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INDUSTRY 4.0 ON STRONG HOLDS OF LEAN MANUFACTURING

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ABSTRACT
Manufacturing industries have been in pursuit of driving value for their customers & keeping their businesses competitive by continuously reducing costs and improving quality. Lean has been popular paradigm since its emergence in Japan in 1980s. Industries all over the world have embraced it to reduce wastage in their processes. Three decades on, a new transformation paradigm has arrived by the name of Industry 4.0, which also promises to create business value but in different way by using nine new age technologies like Internet of things (IoT), Cloud, Bid Data, 3D printing to name a few. While both these paradigms have same goals, they follow different paths with different tools. This generates queries like is one paradigm better than the other or are they competitors or unrelated concepts. Industry 4.0 being new and lean being old there are doubts whether is Industry 4.0 replacing lean. Also, it is known that Industry 4.0 has been embraced at Strong holds of Lean past few years, it generates curiosity on how that integration looks like. This position paper gives an overview of how Industry 4.0 technologies have impacted lean tools. It also highlights how lean helps adoption of Industry 4.0 technologies. Some real-world examples of how lean tools are changing with new age technologies will help researchers & practitioners visualize the changes. A brief perspective on factors of adoption for Industry 4.0 would help technology practitioners & researchers build practical approaches.

Keywords: Lean Manufacturing, Industry 4.0, Lean Tools, Cyber physical systems.

1. INTRODUCTION

Lean Manufacturing which evolved in Japan in 1980s has been widely adopted by diverse industries across globe as a source of competitive advantage. With an unmatched focus on customer value, ruthless identification & elimination of waste, lean has enabled organizations to develop a reliable and profitable response to the evolving customer needs. Lean methodology has been known for its systemic use of lean tools which enable robust problem solving & continuous improvements. It has been a proven technique for many organizations to deliver best quality products at lowest cost, in shortest time by creating physical flow. The transformation technique lays on foundations of stable & standardized processes along with high morale of employees. Lean thinking has made production systems flexible & leaner given continuous elimination of various kinds of wastes.

Over the last one decade, 2011 to be precise, a new paradigm has emerged towards the transformation of manufacturing and business processes, which is primarily enabled by technology and data. This goes by the name of Industry 4.0 and is widely christened as the fourth industrial revolution also. The transformation here is enabled by the possibilities of creating smart networks of machines, products, components, people, and various nodes of supply chains (like production, transportation, material supply etc.), which thereby creates intelligent factories and an intelligent supply chain. Transformational business value creation is envisioned by through superior understanding of customer needs & the abilities to convert demand into supply on a real time basis. This results in quantum improvements on reliability, agility and profitability of manufacturing organizations & thereby makes businesses more competitive.

While both lean & Industry 4.0 enable profitability and growth for an organization, they surely have very different approaches towards value creation. Differences in their approach is logical given the multi -generation gap between the emergence of the two methodologies. As an example, lean focuses on visual management & proximity to people and operations, Industry 4.0 drives value through touchless interconnected processes. There are many such differences between the two, hence it creates curiosity as to how these practices are being looked at together now that they both exist. Do the organizations see any one of them superior to other, or do they see them as independent or inter dependent entities? Also, it is known that many organizations who were on the forefront of lean have already embraced industry 4.0. It again generates curiosity on have they looked at the two, what have been the factors of adoption at their end? Authors of this paper developed a systemic literature review to answer below research questions:

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- Which lean tools have been most impacted by industry 4.0 technologies
- Which of the nine industry 4.0 technologies have had highest adoptions in Lean.
- How do organizations & practitioners view Industry 4.0 and lean together; do they seem them as competitors or enablers
- What have been the factors of adoption for those who have seen synergies between lean & Industry 4.0

This paper is structured in five sections. After providing an introduction, Section two of the paper outlines the methodology used for this study. An extensive literature review will be presented in section three. Basis literature review research questions will be answered in section four. This will be followed by discussion of key points in section five.

2. REVIEW OF LITERATURE

2.1About Lean – History, Principles & Tools

Satolo, E. G.et al. (2020) provide a foundational perspective of the lean production systems. After the Second World War, Toyota Production System (TPM) emerged in the Japanese automobile industry. It was a new production model which enabled them to produce more with lowest possible resources & hence lesser cost by a razor-sharp focus on waste elimination. However, the lean production system came into existence only in late 1980s, when a research project was conducted at the Massachusetts Institute of Technology (MIT) to study the Japanese Toyota manufacturing model. Japan was clearly giving the American automotive industry a big run for its money. The study was carried out by means of extensive interviews of workers, unions, suppliers, and government bodies. It concluded that the reason of Toyota & other Japanese companies outclassing their western competitors was attributed to the Toyota Production System

2.2 About Industry 4.0 – History, Principles & the Technologies

Frédéric Rosin et.al (2020) highlight a technology driven paradigm is knocking the doors of all industries, even the traditional lean strong holds. The new paradigm known as industry 4.0 offers unique opportunities to the organizations to transform their agility, profitability & their capabilities to deal with variability in demand. Key enablers are inter- connectivity of products, equipment & people towards heightened levels of decision making and ultimately fulfilment of customer needs. Using cyber physical systems across end-to-end supply chain, new heights of operational excellence can be now achieved. Instant communication between machines, objects & people make manufacturing systems more flexible to product changes and more responsive to unexpected events.

2.3 Lean & Industry 4.0 together – Competitors Vs Enablers

Varela L et.al (2019) researched the influence of the two production philosophies – Lean Manufacturing (LM) & Industry 4.0 (I4.0) around the three pillars of sustainability – social, economic & environmental. Their study was focused on industrial companies situated in Portugal & Spain. Results revealed that lean manufacturing wasn't strongly correlated with any of the sustainability pillars, while Industry 4.0 showed good correlation with all three pillars of sustainability. While the results were not aligned with the initial expectations, authors argue that lean's correlation might be low since lean as a philosophy focuses more on current state of a unit & doesn't show much concern to the global, integrative, and transformative vision of a company at large. Strong correlation between sustainability & I4.0 might be an indicative of the situation that companies now have a better appreciation of holistic impact of I4.0 on sustainability.

2.4 Factors of adoption of Industry 4.0 in Lean Organizations

Frédéric Rosin et.al (2020) mention that focus on customer value, standardization of process & relentless elimination of waste are the foundations of lean. Strong implementation of these three aspects, results in de-complexification of products & processes, thereby paves way for a smoother implementation of industry4.0. Lean implementations also involve strong change management on people side, this too ensures organizational readiness for industry 4.0, since employees are already conducive to change

3. RESULTS OF RESEARCH QUESTIONS

3.1 Which lean tools have been most impacted by industry 4.0 technologies?

From the various research papers reviewed and analyzed in this study, authors narrowed down to 12 lean tools which seem to be the most widely used. These are 5S, Value Stream mapping (VSM), Andon, Just in Time (JIT), Kaizen, Single minute exchange of dies (SMED), Kanban, Heijunka, Jidoka, Standard work, Total Productive Maintenance (TPM) and Visual Management. Total of 89 data points have been generated for analyzing which of these lean tools have been most impacted by industry 4.0 technologies. Results of this as

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shown in Fig 3 highlight VSM (Value Stream Mapping), Kaizen & Kanban to be the top 3 while Heijunka, TPM and 5S to be the bottom 3.

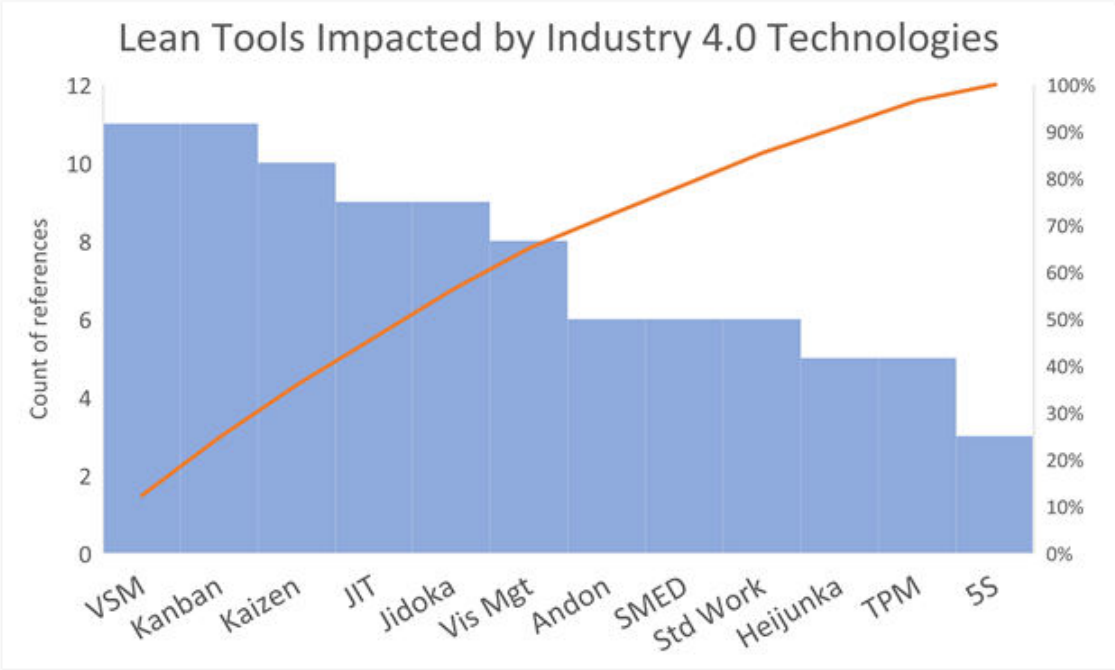

Fig 3: lean tools most impacted by industry 4.0 technologies

3.1.1 Examples of Lean tools impacted by Industry 4.0 technologies

It is evident from this literature survey that there are many lean tools which have now been enhanced or upgraded by using various Industry 4.0 technologies. To develop a better appreciation of how this integration is happening, authors have mapped out some real-world examples on how the most common 12 lean tools are now using Industry 4.0 technologies and how it is driving more value for organizations. Fig 4 captures various use cases (real world examples) & maps the linkages between Lean and Industry 4.0

Fig 4: Examples of lean tools impacted by industry 4.0 technologies basis Literature survey of this paper

Lean Tool	Industry 4.0 Technology	Use Case Details
5S	IoT, RFID	AI enabled shopfloor supervisions; RFID tagged parts ensure everything in place principle of 5S is abided by.
Andon	IoT	Smart Watches replace traditional Andon cords. Technicians receive alerts online issues on a real time basis which reduce the equipment down times.
	ioT	Smart machines can detect abnormalities & shoot out alerts for repairs on smart phones or screens.
	Horizontal & Vertical Integration	Real time alerts of anomalies or breakdowns to OEMs
Heijunka	Big Data	Mayr et al. (2018) mention the use of Anapro software, which smooths out production panning with big data
	Big Data	Workload of workstations is levelled out using generic algorithms & digital twins
Jidoka	IoT	Smart products communicate with equipment & can send alerts when wrong product gets chosen for production
	AR	Augmented reality is proposed by Kolberg and Zühlke (2015) and Mayr et al. (2018) to allow employees to obtain visual feedback if errors occur
	Robotics	Production errors can be detected & corrected by autonomous robots
JIT	Cloud, Horizontal & Vertical	Cloud computing & mobile computing devices can replace e-mail communications with suppliers. This transparency avoids outages and improves supplier relationships

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	Integration	
	Robotics	In a case analyzed from the Wittenstein Company, an integrated system with production and automated guided vehicles (AGVs) determine the milk-run system-based transport interval through real- time demand
	3D	3D printing allows of prototypes to quickly test if modular elements can meet customers requirement
Kaizen	Simulation	Simulation enables rapid modelling on possible configurations which can result in lower scraps, material usages, meeting lean motto of "do more with less "
Kanban	IoT	Physical Kanbans get replaced by e-Kanbans. Missing & empty bins get recognized by smart sensors
	Horizontal & Vertical Integration	iBin comes with optical order systems. A camera detects the charging level of bin and reports wireless the status to an inventory control system. Additionally, iBins sends orders automatically to supplier
	Robotics	AGV empower the supply of materials to workstations and supermarket managed through Kanban
Poka Yoke	IOT	Defects can be detected and eliminated real time by deploying optical sensors on critical to quality points
	IOT, Cloud, Big data	With the use of sensors & machine learning, machines can on their own adjust to irregularities
	AR, IOT	AR and head-mounted displays can be used to achieve zero-error picking
SMED	Robotics	Plug'n'Produce enables Single Minute Exchange of Die (SMED) method into whole production lines.
	3D	Additive manufacturing enables setup time reduction since varying workpieces can be produced with minimum setup times
	IOT	RFID adoption allows to recognize the die and set all the relative parameters up
Std Work	AR	Smart operator gets information about processing cycle time via augmented reality
	Robotics	Wang et al. (2017) offer autonomous robot applications, namely a picking robot (Boudella, Sahin, and Dallery 2018) and a corobot that works in conjunction with an operator (Wang et al. 2017), which helps standardize work procedures
TPM	IOT, Cloud, Big Data	With interconnected man & machines, advanced sensors, analytics preventive maintenance upgrades to a zone of predictive maintenance
	AR, VR	Combination of virtual reality (VR) and augmented reality (AR) as well as head-mounted displays facilitates training as well as maintenance instructions remotely
	IOT, Cloud, Big data	Virtual commissioning contributes to a fast start-up curve as digital twins allow a realistic simulation of production plants
Visual Management	Big Data	Zhong et al. (2015, 2016) use big data to extract relevant information from the large amount of data collected by the sensors distributed in the production system
	Big Data	Production line KPIs can be displayed real time on digital dashboards. This reduces transactional load, drives accuracy of data
VSM	IoT, Horizontal & Vertical Integration	Smart products can collect process data for analysis during & postproduction. Also, data collection for the Value Stream Mapping (VSM) gets much simplified & accurate
	IOT, Cloud, Big Data	Machine learning and data analytics support the creation of a value stream design. Target states are generated automatically and validated before implementation
	IoT, RFID	Main disadvantage of VSM is its static behavior, this can be overcome by the implementation of I4.0 solutions

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3.2 Which of the nine industry 4.0 technologies have had highest adoption in lean?

Total of 57 data points have been generated for analyzing which of the nine Industry 4.0 technologies have been adopted most, taking the top 12 identified lean tools in this study as a reference. Results of this as shown in Fig 5 highlight IoT, Cloud & Big data to be the top 3 while Robotics, Cybersecurity & 3D printing happen to be the bottom 3.

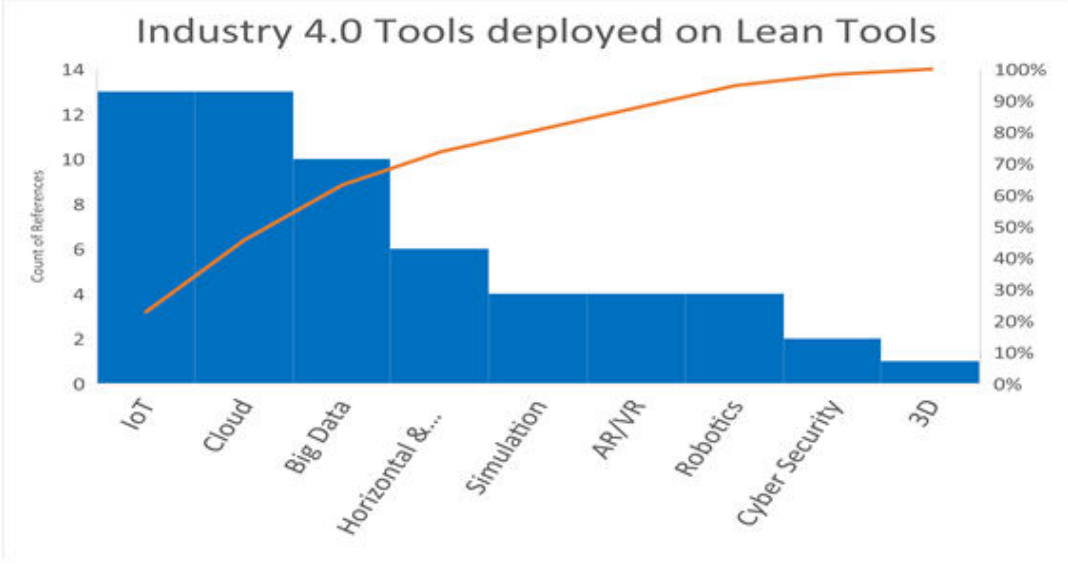

Fig 5: Industry 4.0 Tools most deployed in Lean

3.3 How do organizations & practitioners view Industry 4.0 and lean together; do they see them as competitors, enablers, or standalone entities?

The literature reviewed in this paper brings out multiple comparisons & perspectives related to lean & industry 4.0, which have been very relevant for the purpose of this study. Various researchers have compared the two paradigms broadly on below aspects –

- **Goals & Objectives**

A. Mayr et.al (2018) highlighted complexity reduction & improvement in productivity and flexibility as the common goals of both Lean & Industry 4.0

- **Value Creation Approach**

Christopher et.al (2018) highlighted two fundamental differences between lean management & Industry 4.0. First - Lean typically is a world of methods & aims enabling a continuous flow with least possible waste. Industry 4.0 on the other hand is not based on methods; enabler for value creation there is technology. Second – Lean management believes in implementing methods by employees themselves and encourages continuous improvement by employees at the points of value creation. On the contrary, employee involvement may not be high at implementation stage in industry 4.0

- **Specific Limitations**

DennisKolberg et.al (2015) have argued that lean follows fixed sequence of production and fixed cycle times & as such is not suitable for making personalized products & also products with short product life cycles [1]. Varela L et.al (2019) compared the influence of Lean Manufacturing (LM) & Industry 4.0 (I4.0) around the three pillars of sustainability – social, economic & environmental. They concluded that lean manufacturing wasn't strongly correlated with any of the sustainability pillars, while Industry 4.0 showed good correlation with all three pillars of sustainability

- **Similarities**

DennisKolberg et.al (2015) quote Ohno, father of lean, speaking about the principle of autonomation. Ohno had postulated that processes should be automated wherever possible but then supervised by employees. This clearly extends up to the industry 4.0 technologies also where in humans supported by new age technologies take the same role. Authors have further highlighted that both lean & Industry 4.0 aim for modular structures with low levels of complexities, thereby showing a clear preference for decentralized systems. A. Mayr et.al (2018) highlighted that both lean manufacturing & industry 4.0 focus on a pivotal role of employees though in different ways.

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- **Differences**

Sven-Vegard Bueret.al (2021) have argued that Lean promotes autonomy to employees, decentralized control, simplicity, and transparency of processes. Information Technology on the contrast focuses on creating single versions of truth by generating centralized databases.

- **Perspectives on Co-Existence**

Bruno G. et.al (2016) brought out that industry 4.0 will not compete with lean or make it obsolete. They opined both manufacturing systems will generate mutual dependencies and have their specific areas of application with respect to product variability & volumes. For a high-volume low mix portfolio, Industry 4.0 scores while for a low volume high mix portfolio Lean Single piece f might still be more suitable. Sachin Kamble et.al (2020) confirmed industry 4.0 as an enabler for lean manufacturing. Implementation of the new age technologies make a factory smart & helps organization overcome barriers of lean implementation. [5] Sven-Vegard Bueret.al (2021) concluded upon a strong correlation between length of lean implementation & digitization maturity. Organizations which have been embracing lean for a long time find it more beneficial and simpler to embrace Industry 4.0. Their research further highlighted the point that while lean and digitalization add value when implemented individually, the value creation gets magnified when both are implemented together. [16] Maria Pia Ciano et.al (2021) have highlighted strong interdependency between the two paradigms. Authors have argued that if a company doesn't apply lean principles before embracing new age technologies, the results would be just an automation or digitization of existing wastes.

Below inferences have been drawn out related to objectives of this study –

- **Are the Two Paradigms "Competing" With Each Other?**

While there are multiple differences highlighted & argued between Lean & industry 4.0, there are very few arguments among scholars & practitioners about the two paradigms competing against each other. Recommendations can be seen on one paradigm being more suitable compared to another & that is in context of business situations. Authors of this paper also conclude that the two paradigms do not really compete, it's just that one might be more relevant over the other given the business scenarios.

- **Are the Two Paradigms' "Enablers" to Each Other?**

Literature review brings out overwhelming similarities between the two paradigms in terms of their goals & objectives while also highlighting stark differences in the value creation approach of the two systems. Authors of this paper reach to a conclusion that there are strong synergies which exist between the systems and a purposeful implementation of both will result in amplified value creation. Organizations which have embraced lean, can make themselves more productive by acquiring advanced problem-solving capabilities which come with Industry 4.0. Also, organizations who want to embrace industry 4.0 will deeply benefit if lean fundamentals are also parallelly looked at. Authors of this paper hence see the two paradigms' enablers to each other.

3.4 What have been the factors of adoption for those who have seen synergies between lean & Industry 4.0?

Literature review presented in this paper has helped authors converge upon the factors of adoption into three broad Pillars – People, Process & Performance.

- **People Factors**

First, technology solutions should keep people at the center. These solutions get adopted if they add value to the users by simplifying their work & enabling faster decision making for them. Second, lean implementations usually involve strong change management on people side, this ensures organizational readiness for industry 4.0, since employees are already conducive to change. Lastly, human factors are critical since significant changes occur on shop floors when there is a penetration of technology; workers or operators surely need higher order skills on technology. Conventional operators need to upgrade to "knowledge workers" in the integrated world of lean & industry 4.0 & hence will need investments from their organizations.

- **Process Factors**

First, Industry 4.0 adoption is faster & more effective in organizations where lean implementation is in matured states. It is because such organizations have simpler & more standardized workflows, reduced to essential work only. Second, Practicing & sustaining lean has been a practical challenge for most organizations since work instructions & procedures as defined by lean are not always followed by workers. Industry 4.0 bridges this gap with real time sustaining mechanisms & this becomes a significant factor of adoption.

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- **Performance Factors**

Industry 4.0 solutions are perceived to come up with high investments. users find acceptance in areas where there are cost savings & traditional lean practices are not fulfilling today's requirements. Organizations are required to assess performance beyond financials on two other dimensions which are social & environmental. For a successful integration of industry 4.0 with lean manufacturing, practitioners should outlay impact of smart products & smart processes on all three dimensions of sustainable organizational performance.

4. CONCLUSION

Manufacturing industries have been in pursuit of improving quality, product availabilities, inventories & lead times to remain competitive in business. Lean has been an extremely effective paradigm since 1980s & organizations who embraced it continue doing so it till date, though sustenance remains a challenge. Industry 4.0 is a newer paradigm and that too offers value unlocks in areas where lean adds value. With a multi-generational gap of 3 decades between the two paradigms, there are clear differences in their approach even though similar aspects of business can be impacted by them. Lean drives continuous reduction in wastages using lean tools and methods, whereas Industry 4.0 drives quantum improvements by touchless & intelligent processes using new age technologies.

While analyzing how researchers & practitioners see Lean & Industry 4.0 together, authors found very limited evidence of a competing view between the two. There haven't been examples where Industry 4.0 tools are shown substituting lean tools. However, there are many examples where lean tools have been improvised using industry 4.0 technologies. Many real-world examples have been captured in this paper to illustrate this point.

Authors have found strong views which bring out lean & Industry 4.0 as enablers for each other. Industry 4.0 is a relatively new concept. Acceptance of it comes very different in an organization which has implemented lean Vs that which hasn't. Penetration & acceptance of Industry 4.0 is far higher in matured Lean organizations compared to non-lean ones. It is because lean drives simplification and standardization of processes. It also eliminates all non-value adding activities (NVAs) from various processes, which sets up a robust foundation for Industry 4.0. Also, people mind set in lean organizations is far more receptive to change compared to non -lean ones, which again makes it easier for Industry 4.0 to make inroads.

Integration of lean & Industry 4.0 is evident. Having said this, not all lean tools have changed equally with this integration and nor have all nine Industry 4.0 technologies penetrated the lean world equally. This specific research highlights three most impacted lean tools to be Value Stream Mapping (VSM), Kanban & Kaizen. The industry 4.0 technologies which have been most adopted in lean are IoT, Cloud & Big Data.

Industry 4.0 being the new paradigm offers significant opportunities to drive improvements across various parts of supply chain, beyond manufacturing. Authors conclude three important factors of adoption if an organization choses to embrace Industry 4.0 – (a) People factors – Simplify People's work , proactively upgrade their skills , have a strong change management (b) Process Factors – Simplification & Standardization of processes is an important pre-requisite , automation of transactional activities drives continuity to lean tools , (c) Performance Factors – Value creation shouldn't be confined to financial factors only like ROI, it should cover social and environmental factors also to make the impact holistic.

Lastly, while integration of lean tools with industry 4.0 seems very promising, there seems to be a paucity of active frameworks which can enable digitization the lean tools & enhance their effectiveness with new age technologies. This aspect can surely be an area for further research.

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