

# Identification of Some Major Research Gaps in Lean Manufacturing and Industry 4.0 Integration

Sisitha Rajapaksha<sup>1#</sup>, P. G. S. Amila Jayarathne<sup>2</sup>, Sandamali Galdolage<sup>3</sup>

<sup>1#</sup>University of Sri Jayewardenepura, Sri Lanka, [sisitharajapaksha@gmail.com](mailto:sisitharajapaksha@gmail.com)

<sup>2</sup>University of Sri Jayewardenepura, Sri Lanka, [amilaj@sjp.ac.lk](mailto:amilaj@sjp.ac.lk)

<sup>3</sup>University of Sri Jayewardenepura, Sri Lanka, [sandamali@sjp.ac.lk](mailto:sandamali@sjp.ac.lk)

**Abstract** - In the contemporary business world, digitalization has become a significant factor in economic development. Lean is a prominent topic in both academia and business. Due to the evolution of digital technologies that promote Industry 4.0 because of the industrial revolution, the integration of Lean Manufacturing and Industry 4.0 has attracted the attention of academics and managers. This conceptual paper discusses the integration of Lean Manufacturing and Industry 4.0, as well as the research gaps and prospective research opportunities related to integration. Systematic Literature Review (SLR) in the PRISMA framework has been used to identify research gaps, and future studies could be planned to close these gaps to benefit academia and industry stakeholders. Keyword co-occurrence analysis has been performed using VOSviewer software to identify areas that need the attention of researchers. Articles were extracted from the Scopus database using the keywords "Lean Manufacturing" and "Industry 4.0". This study concentrates on identifying research gaps that industry leaders and managers would be interested in, rather than the gaps in conceptual nature.

**Keywords:** Industry 4.0 and Lean Manufacturing.

## I. INTRODUCTION

The manufacturing sector makes a substantial contribution to a nation's gross domestic product, so it is pertinent to examine how lean and digitalization can aid the manufacturing sector's success. The fourth industrial revolution will alter the landscape of manufacturing, and those who are unable to capitalize on the new technological opportunities will fall behind their competitors (Buer et al., 2018). In the last two decades, Lean manufacturing has been the most prominent strategy for enhancing the operational performance of manufacturing companies by eliminating waste in all its forms and concentrating on activities that create customer value (Buer et al., 2018). At the core of the Lean approach are the principles of continuous improvement, including employees and teamwork, as well as waste reduction, and at the top are the goals of better quality, lowest possible costs, shortest cycle time, highest employee safety, and highest employee motivation (Rosin et al., 2019). Lean manufacturing has aided numerous businesses in reducing waste and thereby enhancing performance in a variety of areas (Buer et al., 2018).

Industry 4.0 aspires for an autonomous and dynamic production that integrates Information and Communication Technologies (ICT) to facilitate the mass production of highly customized goods (Tortorella & Fettermann, 2017). This allows the entire factory to be connected to a network, creating an intelligent environment (Ejsmont et al., 2020). It is necessary to analyze the impact of the combination of Lean Manufacturing and Industry 4.0 on the outcomes of organizations and the impact of external factors on the relationship between these two concepts. There are digital technologies within Industry 4.0 that are transforming manufacturing organizations. The combination of Lean and Industry 4.0 is a set of digitalization-based strategies for increasing resource efficiency, reducing the environmental impact of wastes, and boosting productivity (Hines et al.,

2023). The German government developed Industry 4.0 for the advancement of the industrial sector. The current revolution is the Fourth Industrial Revolution, which is characterized by the development and application of Information Technology (IT) in the manufacturing sector. Cyber-Physical System (CPS), Internet of Things (IoT), cloud computing, and big data analytics are the most important instruments for Industry 4.0 (Vinodh et al., 2020). Industry 4.0 technologies and concepts must be integrated with continuous improvement strategies to maximize the use of available resources (Buer et al., 2018). Lean principles and Industry 4.0 technology are interconnected. Industry 4.0 technologies influence value creation. Cyber Physical System (CPS), Big Data analytics, IoT and artificial intelligence (AI) are the technologies of Industry 4.0. Several advantages of integrating lean principles and Industry 4.0 are the enhancement of equipment flexibility, the replacement of complex decision-making with real-time decision-making, the modularization of the production system, and the improvement of process efficiency (Vinodh et al., 2020). Industry 4.0 is a new industrial paradigm fuelled by disruptive technologies that have the potential to transform manufacturing into a cyber-physical system that integrates products, people, and processes. Existing lean manufacturing (LM) systems provide little guidance on how to implement and integrate Industry 4.0 technologies (Vlachos et al., 2021).

## **II. RESEARCH PROBLEM**

Review of literature reveals that research on the relationship between industry 4.0 and Lean manufacturing is still in its infancy (Narkhede et al., 2022). According to Skalli et al. (2023), there are few case studies verifying and validating the proposed frameworks for the integration of Lean and Industry 4.0. There are empirical gaps in the integration of industry 4.0 and lean manufacturing, according to numerous studies on the subject. There is no comprehensive integration framework for these two concepts. In addition, the literature emphasizes the need to comprehend how these concepts interact. No comprehensive systematization of extant knowledge exists in this field. As both industry 4.0 and lean manufacturing share the objective of increasing manufacturing productivity, there has been considerable confusion in industry and debate in the academic literature regarding the compatibility of the two strategies. Therefore, it is pertinent to review the existing literature to identify some major research gaps and provide directions for future research, particularly in the context of Sri Lanka.

## **III. RESEARCH OBJECTIVES**

This paper has the following objectives:

1. To discuss prevailing knowledge on Lean Manufacturing, Industry 4.0 and Integration of Lean Manufacturing and Industry 4.0.
2. To explore key studies on Integration of Lean and Industry 4.0.
3. To present some research gaps in connecting Lean Manufacturing and Industry 4.0.

## **IV. REVIEW OF RELEVANT LITERATURE**

The fusion of Lean and Industry 4.0 or digital transformation is a relatively new concept in academic circles, and it is not extensively discussed currently. Future research should also concentrate on bibliometric studies or literature reviews on the integration of Lean Six Sigma and Industry 4.0 to visualize scholarly activity and trends and to emphasize the significance and impact of integrating both principles on organizations (Alsadi et al., 2023).

It has not been studied how the introduction of Industry 4.0 will impact well-established management practices such as lean manufacturing, nor how lean manufacturing will impact the implementation of Industry 4.0 (Buer et al., 2018). Links between Industry 4.0 technologies and Lean principles have not been formalized from a research standpoint. (Rosin et al., 2019). Literature correlating Lean Production and Industry 4.0 is scant and only implies a positive relationship between these approaches, without empirical testing. Tortorella and Fettermann (2017) report a dearth of studies that empirically investigate the relationship between a successful lean implementation and the progression into Industry 4.0 in manufacturing companies from emerging economies. (Ejsmont et al., 2020) It is necessary to analyze the impact of the combination of Lean Manufacturing and Industry 4.0 on the outcomes of organizations, as well as the impact of external factors on the relationship between these two concepts.

Industry 4.0 and its associated technologies are increasingly portrayed as indispensable for enhancing the productivity of manufacturing companies. By emphasizing immediate communication between machines and objects, it is possible to make manufacturing systems more adaptable to product modifications and responsive to unanticipated occurrences. A consensus has not yet been reached on the definition of Industry 4.0 (Rosin et al., 2019).

Lean is a philosophy that helps organizations establish a culture of continuous improvement by eliminating waste and minimizing resource consumption. Industry 4.0, on the other hand, is a complex high-tech paradigm that contributes to the development of flexible organizations using various technologies, including IoT, cloud computing, blockchain, virtual reality, and artificial intelligence. The concept of incorporating Lean Principles and Industry 4.0 is still very new and limited, and there is no bibliometric perspective in the literature (Alsadi et al., 2023). The literature lacks both theoretical models that combine Lean and Industry 4.0 as well as quantitative case studies or empirical research results (Ejsmont et al., 2020).

## **V. KET STUDIES IN LEAN MANUFACTURING AND INDUSTRY 4.0 INTEGRATION**

Kolberg and Zuhlke (2015) have suggested that a framework is necessary for integrating Industry 4.0 and lean principles, and it is necessary to investigate this in depth. To determine the condition of a machine, Li et al. (2016) have developed a framework that is pertinent only to maintenance activities. They have not included techniques for supplying solutions for detected errors.

According to Dogan and Gurcan (2018), additional research is required to effectively implement this concept and validate the results. According to Bittencourt et al. (2020), there is more work to be done on this topic, namely how Lean enables Industry 4.0. Integration of Lean and Industry 4.0 has been studied by Ciano et al., 2020, which suggests that additional research is required to further validate the framework, extend it to other geographical and industrial contexts, and empirically test all the hypothesized relationships in a larger, more heterogeneous, and statistically significant sample. Moreover, once the relationships are validated, it is necessary to comprehend their impact on performance, a crucial aspect that can assist businesses in understanding the significance and quantifiable benefits of practices or technologies.

According to Narkhede et al. (2022), Industry 4.0 and Lean require extremely agile and risk management configurations to address compatibility issues and rapidly changing business environments. In addition, the authors propose enhancing the

interoperability between Industry 4.0 and lean to reduce automation waste and unleash the potential advantages of Industry 4.0 technologies. In addition, the authors note that the integration of Lean and Industry 4.0 necessitates additional research and innovation regarding their influence and degree of technological intensity or transformation within manufacturing organizations.

Most of the existing literature on integrated approach, according to Chiarini and Kumar (2020), is either conceptual or employs surveys to explain the relationship between Lean and Industry 4.0. Further, they have mentioned that the integration of Lean Manufacturing and Industry 4.0 needs to be performed with the help of mapping tools such as Values Stream Mapping. According to Vlachos et al., 2021, the introduction of 5G mobile networks could reshape the manufacturing cyberspace and the interactions between IoT and AGVs. According to their action plans, performance objectives, and physical constraints, managers should evaluate available technologies.

Buer et al. (2020) have studied the integration, which reveals that the most recent trend manufacturers have adopted to enhance operational performance is the use of a vast array of digital technologies commonly associated with Industry 4.0. However, few studies have investigated the relationship between such technologies and the well-established lean manufacturing domain, and how they affect operational performance in conjunction. Recently, the technology-driven Industry 4.0 concept has been marketed as the next performance enhancement enabler.

There are few studies investigating this issue in the context of a developed nation, and the role lean manufacturing will play in this new industrial era of digitalization is an important topic to investigate. In addition, the authors note that future research will focus on measuring what a successful Industry 4.0 and lean manufacturing integration entails and comparing the performance impacts to those of a 'pure' Industry 4.0 or lean manufacturing system. The authors have also mentioned that the immaturity of this research field is a natural explanation for why no implementation framework for the integration of Industry 4.0 and lean manufacturing has been published.

Tortorella et al. (2020) conducted a study on the integration of Lean and Industry 4.0 and identified several empirical research gaps. According to them, the primary Industry 4.0 technologies could be linked to Lean Production practices, but scant empirical evidence was presented to support these claims. Also, some research needed to empirically demonstrate the impact of the combined implementation of Lean and Industry 4.0 on operational performance. In addition, they have stated that Industry 4.0 is a new operations management paradigm that must be unveiled. In this context, one of the most pressing issues is how to incorporate such disruptive technologies into well-established management strategies, such as Lean, to address the current organizational challenges. Rosin et al. (2019) notes that, from a research standpoint, no formalized connections exist between Industry 4.0 technologies and Lean principles. Validating the effect of Industry 4.0 technologies on industrial systems would be a pertinent research perspective

According to Skalli et al. (2023), there is a paucity of case studies testing and validating the proposed frameworks for Lean and Industry 4.0. In addition, there are several performance measurement KPI evaluation discrepancies. In addition, they noted that there are no studies discussing the applications of Lean and Industry 4.0 for small and medium-sized businesses. The preponderance of research on this topic has been conducted in developed nations, and there are no studies discussing the drivers and barriers to implementing these concepts.

In addition, the authors have identified specific integration deficiencies. Advance research in the use of Industry 4.0, digital transformation to model production chains, exploration of application of big data with other Industry 4.0- related technologies, examination of how to create new digitalization culture centered on big data, gaining and insight on how big data and advanced technology analytics can improve operational excellence, and conducting empirical research to investigate the potential support of Industry 4.0 in promoting operational excellence are some of the deficiencies.

Tortorella & Fettermann (2017) have revealed that empirical studies examining the relationship between a successful lean implementation and the progression into Industry 4.0 in manufacturing companies in emerging economies are scarce.

Literature correlating Lean and Industry 4.0 is scarce and only implies a positive relationship between these approaches, without empirical testing. Their investigation has empirically confirmed the link between Lean implementation and Industry 4.0 and the enhancement of operational performance.

Due to the paucity of evidence in the literature regarding the likelihood of any interdependent influence, additional sampling of businesses would be required to establish a more comprehensive understanding of the issue. Such an expansion would necessitate a more intricate data acquisition and analysis procedure.

According to Alsadi et al. (2023), to motivate organizations to successfully integrate Lean and Industry 4.0, it is necessary to investigate the potential performance implications. However, there are no available studies that present evaluations of organizational performance based on the proposed framework. There is a dearth of articles that propose a generic framework for evaluating Lean and Industry 4.0 adaptation by professionals in any industry. In addition, the lack of actual case studies is one of the most significant scientific gaps. Another lacuna in the literature is the absence of empirical studies on the integration of Lean and Industry 4.0. In addition to the manufacturing sector, the integration of Lean and Industry 4.0 and its impact on other sectors such as healthcare, higher education, and the service industry are briefly discussed in the literature.

According to Ejsmont et al. (2020), even though Industry 4.0 is one of the most frequently discussed topics among practitioners and academic teachers over the past few years, no single, widely accepted definition of this concept has been developed. Furthermore, Ejsmont et al. (2020) emphasized that the literature on Lean and Industry 4.0 integration is inconsistent. In addition, it is necessary to analyze the effect of the combination of Lean and Industry 4.0 on the outcomes of organizations, as well as the effect of external factors on the relationship between these two concepts. Additionally, it would be intriguing to investigate the obstacles and contradictions that influence the synergy between Industry 4.0 and Lean.

Moreover, according to Hines et al., (2023), the performance effects of integration, the development of conceptual models for integration, enablers, and barriers to integration, how to measure maturity, the role of people, and whether the approach is more applicable in certain industries are significant issues and research gaps in this area. Varela Et al., (2019) have studied the sustainability implications of the integration of Industry 4.0 and Lean Manufacturing.

## VI. METHODOLOGY

This paper used a systematic Literature Review (SLR) and PRISMA framework according to the method used in Dogra and Priyashantha (2023). This study explored key research efforts related to Lean Manufacturing and Industry 4.0. 59 research articles related to Lean Manufacturing and Industry 4.0 were downloaded using the Scopus database. Article selection was done using the PRISMA method with the keywords “Lean Manufacturing” and “Industry 4.0”.

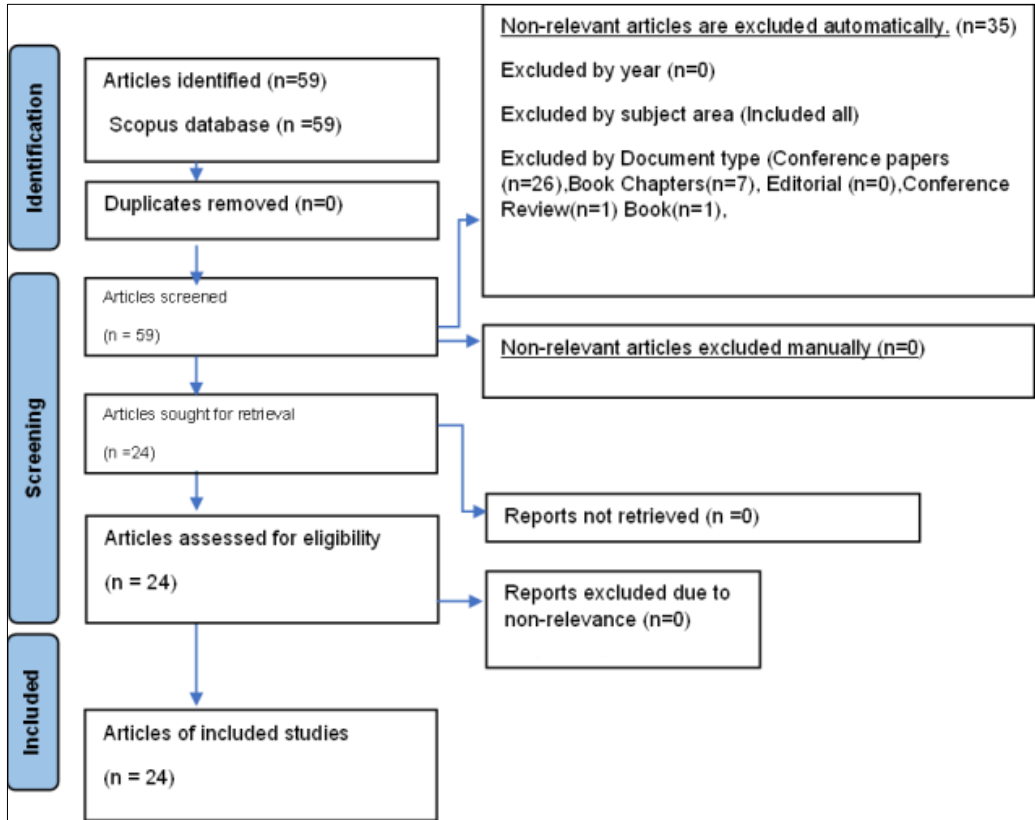
**Table 1. Review Protocol**

Article Selection Method	PRISMA guidelines
Search Strings	Industry 4.0, Lean Manufacturing
Inclusion Criteria	<ol style="list-style-type: none"> <li>1. Year range: All</li> <li>2. Subject area: All</li> <li>3. Language of article: English</li> <li>4. Keywords: Industry 4.0, Lean Manufacturing</li> <li>5. Source type: Academic Journals</li> <li>6. Type of Study: Literature Review</li> <li>7. Methodological quality: Articles that followed the quantitative methodology</li> </ol>
Databases	Scopus
Analysis Method	Keyword Co-occurrence Analysis
Reporting Structure	PRISMA guidelines
Search Strategies	*Industry 4.0* AND *Lean Manufacturing*

Source: Authors compilation based on PRISMA guidelines.

Articles have been selected based on the PRISMA methodology as follows. The PRISMA flow diagram indicates article Identification, Screening, Inclusion, and Exclusion criteria.

**Figure 1. PRISMA Article Selection Flow Diagram**

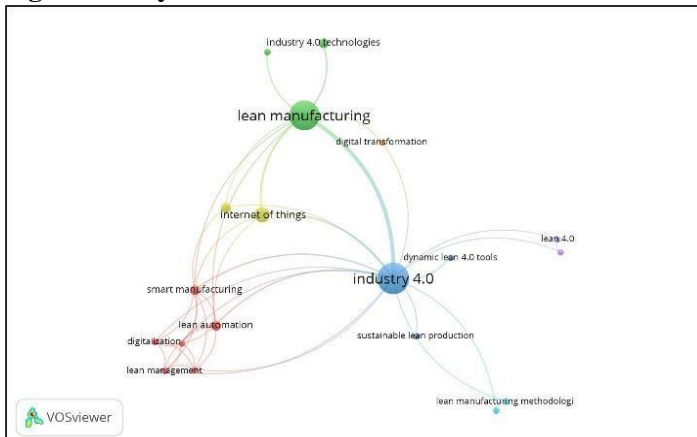


Source: Authors' compilation.

## VII. DATA ANALYSIS

VOSviewer (Version 1.6.19) software has been used as explained in Dogra and Priyashantha, (2023). Keyword co-occurrence analysis has been used to generate results. VOSviewer has grouped keywords into 7 clusters. Clusters have been indicated in different colors, which indicates that keywords in a particular cluster are connected.

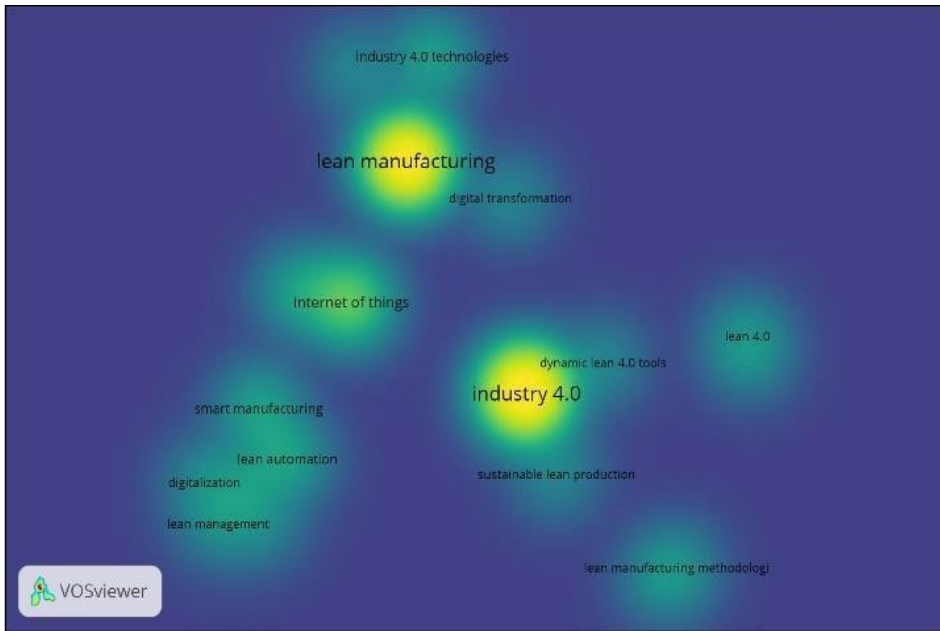
**Figure 2. Keyword Co-occurrence Network Visualization**



Source: VOSviewer Output.

Density visualization map of the keywords has been generated and it shows the extent of research conducted in areas indicated in different colours.

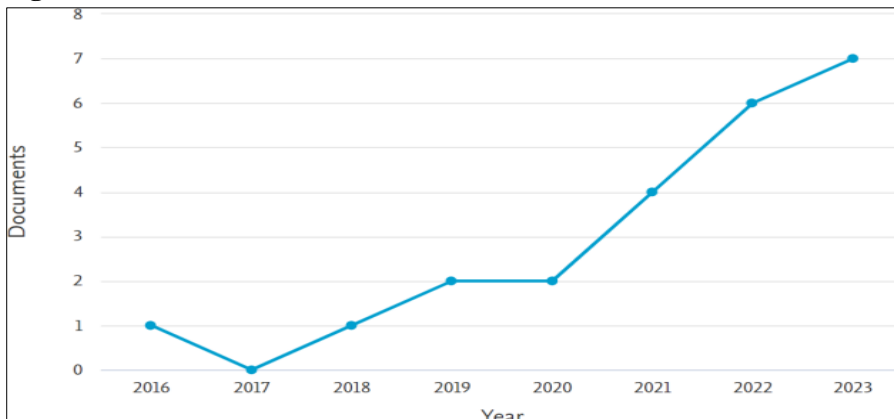
**Figure 3. Density Visualization Map of Key Words**



Source: VOSviewer output.

The density visualization map indicates that the keywords in the yellow and green area need to be researched more and the knowledge of the findings represented by such keywords is less since they have been researched in a smaller number of occasions. If the keywords are in a red color area, it shows that extensive research has been done in that area and sufficient knowledge is available (Dogra & Priyashantha, 2023). Therefore, more research can be conducted related to the keywords in the green areas. Further analysis has been performed using the Scopus database and the figure 03 illustrates the publication trend related to industry 4.0 and lean manufacturing.

**Figure 4. Publication Trend of Article**

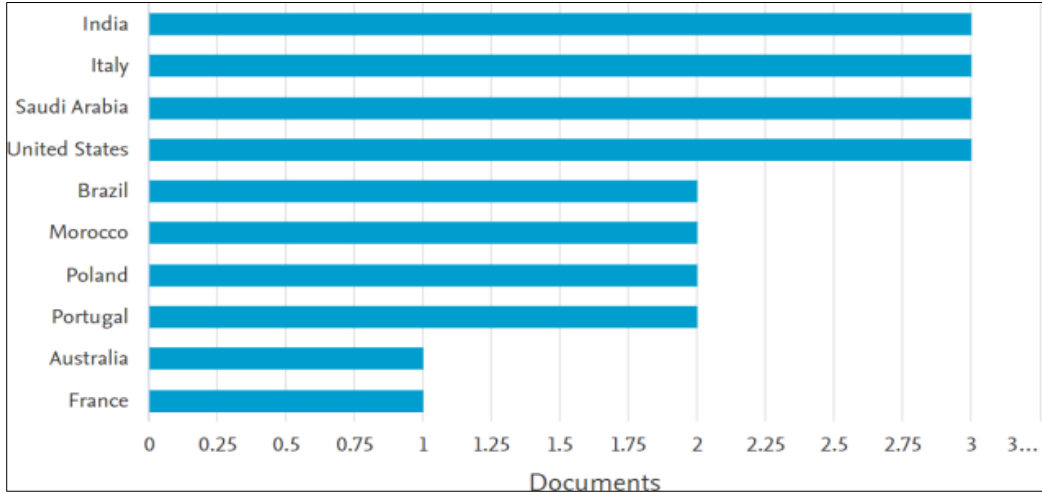




Source: Scopus Database.

This graph illustrates that there is an increasing trend in the publications related to industry 4.0 and lean manufacturing.

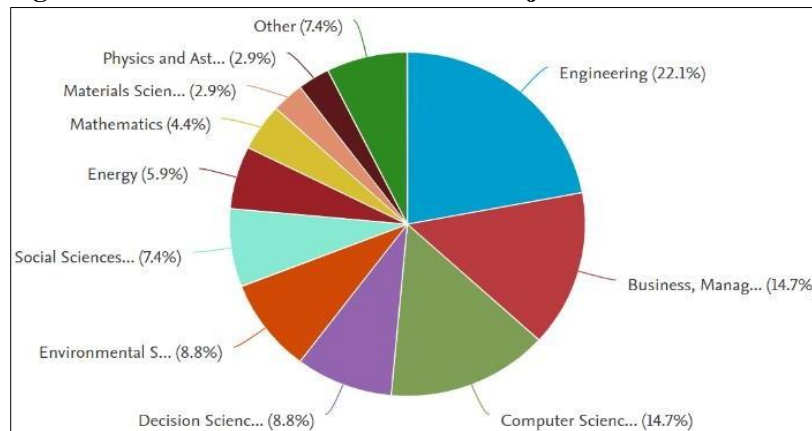
**Figure 5. Country Wise Publications**



Source: Scopus Database.

The above graph shows the publication rate for different countries.

**Figure 6. Publications from Different Subject Areas**



Source: Scopus Database.

Physics and Astronomy and Materials Science are the two least published subject areas for lean manufacturing and industry 4.0.

## VIII. RESULTS AND DISCUSSION

Table 02 shows a summary of research gaps identified in each of the articles selected for the study.

**Table 2. Summary of Articles and Major Research Gaps**

	Authors	Title	Research Gaps
1	Ionel R.D.S. Lamanna G.; Opran C.G.	Intelligent Link between Lean Manufacturing and the Cyber-Physical Industry 4.0 System	Defining and integration of Lean tools at the cyber physical level
2	Pamornma st C.; Sriyakul T. Jermstittipa rsert K.	Can lean manufacturing and the 4.0 industry enhance the financial performance of the pharmaceutical industries of Thailand? Mediating role of waste reduction behavior	Do not have access
3	Tardio P.R. Schaefer J.L.; Nara E.O.B. Gonçalves M.C.; Dias I.C.P. Benitez G.B. Castro e Silva A.	The link between lean manufacturing and Industry 4.0 for product development process: a systemic approach	Effect of Lean manufacturing and Industry 4.0 on Market Performance
4	Sartal A.; Llach J.; León- Mateos F.	Do technologies really affect that much? exploring the potential of several industry 4.0 technologies in today's lean Manufacturing shop floors	Sequential or simultaneous implementation of Lean Manufacturing and Industry 4.0.
5	Pereira C.; Sachidana nda H.K.	Impact of Industry 4.0 Technologies on Lean and Organization Performance	Only empirical method has been used. Different methodologies such as case studies and qualitative methods are to be used.
6	Fortuny- Santos J.; López P.R.- D.-A.; Luján- Blanco I.; Chen P.-K.	Assessing the synergies between lean manufacturing and Industry 4.0	Lack of real implementations of lean manufacturing and Industry 4.0 integration
7	Huang Z.; Jowers C.; Kent D. Dehghan Manshadi A. Dargusch M.S.	The implementation of Industry 4.0 in manufacturing from lean manufacturing to product design	Lack of standardized frameworks for integrating and analyzing multiple types of data collected from legacy non-interfaced equipment in SMEs.  Difficulty in accurately assessing leanness in production systems due to the

Authors	Title	Research Gaps
		complexity and conflicting objectives of these systems.
		Limited availability of ideal indicators that can accommodate every system perfectly, leading to subjective assessments of leanness.
		Overestimate on of leanness levels in manufacturing systems
		Need for more accurate and intuitive measures of leanness that consider input excesses and output shortfalls, such as the slacks-based measure (SBM). Integrating legacy machinery, assessing leanness, and developing accurate measures of leanness in the context of Industry 4.0 implementation on in manufacturing g.
8	<p>Ciliberto C.; Szopik- Depczyńska K. Tarczyńska- Łuniewska M. Ruggieri A. Ioppolo G.</p> <p>Enabling the Circular Economy transition: a sustainable lean manufacturing recipe for Industry 4.0</p>	<p>Lack of clear research definition for lean-green manufacturing</p> <p>Need for practical business-oriented strategies for sustainable production paths</p>
9	<p>Ghouat M. Benhadou M. Benhadou B. Haddout A.</p> <p>Assessment of the Potential Impact of Industry 4.0 Technologies on the Levers of Lean Manufacturing in Manufacturing Industries in Morocco</p>	<p>Implementation on of technologies on other activities other than ERP systems.</p>

	<b>Authors</b>	<b>Title</b>	<b>Research Gaps</b>
10	Ghaithan A.; Khan M. Mohammed A. Hadidi L.	Impact of industry 4.0 and lean manufacturing on the sustainability performance of plastic and petrochemical organizations in Saudi Arabia	Lack of research on the integrated impact of Industry 4.0 technologies and lean manufacturing principles on sustainability performance.  Scarcity of information on the implementation of Industry 4.0 technologies in the plastic and petrochemical industries.
11	Vlachos I.P. Pascazzi R.M. Zobolas G. Repoussis P. Giannakis M.	Lean manufacturing systems in Industry 4.0: A lean automation plan of AGVs/IoT integration	Do not have access
12	Ghouat M. Handout A. Benhadou M.	Impact of Industry 4.0 Concept on the Levers of Lean Manufacturing Approach in Manufacturing Industries	Do not have access
13	Cimini C.; Lagorio A. Gaiardelli P.	The evolution of operators' role in the production: How Lean Manufacturing and Industry 4.0 affect Job Enlargement and Job Enrichment	The effect of lean manufacturing and Industry 4.0 on the operator's long-term performance can be analyzed.
14	Pagliosa M. Tortorella G. Ferreira J.C.E.	Industry 4.0 and Lean Manufacturing: A Systematic Literature Review and Future Research Directions	Need for further investigation into the relationship between Industry 4.0 (I4.0) technologies and Lean Manufacturing (LM) practices, as there are still research gaps in this area.  The systematic literature review conducted in the paper identifies the synergies between I4.0 technologies and LM practices but suggests the need to validate. These proposed synergies and examine their effects on operational performance.

Authors	Title	Research Gaps	
15	Ramadan M.; Salah B. Othman M. Ayubali A.A.	Industry 4.0-based real-time scheduling and dispatching in lean manufacturing systems	<p>Most of the developed scheduling models in lean manufacturing are buried in mathematical treatments with unrealistic assumptions, making them inappropriate and impracticable in the production shop floor (PSF). Scheduling research needs to shift its focus to real-time and smart scheduling and product-flow optimization. There is a need for oreattention to be given to the conflicts between commands generated based on different real-time lean control rules (RT- LCRs) and ensuring their perfect coordination.</p>
16	Maware C.; Parsley D.M., II	Can Industry 4.0 Assist Lean Manufacturing in Attaining Sustainability Time? Evidence from the US Organizations	<p>Overall, the research gaps in this area include the need for more practical and realistic scheduling models, real-time and smart scheduling approaches, coordination of commands based on different RT-LCRs, addressing overlapping RFID readings, and exploring big data applications in lean manufacturing. No study on the specific impact of Lean</p> <p>No exploration of incorporation of Industry 4.0 technologies in different industries</p>
17	Rahardjo B.; Wang F.-K.; Yeh R.H. Chen Y.-P.	Lean Manufacturing in Industry 4.0: A Smart and Sustainable Manufacturing System	<p>There are few studies on the application of Smart and Sustainable Manufacturing Systems (SSMS) using Industry 4.0 technologies and Lean Manufacturing tools.</p>

Authors	Title	Research Gaps
18	Kamble S.; Gunasekar A.; Dhone N.C. Industry 4.0 and lean manufacturing practices for a sustainable organisation and its performance in Indian manufacturing companies	<p>More applications of Dynamic Lean 4.0 tools in SSMS should be explored.</p> <p>The relationship between Lean Manufacturing and Industry 4.0 technologies needs further research.</p> <p>The industry 4.0 and Lean manufacturing principles on corporate performance is an area that requires more investigation. The impact of Lean Manufacturing and Industry 4.0 on organizational performance is rarely investigated in real case studies.</p> <p>Overall, the research gaps in this study include the need for more studies on SSMS, exploring the application of Dynamic Lean 4.0 tools, understanding the relationship between Lean manufacturing technologies, and investigating the impact of these approaches on organizational performance</p> <p>The research gaps addressed in this study include the lack of empirical investigation on the integrated effects of Industry 4.0 and Lean Manufacturing Practices on SOP, as well as the need to identify Industry 4.0 as an enabler of Lean Manufacturing Practices for enhancing SOP.</p>

	<b>Authors</b>	<b>Title</b>	<b>Research Gaps</b>
19	Medyński D. Bonarski P.; Motyka P. Wysoczański A.; Gnitecka R. Kolbusz K. Dąbrowska M. Burduk A.; Pawelec Z. Machado J.	Digital Standardization of Lean Manufacturing Tools According to Industry 4.0 Concept	Not available
20	Ghaithan A.M. Alshamma khi Y.; Mohammed A. Mazher K.M.	Integrated Impact of Circular Economy, Industry 4.0, and Lean Manufacturing on Sustainability Performance of Manufacturing Firms	Integrated impact of circular economy, industry 4.0, and lean manufacturing on sustainability performance not adequately addressed.  Manufacturing firms lagging in environmental and sustainability performance. The paper highlights the gap in perceiving the potential of executing lean manufacturing within the realm of Industry 4.0.
21	Sanders A. Elangeswaran C.; Wulfsberg J.	Industry 4.0 implies lean manufacturing: Research activities in Industry 4.0 function as enablers for lean manufacturing	The integration of lean manufacturing and Industry 4.0 is an important research field that needs further exploration.  Independent research in various fields related to Industry 4.0 holds the potential for solutions to barriers in implementing lean manufacturing, even if the primary focus of the research is different.  The challenges faced by factories in implementing lean due to a lack of resources

Authors	Title	Research Gaps
22 Kumar N.; Singh A.; Gupta S.; Kaswan M.S. Singh M.	Integration of Lean manufacturing and Industry 4.0: a bibliometric analysis	Overall, the research suggests that there is a need for further investigation and exploration understand and leverage the potential of integrating lean manufacturing and Industry 4.0.  No keyword co-occurrence analysis has been performed
23 Buer S.-V.; Strandhage n J.O.; Chan F.T.S.	The link between industry 4.0 and lean manufacturing: Mapping current research and establishing a research agenda	Limited studies investigating the link between Industry 4.0 and lean manufacturing g. Insufficient research on impact of Industry 4.0 on ‘soft’ lean practices.  Lack of implementation framework for integrating Industry 4.0 and lean manufacturing. Need for more in understanding of how Industry 4.0 and lean manufacturing interact.  Limited empirical research on the actual performance benefits of an integrated Industry 4.0 and lean manufacturing solution.  Call for synthesizing the knowledge into an implementation framework.  Potential for exploring findings from studies on earlier Technological shifts to support research on Industry 4.0.



	Authors	Title	Research Gaps
24	Varela L.; Araújo A.; Ávila P.; Castro H.; Putnik G.	Evaluation of the relation between lean manufacturing, industry 4.0, and sustainability	The social dimension of sustainability in the context of Industry 4.0 and Lean manufacturing

Source: Authors' compilation.

In summary, below major types of research gaps (Knowledge gaps, Empirical gaps, and Contextual gaps) have been identified during this unique research effort.

**Empirical Gaps** - The need for more empirical investigations between Lean manufacturing and Industry 4.0 providing insights to implementers and managers in the industry to gain confidence in cope up with digitalization challenges that they face in the digital era. The lack of case study-type research has been identified as one of the critical gaps since it will provide feedback related to real-world scenarios. Area to investigate as it cannot be neglected since machines have limited capabilities compared to humans. Moreover, managers in the industry would like to know, from research perspective, what would happen to human factor in implementing digital systems which comes with Industry 4.0 and its consequences on humans.

**Contextual Gaps** – According to the country-wise data analysis, very few countries have performed the research related to this area, and the lack of research related to the integration of Industry 4.0 and Lean Manufacturing in the Sri Lankan context is another significant gap found in this study.

## IX. CONCLUSION

As a consequence of a comprehensive literature review, significant research gaps relating to the integration of Lean Manufacturing and Industry 4.0 were identified. During this endeavor, all research objectives were attained. Integration of Lean Manufacturing and Industry 4.0 is a relatively new topic that requires more attention from academicians and industry managers. The manufacturing industry is undertaking a significant technological transformation, making it imperative to evaluate the implementation concerns and challenges associated with incorporating Industry 4.0 into an existing Lean Manufacturing system. Efforts involving empirical research and case studies in this area will undoubtedly yield immense benefits for all parties involved, especially the managers in the Knowledge Gaps - There is a need for further validation of the integration framework to provide directions to industry audiences to assess their readiness to integrate Lean Manufacturing and Industry 4.0 minimizing the risk of failure. Performance implications of Lean Manufacturing and Industry 4.0 integration need to be researched further to provide insights to the industry in such a way that they can perform a cost-benefit analysis in implementing and integrating Lean Manufacturing and Industry 4.0. Enablers, barriers and challenges in Lean Manufacturing and Industry 4.0 integration need to be investigated further to provide managers who implement these concepts on the shop floor in the industry with the required prior knowledge so that they can anticipate the reality. Human factor in implementing Industry 4.0 in a Lean Manufacturing environment would be a critical industry that implement these concepts in the real world. Future research on the integration framework is urgently required to attain a comprehensive understanding of the issue at hand.

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