INTERNATIONAL JOURNAL OF RESEARCH CULTURE SOCIETY
Monthly Peer-Reviewed, Refereed, Indexed Journal
Volume - 8, Issue - 12, December - 2024
ISSN(O): 2456-6683
[Impact Factor: 9.241]
IJRCS

DOIs:10.2017/IJRCS/202412029 --:-- Research Paper / Article / Review

Synergizing Lean manufacturing and Theory of Constraints in the Era of Industry 4.0

[1]Jigmet Yangchan, [2]Munish Baboria

[1] B. Tech Student, Mechanical Engineering Department, G.C.E.T, Chak Bhalwal, Jammu, India
[2] Assistant Professor, Mechanical Engineering Department, G.C.E.T, Chak Bhalwal, Jammu, India
Email – [1]munishb.me.21@gmail.com, [2]jimmy2781320@gmail.com

Abstract: *The manufacturing sector is experiencing an unprecedented surge in demand, driving the need for innovative, cost-effective production methods. As competition intensifies, manufacturers are under pressure to adapt and transform their processes to mitigate global circumstances. The situation has become more challenging in presence of various constraints such as limited resources, equipment capacity, and manual processes which hinder a facility's operational capacity. It a crucial time for managers to identify and address these constraints to enhance productivity and profitability. In this regard, Lean manufacturing offers a solution, focusing on waste elimination, process optimization, and continuous improvement. This approach aligns with Industry 4.0's goals of promoting smart manufacturing, efficiency and flexibility. The merger of lean manufacturing, Industry 4.0 and the theory of constraints provides a holistic solution to navigate modern manufacturing complexities. By leveraging advanced technologies, engaging employees, and adopting a data-driven mindset, manufacturers can enhance productivity and efficiency. This research paper targets to explore novel opportunities in merging lean manufacturing strategies with industry 4.0, analyzing the challenges and opportunities associated with its implementation in numerous manufacturing structures.*

Key Words: *Global competition, industrial revolution 4 (IR4), industry 4.0, internet of things (IoT), lean manufacturing (LM), production systems, theory of constraints (TOC),*

1. INTRODUCTION:

Theory of Constraints

The Theory of Constraints (TOC), developed by Eliyahu M. Goldratt in the 1980s, is a management philosophy and methodology which is aimed at enhancing organizational performance, particularly in manufacturing. TOC focuses on identifying and eliminating constraints that hinder overall productivity. By focusing on constraints and optimizing the flow of materials and information, the theory of constraints aims to improve productivity, reduce production time, and ultimately increase the profitability of manufacturing companies. It provides a systematic framework for managers to identify and address the factors that limit the effectiveness of their system, helping them make informed decisions about process improvement. The theory of constraints provides a structured and systematic approach to identifying and mitigating constraints in systems. The fundamental principles of TOC include:

1. Identify the constraint: Initially identification of the bottleneck or constraint that limits the system's output is done. It could be a machine with low capacity, a scarce resource, or a process that takes longer than necessary. By pin pointing the constraint, efforts can be directed towards improving its performance.

2. Exploit the constraint: Once the constraint is identified, TOC advocates for fully utilizing its capacity to maximize production. Other non-constraint elements in the system should be synchronized with the constraint for a smooth flow of materials and avoid creating idle time for the constraint.

3. **Subordinate non-constraints**: The non-constraint elements in the system should operate in a way that supports the performance of the constraint. Their activities should be aligned to match the pace of the constraint, avoiding overproduction that might cause accumulation of work in progress or inventory.
4. Elevate the constraint: Rather than accepting the constraint as a fixed limitation, TOC encourages finding ways to improve or elevate its capacity. This can involve investing in additional resources, enhancing the skills of operators, or optimizing the scheduling and operations of the constraint.
5. **Repeat the process**: Once a constraint is improved or eliminated, a new constraint may emerge elsewhere in the system. The TOC approach encourages a continuous improvement cycle, repeating the above steps to identify and address new bottlenecks to improve overall system performance.
The basic framework of TOC is systematically shown in **Figure 1**

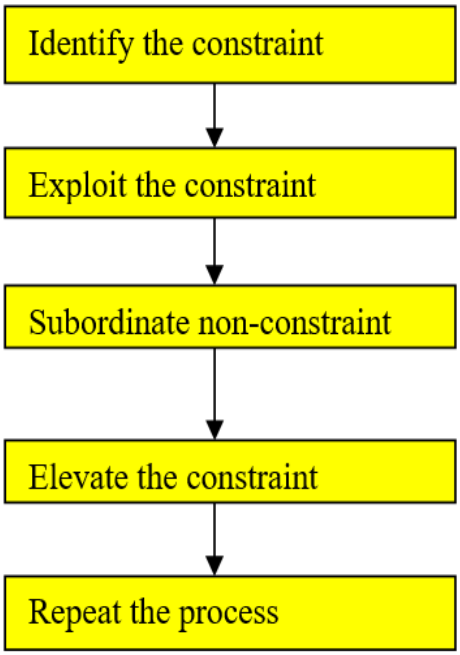

Figure 1 Framework of Theory of Constraints

By applying the principles and techniques of the theory of constraints in an optimized manner, organizations have the opportunity to improve operational efficiency, optimize resource utilization, and significantly alter the overall performance of their system. It stresses upon the practical and scientific approaches to propose changes, assuming that any complex production system is made up of many simpler elements that act in a chain (31). This research work will examine the basic principles of the constraints applied to a manufacturing process and examine the challenges involved in the process. Databases and search engines were used in the search for relevant literature because of their extensive literature archives on operations and supply chain management.

Lean Manufacturing

Lean manufacturing is a scientific approach aimed at maximizing customer value through minimizing waste and optimizing processes. Originating from the Toyota Production System (TPS) in the 1950s, it has been globally adopted across various industries. The core principle of lean manufacturing involves identifying and eliminating wasteful activities, enabling organizations to streamline operations, efficiency enhancement and cost curtailment. This methodology imbibes in a culture of continuous improvement and motivates employees to contribute to optimized processes. It stresses on the simplification of complex manufacturing process by cutting down time consuming activities and bottlenecks thereby clearing up the assembly line. This results in curtailment of lead time in production assembly lines thereby enhances productivity of the plant.

ISSN(O): 2456-6683
[Impact Factor: 9.241]

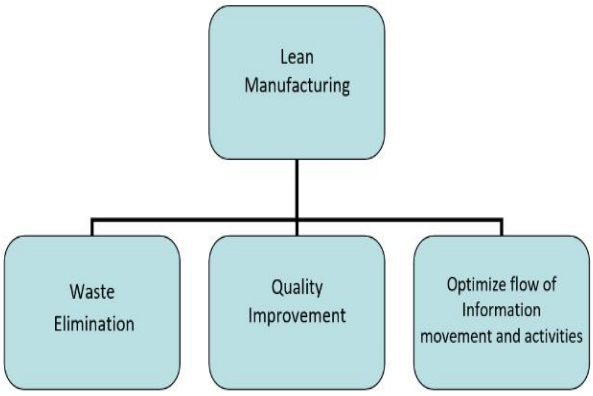

Figure 2 Objectives of Lean Manufacturing

LM is focused on customer values which aligns with the concept of smooth and uninterrupted movement of materials, information, and activities throughout the production process. This helps prevent overproduction and excess inventory. It makes use of waste identification and elimination tools and techniques such as value streaming, which reveals the flow of materials and information, showing the areas of waste and improvement opportunities. It has been embraced by various industries, ranging from manufacturing to healthcare, services, and beyond, due to its proven effectiveness in improving efficiency and driving sustainable growth. Lean principles include just-in-time (JIT) production, kanban systems, value stream mapping, 5-S methodology and continuous flow represented in **Figure 3**

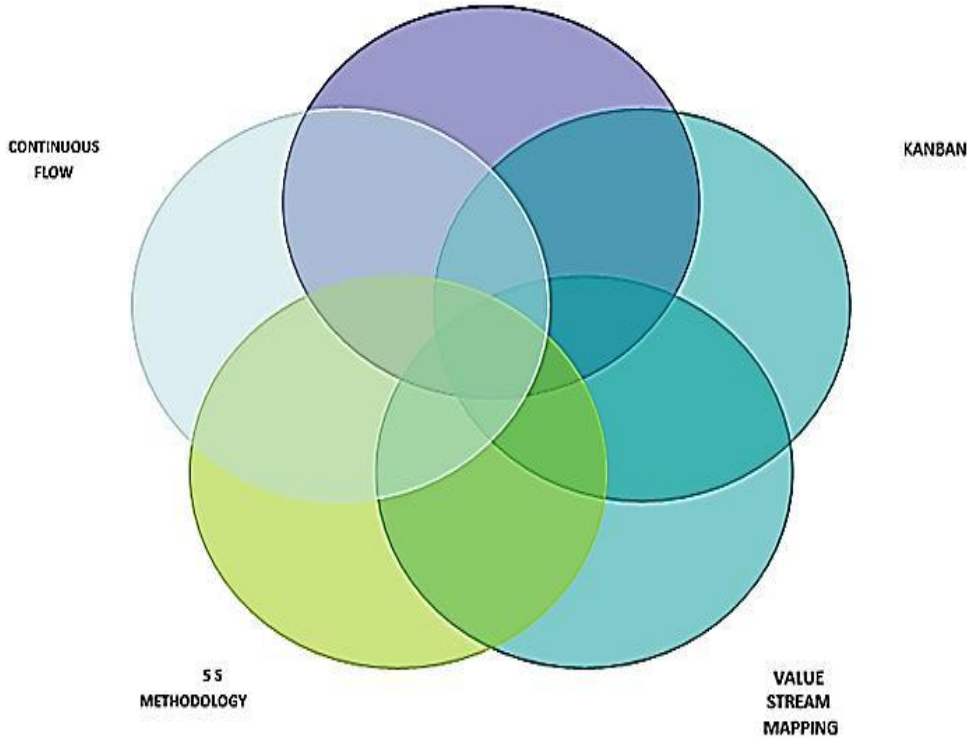

Figure 3 Lean Manufacturing principles

To effectively implement lean manufacturing methodology with Industry 4.0, it is important to have a clear understanding of lean manufacturing principles, strategies with tools and technologies associated with Industry 4.0. Implementing lean manufacturing is a comprehensive and continuous effort. Here are some key strategies to consider when implementing lean manufacturing:

1. **Establish Clear Goals and Objectives**: Define your objectives for implementing lean manufacturing. Decide on the specific goals you want to achieve, such as reducing lead times, improving quality, or increasing productivity. Ensure that these goals align with your overall business strategies and communicate them effectively to all employees.
2. **Create a Culture of Continuous Improvement**: Imbibe a culture that encourages employees at all levels to identify and eliminate waste in their processes. Implement a system that enables employees to provide suggestions for improvements and recognize and reward their contributions.
3. **Value Stream Mapping**: Start by mapping the value stream, which is the end-to-end process flow of delivering a product or service. Identify all the steps, activities, and resources involved from the initial order to final delivery. This visual representation helps identify non-value-added activities, bottlenecks, and opportunities for improvement.
4. **Identify and Eliminate Waste**: Waste is a key focus in lean manufacturing. Identify the different types of waste, including overproduction, excess inventory, waiting time, transportation, defects, motion waste, and unnecessary processing.
5. **Standardize Processes**: Establish clear and standardized work procedures that reduce variations, improve quality, and streamline operations. Encourage employees to contribute to the development of standardized work instructions based on their expertise and experience. Regularly review and update these processes to incorporate improvements.

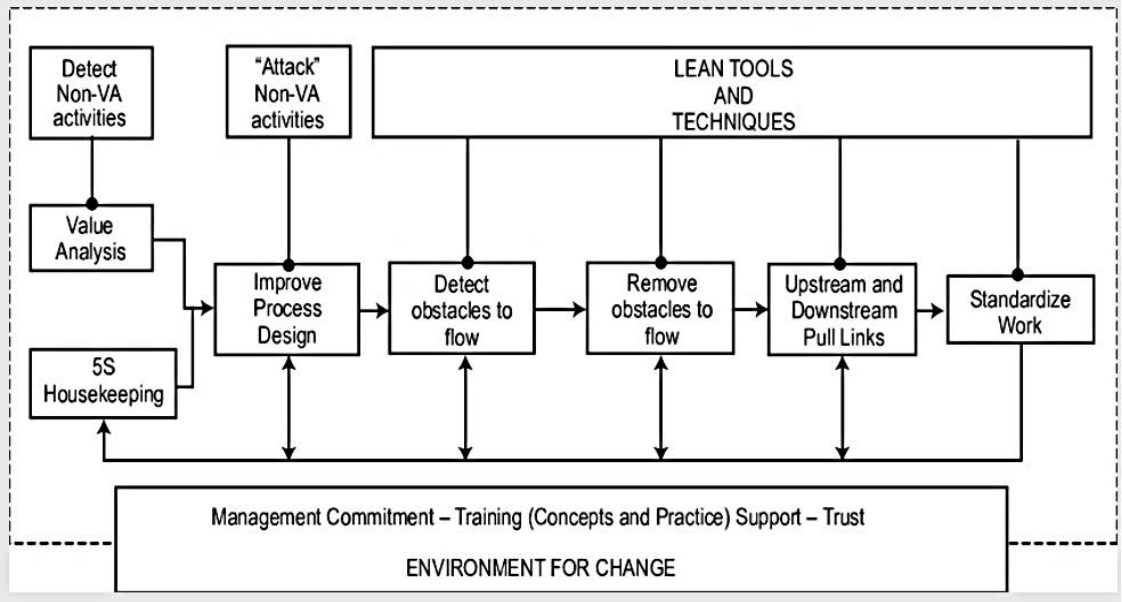

Figure 4. Strategy of implementation of lean manufacturing

6. **Implement Pull Systems**: Utilize pull-based systems, such as Kanban, to align production with customer demand. Its main focus is on ensuring that production is triggered on actual customer demand.
7. **Engage and Empower Employees**: Involve employees in the implementation process by conducting training sessions and workshops and providing them with the necessary tools and resources. Encourage them to take ownership of their work areas, suggest improvements, and address issues proactively.
8. **Continuous Monitoring and Metrics**: Establish key performance indicators (KPIs) to measure the success of lean initiatives. Monitor these metrics regularly to track progress, identify areas for improvement, and take corrective actions as needed.
9. **Supplier Collaboration:** Engage with suppliers to enhance collaboration and eliminate waste across the supply chain. Implement strategies like Just-in-Time delivery, vendor-managed inventory, and long-term partnerships to reduce lead times, minimize transportation costs, and optimize the quality of inputs.
10. Lean Leadership and Commitment: Strong leadership support is crucial for successful implementation. Leaders should demonstrate their commitment to lean principles, provide resources and support, and encourage open communication and problem-solving.

In short, lean manufacturing is a continuous process demanding continuous improvement and adjustment as per received feedback and variation in conditions. It is based on staying committed, employee's involvement, and readiness to learning and adaptation.

Collaboration of LM with TOC:

Lean manufacturing, when synchronized with Theory of Constraints in the domains of Industry 4.0 can bring several benefits to manufacturing organizations. By eliminating waste, reducing lead times, and improving overall system efficiency, companies can achieve increased productivity, cost savings, and enhanced customer satisfaction. By utilizing blending lean principles and TOC principles, organizations multiply their ability to prioritize improvement initiatives based on the impact they have on the overall system performance. In addition, the integration of lean manufacturing with TOC encourages a culture of collaboration and employee engagement. This not only enhances employee satisfaction but also leads to more effective and sustainable improvements. By leveraging advanced technologies, engaging employees, and adopting a data-driven mindset, manufacturers can successfully navigate the complexities of modern manufacturing to gain a competitive edge in the dynamic environment.

2. LITERATURE REVIEW:

Industry 4.0

Industry 4.0, also referred to as the fourth business revolution, is a term that describes the combination of superior digital technologies into commercial approaches and manufacturing systems. It represents a shift toward clever factories, in which automation, IOT (Internet of things), machine learning and artificial intelligence are leveraged to optimize manufacturing operations to achieve enhanced productivity (1). It has been seen that governments, industries, and educational establishments are investing in research, development, and implementation of these concepts to transform their production sectors. While Germany played a crucial role in initiating the concept, it has gained global recognition and adoption as countries worldwide strive to embrace digitalization in their manufacturing sectors The origins of Industry 4.0 can be seen as a continuation and evolution of previous industrial revolutions (2). The First Industrial Revolution, driven by the introduction of steam power and mechanization, transformed manual labor into machine-based production. The Second Industrial Revolution introduced electricity and assembly line production, enabling mass production on a larger scale. The Third Industrial Revolution, also known as the digital revolution, involved the utilization of computers and automation to streamline manufacturing processes (3-10). Industry 4.0 encompasses a variety of technology (such as the Industrial Internet of Things, the cloud, edge computing, and digital twins) that is converging leaner manufacturing. is the foundation of the Fourth Industrial Revolution (IR4) is based on the automation of data collecting and communicating systems making industrial and manufacturing practices more efficient. With the evolution of the global markets, manufacturing systems become smarter, more flexible, digital, agile to pace with volatile market (10). Manufacturers around the world adopting new technologies, such as cloud computing, big data analytics, robotics, and the Internet of Things (IoT) have a significant impact on their performance. They use better machines, advanced modes of communication, improved working conditions, and product quality (11).It has been seen that the use of modern technologies like internet of things, sensors, and big data has remarkably improved the environmental, social and economic sectors especially plastics industry in Brazil (12).By making use of digital technologies, manufacturing industries can curtail costs associated with the production and transportation as well as lead times causing increment in customer satisfaction and organization's profits (13).As far as environment is concerned, data sharing among supply chain stakeholders, and the availability of real-time data facilitate the efficient allocation has resulted in reduction of the resource consumption and waste generation (14).Industry 4.0 comes with new technologies that enhances motivation and morale of employees as they feel safe in workplace (15).It has provided a brand new level of industrialization wherein groups can reap extra business overall performance by integrating vertical and horizontal production processes It allow everyday machines to come to be self-aware and self-mastering a good way to carry out better maintenance through actual-time tracking of data, monitoring the repute and place of products, and controlling production methods (24). Autonomous robots are being employed for more precise execution of autonomous production methods and operations where the work of human workers is risky (25). Integration of the sensory data with digital simulation can improve the efficiency of production planning and execution by increasing the credibility of production system (26). Internet of things includes the dynamic control of complex structures through the real-time interaction of human beings, machines, items, and information and verbal exchange generation systems (27). The use of additive manufacturing reduces the complex manufacturing process leading to curtailed time and money. It permits rapid prototyping with decentralized production processes (28). Augmented Reality (AR) provides remote maintenance support in a digitalized and easily comprehensible manner (29). In short, the effect of novelty in production is witnessed in all spheres of production through Industry 4.0.

ISSN(O): 2456-6683
[Impact Factor: 9.241]

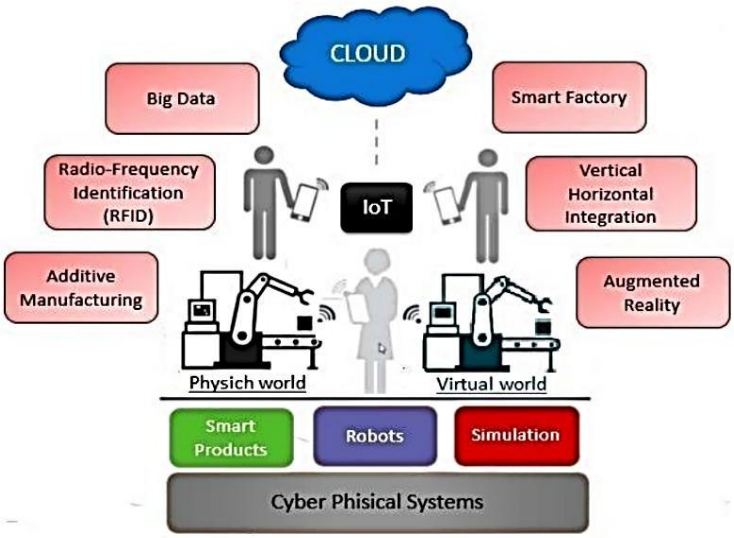

Figure 5. Industry 4.0 Technologies (30)

3. COLLABORATION OF LM WITH INDUSTRY 4.0:

Lean manufacturing methodology and Industry 4.0 are two complementary processes that may be blended to maximize operational performance and productivity in production setup. Lean manufacturing, also known as the Toyota Production System (TPS), aims to eliminate waste, improve quality, and optimize processes. It focuses on continuous improvement, respect for people, and the pursuit of perfection. On the other hand, Industry 4.0 is driven by advancements in digital technologies with the aim to achieve real-time connectivity, data-driven decision-making, predictive maintenance, and autonomous systems (16). Integrating LM into Industry 4.0 can be considered a stimulus or a pre-requisite for its introduction in production systems (17). Mergers of Industry 4.0 with the principles of LM will remarkably benefit the manufacturing sector in future. It has been observed that the combination will reduce waste and cost in areas where LM alone is not feasible (18).

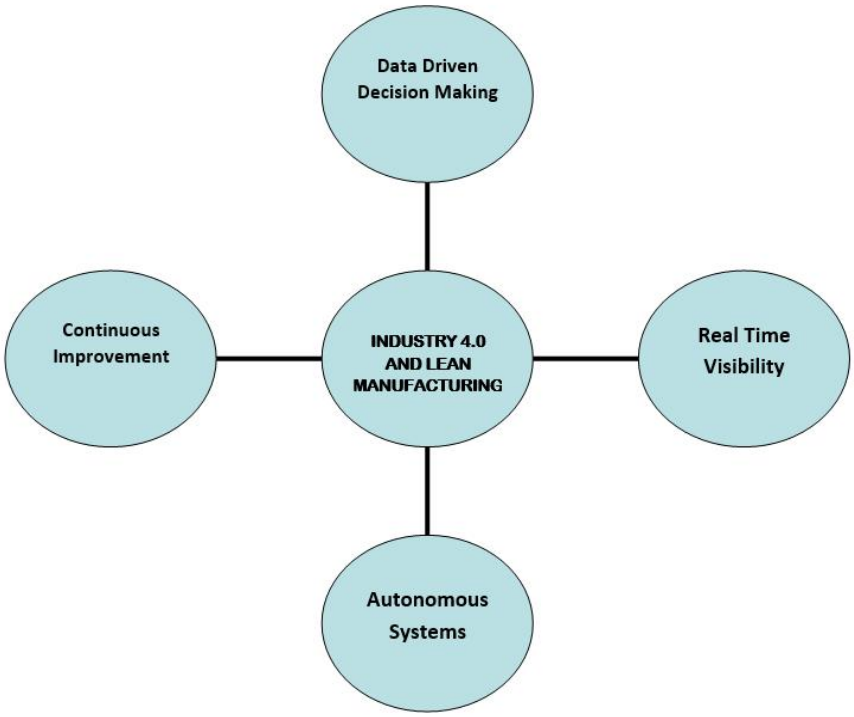

Figure 6. Collaboration of lean Manufacturing with Industry 4.0

4. BENECFITS OF COLLABORATION:

When combined, lean manufacturing methodology and Industry 4.0 can enhance manufacturing processes and drive improvements in several ways:
1. Data-driven decision-making: Industry 4.0 technologies enable the collection and analysis of vast amounts of data from various sources within the manufacturing process. This data can be used to identify areas of waste, bottlenecks, and quality issues, allowing lean practitioners to make more informed decisions for process optimization.
2. Real-time visibility: Industry 4.0 technologies provide real-time visibility into production, allowing for better monitoring and control of manufacturing operations. This visibility enables lean practitioners to identify issues as they arise and make quick adjustments to maintain flow and optimize production.
3. Autonomous systems: Industry 4.0 technologies, such as robotics and automation, can be integrated into lean manufacturing processes to eliminate manual handling, reduce human error, and improve efficiency. Autonomous systems can perform tasks which are risky and repetitive, allowing employees to focus on value-added activities.
4. Continuous improvement: The combination of lean and Industry 4.0 is a data-driven approach that identifies waste and monitor results in a more systematic and efficient manner.

5. LIMITATIONS/CHALLENGES ASSOCIATED WITH THE COLLABORATION:

There are several challenges associated with Collaboration of lean manufacturing with Industry 4.0 and constraints theory. While lean manufacturing has numerous benefits, it does have a few limitations. Some of the limitations include:

1. Resistance to change: Implementing lean manufacturing requires a significant cultural and organizational shift. Changes imposed are prone to be resisted by employees in their well-established work processes and be reluctant to adopt new practices.
2. Time-consuming implementation: Lean manufacturing requires substantial time and effort to implement effectively. Organizations must invest in training, process mapping, and continuous improvement initiatives, which can be resource intensive.
3. Resource constraints: Implementing lean manufacturing often requires investments in new technologies, equipment, and training. Small companies with limited resources can find it challenging to adopt lean practices.
4. Lack of flexibility: Lean manufacturing eliminate waste and leading to standardized and efficient processes. This can limit flexibility in accommodating custom orders or sudden changes in customer demand, particularly in industries with high variability or customization.
5. Narrow focus: Lean manufacturing primarily focuses on improving efficiency and reducing waste in production processes. It may not address broader organizational issues such as marketing, strategy, or product development.
6. Employee burnout: Continuous improvement and relentless pursuit of efficiency may put excessive pressure on employees, leading to burnout and decreased job satisfaction.
7. Risk of oversimplification: Lean tools and techniques, if implemented as-it-is, with no or less understanding of the underlying principles, can lead to oversimplification. This can result in inadequate solutions that will not address the main causes of problems.
8. Incompatibility with certain industries: While lean manufacturing is widely applicable, certain industries with complex and non-repetitive processes, such as aerospace or pharmaceuticals, may find it challenging to fully adopt lean practices due to stringent quality requirements and regulatory constraints.

Regardless of these limitations, lean production remains a valuable framework for enhancing operational performance and reducing waste in lots of companies. It's miles important to consider the precise context and constraints of every enterprise whilst enforcing lean practices to mitigate those obstacles and maximize the blessings.

6. CONCLUSION:

The merger of lean manufacturing and industry 4.0 holds tremendous ability for enhancing average performance and productiveness in a business enterprise. This strategic integration can result in optimized resources usage, minimized waste, elevated flexibility, and optimized choice-making tactics.

1. It can provide a platform for enhancing performance and productivity in a business enterprise. This strategic integration can result in advanced useful resource usage, minimized waste, elevated flexibility, and optimized choice-making tactics.
2. By adopting lean manufacturing practices, companies can discover and remove bottlenecks, optimize using assets, and improve the overall cost move.
3. Industry 4.0 entails the integration of virtual technologies and automation with conventional manufacturing processes. The technologies can be utilized for improved tracking, predictive renovation, and agile manufacturing.
4. It has been seen that the integration of lean manufacturing and Industry 4.0 constraints facilitates identification and mitigates bottlenecks more efficaciously by using leveraging actual-time information and analytics. Secondly, the combination permits more optimized useful resource usage.
5. With the utilization of integrated real-time information from Industry 4.0 techniques into the manufacturing system, groups can optimize the allocation of assets, reduce downtime, and enhance overall operational performance.
6. The collaboration will enhance decision-making, real-time tracking analytics provided will offer insights into work performance, costumer demands, and market developments. This will lead to make information-based selections in actual-time, ensuring powerful utilization of sources and timely management of constraints.

In short, Industry 4.0 represents a brand-new trend of manufacturing that blends virtual technology, advanced analytics, and connectivity to create wise, efficient, and flexible production systems. Its origin lies in the German initiative, but it has quickly become a global phenomenon, setting the stage for the smart factories of the future.

REFERENCES:

1. C. Cheng, T. Guelfirat, Schmitt, M. Schelte and P. Weber, (2015): Semantic degrees for industry 4.0 engineering: deciding on the degree of semantic formalization to select appropriate technologies, in Proc. 10th Joint Meeting on Foundations of Software Engineering (ESEC/FSE 15), Italy, 1010–1013.
2. M. Hermann, T. Pentek and B. Otto, (2016): Design principles for industry 4.0 scenarios: A literature review, in Proc. 49th Hawaii International Conference on System Sciences (HICSS), USA, 3928–3937.
3. Bitkom and ZVI, (2016): Implementation strategy industry 4.0, Frankfurt, Report on the results of the industry 4.0 platform,12(5),250-262.
4. J. Posada et al., (2015): Visual computing as a key enabling technology for industry 4.0 and industrial internet, IEEE Computer Graphics and Applications, 35(2), 26–40.
5. J. Smit, S. Kreutzer, C. Moeller and M. Carlberg, (2016): Industry 4.0, An economic and scientific policy, Rep. European Parliament's Committee on Industry, Research and Energy (ITRE),32-40.
6. M. Falk, M. Klien and G. Schwarz, (2015): Large manufacturing firms plan to increase their investments in 2015, Woof Spring 2015 investment survey, WIFO Monatsberichte (monthly reports),88(7),581–591.
7. G. Tassey, (2014): Competing in advanced manufacturing: the need for improved growth models and policies, Journal of Economic Perspectives, 28(1), 27–48.
8. H. Lassi, P. Fettke, H.G. Kemper, T. Feld and M. Hoffmann, (2014): Industry 4.0, Business & Information Systems Engineering,6(4), 239–242.
9. H. Kagermann, W. Wahlster and J. Helbig, (2013): Recommendations for implementing the strategic initiative industry 4.0, Acatech -National Academy of Science and Engineering, Frankfurt, Final Report of the industry 4.0 ,123-134.
10. European commission Report for innovation in Industries, (2024): Horizon 2020, The EU framework Programme for Research and Innovation.34(2),45-53.
11. The Industrial Internet Consortium, (2014): A global nonprofit partnership of industry, government and academia,21(3),310-317.
12. K.Q.Li, (2015): Report on the work of the government, in Proc. Third session of the 12th national people's congress, China,124-132.
13. E. Alkaya, M. Bogurcu, F. Ulutas and G.N. Demirer, (2015): Adaptation to climate change in industry: improving resource efficiency through sustainable production applications, Water Environment Research, 87, (1),14–25.

14. R. Schmidt, M. Möhring, C. Reichstein, P. Neumaier and P. Jozinovic, (2015): Industry 4.0-potentials for creating smart products: empirical research results, International Conference on Business Information Systems (BIS), 208(3),16–27.
15. T. Bauernhansl, M. Ten Hempel and B. Vogel-Heuse, (2015: Industrie 4.0 in Produktion, Automatisierung und Logistik. German: Springer Vieweg ,45-56.
16. A. Khan and K. Turowski, (2016): A survey of current challenges in manufacturing industry and preparation for Industry 4.0, in Proc. First International Scientific Conference on Intelligent Information Technologies for Industry, 15-26.
17. M. Bahrin, F. Othman, N. Azli and M.Talib,(2016): Industry 4.0: a Review on Industrial Automation and Robotic, Jurnal Teknologi, 78(2),137-143.
18. M. Cotteleer, J. Holdowsky, and M. Mahto, (2013): The 3D opportunity primer: the basics of additive manufacturing, Deloitte University Press, 113-121.
19. J. Xu, E. Huang, L. Hsieh, and H. Chen, (2016): Simulation optimization in the era of Industrial 4.0 and the Industrial Internet, J Simulation, vol.10(4), 310-320.
20. S. Wang, J. Wan, D. Li and C.Zhang, (2016): Implementing smart factory of Industrie 4.0: an outlook, Int. Journal of Distributed Sensor Networks,12(1),1-10.
21. P. Zheng, H. Wang, Z. Sang, (2018): Smart manufacturing systems for Industry 4.0: conceptual framework, scenarios, and future perspectives, Front. Mech. Eng.,20(2),11-18.
22. H. Cheng, P. Zeng, Z, Shi, P. Wang and H. Yu, (2016): Manufacturing ontology development based on Industry 4.0 demonstration production line, Third International Conference on Trustworthy Systems and Their Applications (TSA),23-35.
23. Deloitte J, (2015): Industry 4.0, An Introduction, Rep., Holanda,21(2) ,32-42.
24. P. Gerbert, M. Lorenz, M. Rusmann, et al., (2015): Industry 4.0: the future of productivity and growth in manufacturing industries," Rep. The Boston Consulting Group (BCG), 68-75.
25. European Commission Report on Industries, (2015): SMEs to the Industry 4.0,234-256.
26. T. Kaihara, Y. Katsumura, Y. Suginishi and B. Kadar, (2017): Simulation model study for manufacturing effectiveness evaluation in crowdsourced manufacturing, Manufacturing Technology,66(1), 445-448.
27. A. Khan and K. Turowski, (2016): Perspective on industry 4.0 from challenges to opportunities in production systems, in Proc. International Conference on Internet of Things and Big Data, Rome, 441–448.
28. Horst, D.J, Duvoisin, Almeida, (2018): Additive Manufacturing in Industry 4.0, International Journal of Engineering and Technology,3-8.
29. Mourzits.D, Zogopoulos.V, (2017): Integrated production and maintenance scheduling through machine monitoring and AR, An Industry 4.0 approach, International Conference of Advances in Production Management,354-362.
30. Benedictus Rahardjo, Fu-Kwun Wang, Yu-Ping Chang, (2023): Lean Manufacturing in Industry 4.0, A Smart and sustainable Manufacturing System, Machines, MDPI,1-17.
31. Costas, J., Ponte, B., de la Fuente, & Puche, (2015): Applying Goldratt's Theory of Constraints to reduce the Bullwhip Effect through agent-based modeling", Expert Systems with Applications), 2049–2060.