouts, green procurement, etc. More advanced tools and techniques enabling lean sustainability are being developed and will be widely used in future.

- Based on the literature, it is evident that very few decision-making models are available for integrated lean sustainable manufacturing. The integrated lean sustainable decision-making models help the decision-makers in arriving right decisions pertaining to lean sustainability and also help in choosing the appropriate tools and techniques needed for enhancing the system's lean and green performance.
- The researchers have proposed and modeled various performance measurement and evaluation models to assess the performance of lean and sustainable systems separately. However, very few research has been carried out for evaluating the performance of integrated lean sustainable manufacturing system. Based on the discussions, some of the indicators for assessing the performance of integrated lean sustainable system include recyclability and remanufacturability, waste reduction rate of production facilities, JIT delivery to customers, inline energy consumption, energy consumption for transportation, usage of TQM tools, lifecycle global warming potential, community and social cohesion, customer response adoption, reverse logistics and supplier management, integrated product design, environmental impact, etc.
- Though the application of integrated lean sustainable manufacturing has not been EXPLORED much, this approach can be applied to several industrial sectors. Manufacturing sectors extract maximum benefit on successful implementation.

7. Conclusions and future research directions

Lean manufacturing principles enables manufacturing and service organizations to attain competitiveness and creates opportunities to sustain in the volatile markets. To achieve this, practitioners must create an obvious understanding about the core principles, selection and application of suitable tools of lean manufacturing and its deliverables. A sustainable manufacturing system aims at fulfilling the needs of the present without the compromise of ability future generations to meet their own needs. The modern manufacturing firms have been adopting both lean and sustainable manufacturing paradigms to sustain in the competitive landscape. The focus of this research is to consolidate the existing knowledge on lean and sustainable manufacturing to provide an insight on various perspectives. This article presents a review of the literature on lean manufacturing and sustainable manufacturing. A total of 80 articles have been reviewed and inferences have been presented. The literature review has been done in seven different perspectives, namely, origin, definition, decision-making, performance measurement, product development, applications and integrated lean sustainable manufacturing. This research also investigates the need for integrated lean sustainable manufacturing and recognized through review of few studies. Insights for integrated lean sustainable manufacturing approach has been presented. Also, this study contributed a brief overview on several aspects of lean and sustainable manufacturing inferred from the literature and will be useful for both beginners and middle-level managers to understand the concepts of lean and sustainable manufacturing from different perspectives. In future, the review can be enhanced by exploring more

perspectives and scope exists for creation of integrated framework of lean and sustainable manufacturing that offers operational improvements. The implication of the study is that it helps organizations that are in the initial stages of implementing lean and sustainable manufacturing concepts by providing necessary knowledge and ensures them a hurdle-free implementation journey. The limitation of this study is that though several insights for integrated lean sustainable manufacturing are being identified, a comprehensive framework encompassing these insights needs to be developed and tested with reference to industrial settings as a future work. The insights gained based on the perspectives are not conclusive as the research expands and diverge, and more critical outcomes are expected to occur that lead to varied future research directions.

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