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When Industry 4.0 Meets Lean Six Sigma: A Review

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ABSTRACT: Quality improvement techniques highly rely upon the collection and analysis of data for the purpose of solving quality related issues. Synergy of Lean Manufacturing and six sigma aims to reach the quality levels of 3.4 part per million defects by reducing the variations in the processes. Industry 4.0 is trending towards the digitalization of manufacturing activities with powerful data analysis methods that can drive meaningful results out of the big data available. It is possible to drive meaningful decisions by using these methods in each and every step of Lean Six Sigma cycles. The main purpose of this study is to guide the practitioners to apply lean six sigma for getting faster and more reliable decisions with available set of big data. It will contribute towards the lean six sigma by reducing lead time and producing better quality products with effective decision making.

KEYWORDS: *Lean Six Sigma, Digitalization, Industry 4.0, Value Stream Map, ARC Advisory Group.*

1. Introduction

The history of industrial revolutions in the last three centuries highlights a shift from power sources to automation, to information technology and automated production, all the way to connectivity. However, all industrial revolutions revolve around three main categories: people, processes and technologies, with one of these driving the change, and initiating a circular pattern of mutual influence. Three pillars of industrial revolutions Relying on assess such as the concept of smart factory, the Internet of Things (IoT), Additive Manufacturing, Big Data, Industry 4.0 has been defined by the World Economic Forum as the latest industrial revolution which revolves around the so called Cyber Physical Age [1], whereby the revolution happens with the integration of physical and digital world through the proliferation of sensors and devices creating an interconnected ecosystem with multiple stakeholders. Such 4th industrial revolution has involved a paradigm shift from a client-centred product cycle to a client-centred experience cycle. This means that the client is involved in the lifecycle of the product from conception to post-purchase feedback, and that the client experience becomes pivotal for the success of companies, in any sector. In literature, the term Industry 4.0 is used to represent a deep change in many sectors: from manufacturing to HealthCare. Its disruptive diffusion is due to several Enabling Technologies, such as Internet of Things (or Internet of Everything or Industrial Internet of Things), and, as said, it is a vision rather than a technological step forward. Industry 4.0 is able to create value during the entire product, process or service life cycle. For the reasons described above, the outcome of this revolution may be an object but also a service designed for a final user, whose development is driven by innovation in several areas: IT, mechanical engineering, embedded systems, production, automation technique and all of them combined in order to deliver more complex systems as we know today. In this scenario, for example, Autonomous and Connected Vehicles (ACV) represent the perfect connection between digital and real world, an issue that stands in the centre of Industry 4.0 [2]–[3]. The automotive industry is experimenting new challenges and frontiers with the socalled autonomous and connected vehicles, which are becoming “smart” and totally connected with the rest of the world through Internet technologies. The Internet of Things applications are part of our life and many human and industry activities are based on this technology: from e-Health [4] to Cultural Heritage [5]–[8], from legal domain [9]–[11] to Public Administration [12]– [15], and Humanitarian Assistance and Disaster Relief [16]– [18], but also home automation, and wearable technology. The aims consist of changing our lives to make them easier, more efficient and "smart". The IoT devices, as said, are able to collect and share data directly with other devices through the cloud environment, providing a huge amount of information to be gathered, stored and analysed for dataanalytics processes. It has been proved that HealthCare applications represent an important field of interest for IoT devices, due to the capability of improving the access to care, reducing the cost of HealthCare and most importantly increasing the quality of life of the patients [19]. All the above-mentioned complex systems, often require complex algorithm execution that could be optimised by using distributed systems [20]-[22] or other complex techniques [23]-[26]. However, in embedded systems, weight and power consumption [27], does not allow such solutions and consequently, different approaches based on the using of an embedded microprocessor and hardware accelerators will be used [28], [29]. The potential to integrate Lean Manufacturing to Industry 4.0 has been debated [30], and, more specifically, Lean Six Sigma (LSS) has been investigated in its applications to accelerate the process of extracting key insights from Big Data, and how Big Data processing can help to innovate and cast a new light on the projects requiring the use of Lean Six Sigma [31], [32]. As it is known, indeed, Lean Six Sigma has been successfully applied to many areas, such as government, industry, services, and, ultimately, to HealthCare. In literature, many items exist that demonstrate the effect of the Lean Six Sigma applied to the HealthCare system. In [33] the purpose consists of demonstrating the power of LSS methodology in a hospital environment to reduce patient waiting time in out-patient department. Furthermore, has been demonstrated that the design and the assessment of HealthCare systems require many trade-offs and has a major impact on the patient experience and the quality and efficiency of care [34]. An interesting systematic literature review has been proposed by [35] in order to independently assess the effect of Lean or Lean interventions on worker and patient satisfaction, health and process outcomes, and financial costs. In [36] it has been explored the processes by which new Quality Improving (QI) methodologies are been developed and disseminated and the impact this has on the effectiveness of QI programmes in HealthCare organizations. While in [37] the authors have considered a particular case-study describing the success of the Six Sigma methodology in a hospital for a specific project. In particular, have proved the importance of verifying ideas before developing improvement actions, as a non-negligible aspect in the LSS methodology. With the onset of Industry 4.0 and its technologies, health care research has taken advantage of patient data digitization, in order to develop medicines and devices more and more tailored to patient needs, which could be, therefore, more efficient in treating conditions. For example, using Additive Manufacturing techniques [38] it is possible design and create personalized products, such as also large prosthetic devices due to its assembly-free and time efficient. As a consequence, this paper aims at tracking down the recent development of Lean Six Sigma as applied to the challenges of the Health Care system [39], while answering the needs of Industry 4.0. Basically, this paper aims at isolating the methodological features and applications of an ever-evolving Lean Six Sigma, and to evaluate the foundations and potential future applications of what we define as Lean Six Sigma 4.0.

2. LEAN SIX SIGMA

Lean and Six Sigma provide two compatible problem-solving methodologies. In both cases, people who do the actual work collaborate in a kaizen event (a team meeting). The team examines the process they are involved with to identify and implement improvements [39].

Put simply, lean typically starts with understanding the added-value for the customer, and then examining a process in detail using value stream mapping (VSM). Incremental improvements involve either eliminating waste (activities, delays, or resources) or incorporating newer technologies that didn't exist when the process was established.

When the VSM identifies a quality issue in a process step, Six Sigma provides a methodology for data driven analysis to define and quantify the types of errors. Statistical analysis is used to identify root causes and implement process improvements that reduce the errors.

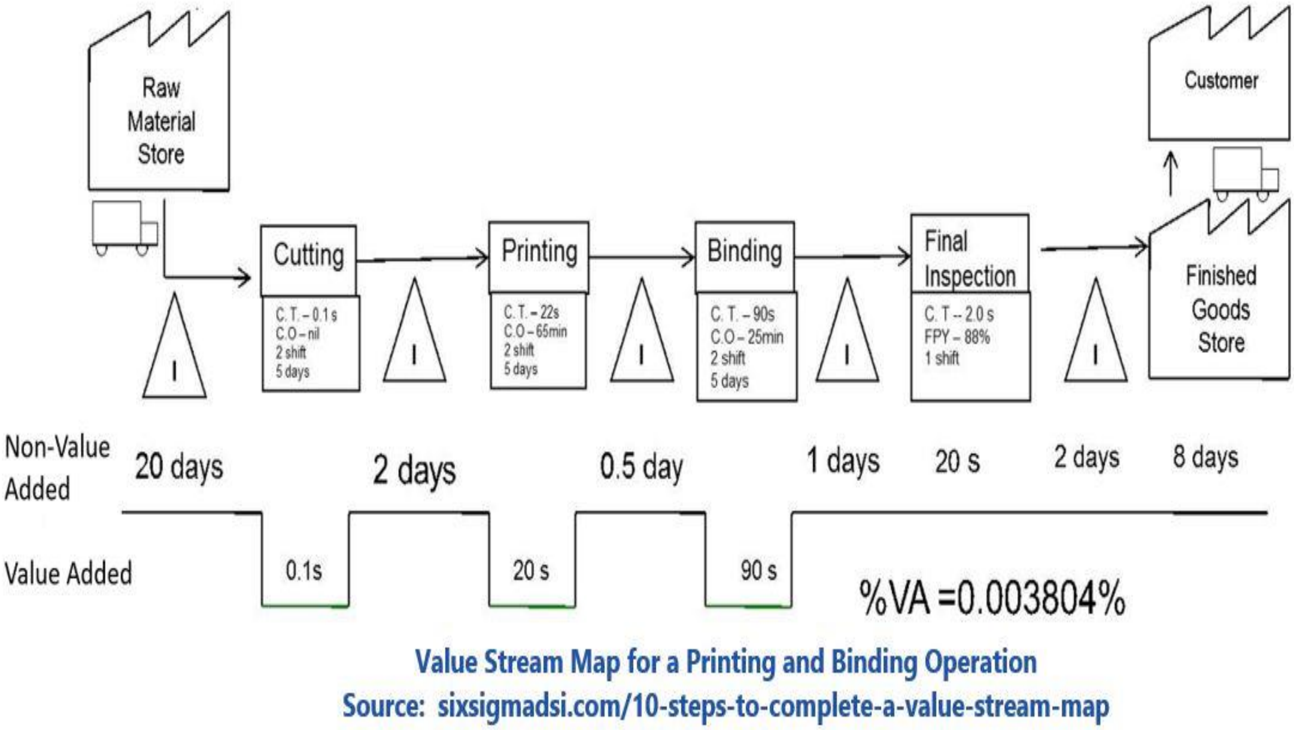

Fig. 1. Value stream mapping

Continuous improvement is a process examining existing activities and processes to identify improvements. These changes can be considered organic in nature because they build on and optimize existing processes. Radical transformation involves creating new processes and new business models[55].

3. INDUSTRY 4.0

Industry 4.0 is a strategic initiative recently introduced by the German government. The goal of the initiative is transformation of industrial manufacturing through digitalization and exploitation of potentials of new technologies. An Industry 4.0 production system is thus flexible and enables individualized and customized products [40]. Industrial production is nowadays driven by global competition and the need for fast adaptation of production to the ever-changing market requests. These requirements can be met only by radical advances in current manufacturing technology [54]. Industry 4.0 is a promising approach based on integration of the business and manufacturing processes, as well as integration of all actors in the company's value chain (suppliers and customers). Technical aspects of these requirements are addressed by the application of the generic concepts of Cyber-Physical Systems (CPS) and industrial Internet of Things (IoT) to the industrial production systems. The Industry 4.0 'execution system' is therefore based on the connections of CPS building blocks. Blocks are embedded systems with decentralized control and advanced connectivity that are collecting and exchanging real-time information with the goal of identifying, locating, tracking, monitoring and optimizing the production processes [41]. Furthermore, an extensive software support based on decentralized and adapted versions of Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) is needed for a seamless integration of manufacturing and business processes. The third important aspect is handling of a big amount of data collected from the processes, machines and products. Typically the data is stored in a cloud storage [53]. Critical factors influencing the cloud computing adoption (CCA) in the manufacturing micro, small and medium enterprises (MSMEs) by employing a decision-making trial and evaluation laboratory (DEMATEL) methodology [42]. Nowadays, the fourth industrial revolution—fourth in the sense of its innovative and qualitative nature—is taking place. On the one hand, the quality of the changes can be seen in the fact that the whole production process is managed and supervised in an integrated way, and is combined, yet flexible. In order to remain competitive in a globalized environment, manufacturing companies need to constantly evolve their production systems and accommodate the changing demands of markets [52]. These, in turn, have a large impact on industry and markets, while affecting the whole life cycle of the product, providing a new means of production and of conducting a business, allowing for an improvement in processes and an increase in the competitiveness of enterprises. Computers, automation and robots existed in previous decades, but the opportunities provided by the Internet revolutionize their use, and the opportunities they provide. The increasingly cheaper solutions allow us to monitor the activities, operation and processes of machines, materials, workers and even products themselves, and to collect, analyze and utilize data in real-time decision making. The fourth industrial revolution is based on data. The way it can be gathered and analyzed, and used to make the right decisions and develop, has become a competitive factor [43].

The source of competitive advantage, therefore, will not only be production on a coordinated or completely new basis (e.g., additive production), but also the embedding of products with digital services (e.g., in the event of a failure, the machine itself indicates which replacement part should be brought in), i.e., how companies filter the relevant information from the generated data in order to support decision-making. In recent decades, manufacturing and production systems have been gradually supplemented by information technology support instruments, because controlling more and more complex technologies, the demands of multi-site production, and supporting logistic processes have become even more complex tasks [51]. The inevitable role of IT (Information Technology) at companies has transformed both working conditions and efficiency, and its importance is unquestionable. Regarding Industry 4.0 readiness, Berger notes that while Hungary is among the most industrialized countries in Europe in terms of manufacturing output versus GDP, the country is below the European average in terms of indicators such as production process sophistication, degree of automation, workforce readiness and innovation intensity. “Industry 4.0” provides the relevant answers to the fourth industrial revolution [44]. The main purpose of Industry 4.0 is to achieve improvements in terms of automation and operational efficiency, as well as effectiveness. Implications of organizational knowledge, source of information and functional orientation, resource-based view of the manufacturing and global orientation, on manufacturing practices which nclude advanced manufacturing strategies [50]. The emerging Industry 4.0 concept is an umbrella term for a new industrial paradigm which embraces a set of future industrial developments including Cyber-Physical Systems (CPS), the Internet of Things (IoT), the Internet of Services (IoS), Robotics, Big Data, Cloud Manufacturing and Augmented Reality. The adoption of these technologies is essential to the development of more intelligent manufacturing processes, which includes devices, machines, production modules and products that are able to independently exchange information, trigger actions and control each other, thus enabling an intelligent manufacturing environment. The objective of this study is to discover how companies operating in Hungary interpret the phenomenon of Industry 4.0, what kind of Internet of Things (IoT) tools they use to support their processes, and what critical issues they face during adaptation. This paper makes two potential major contributions to the body of knowledge. Firstly, and in general terms, it can provide evidence for the uptake of IoT and its impact on value chains, and secondly it provides an insight into a very specific country context (and potentially addresses both economic integration and re-industrialization as current phenomena), which can be a useful benchmark for other Central and Eastern European countries. Following this introduction, the paper is structured as follows [46]. At the beginning of our research, in the literature review we summarize the importance of industrial digitization and create a unified [49].

4. LEAN SIX SIGMA AND INDUSTRY 4.0: A SYNERGY

In 1978, Taiichi Ohno wrote his book on the Toyota Production System (TPS) (the term “Lean Manufacturing” was coined 13 years later). Considering the state of IT in 1978 with punch cards, weekly batch runs, and voluminous printed reports, it is no wonder that Ohno had a bias against technology. Obviously, technology has advanced a long way since then [47].

What impact does Industry 4.0 have on Lean Six Sigma programs? Lean manufacturing methodologies have been deeply internalized into the culture of most industrial companies since the 1990s. Typically, the program has an internal name and is modified slightly to fit the unique needs of a company’s business model and processes [49]. Today, nearly all large and mid-size manufacturers worldwide have a corporate business improvement program based on lean six sigma. For sustained adoption, adding Industry 4.0 must occur in a way that aligns with the lean six sigma culture [48]. Future processes will embed more technology and may become smarter, but they'll remain processes. This trivial reminder is a hint that use cases for Six Sigma will still exist. Capabilities and deviations must be mastered, drifts must be controlled and there will be needs to pinpoint the few influent parameters in an even greater ocean of many. With more automation and the potential faculty to mass-manufacture unique products, the traditional - and sometimes convenient- excuse of lack of repetition in high mix low volume production, hence lack of statistical significance should vanish. Smart automated processes should produce more data and faster to which smart objects will add theirs, creating a permanent data flood [37]. New parameters will be measured by embedded or affixed sensors, like temperature, moisture, acceleration, orientation, pressure, brightness, etc. That's where Six Sigma could need to evolve as this data flood will enter the Big Data world. Analysis of such mass of data will not be done with usual Six Sigma statistical techniques but with scenario correlation analysis. The new statistical management and control models will be multi-criteria base, both because the techniques allow it and the new processes require it Those techniques are said to give predictive and self-learning abilities to machines, smart material and all objects associated; e.g. molds, tools, test benches, ovens, etc [43]. Design of experiment, originally designed to reduce the number of required experiments to the bare minimum in order to isolate the few influent parameters, could go obsolete as High Performance Computing takes over. The latest uses low cost resources (massively paralleled multicore processors) to calculate at high speed large amounts of data, thus allowing exhaustive explorations of several scenarios. Among the three TLS (ToC, Lean & Six Sigma) approaches, Six Sigma is by its nature the one most likely to be passed over to the machines. Future machines and equipments will take over, individually or in collaboration, statistical controls, real time analysis, self corrections, and so on [36]. If I'm right, Black Belt and Master Black Belts expertise can be passed over to machines, maybe even to smart objects. The need for experts will be reduced to those engineering the embedded Six Sigma intelligence. In this future nevertheless, problems will still happen and the way to understand the causes and solve the issues will not change fundamentally. New tools will show up, but good old DMAIC, PDCA, Pareto or fishbone diagrams will still be used. Despite possible transfers to smart devices, problem solving will still require intuition and the kind of reasoning (say gut feeling) machines should not have so soon. Therefore, until artificial intelligence demonstrates human-equivalent abilities, some (human) earthlings will still be required in smart factories. Manufacturers who have already begun their Industry 4.0 implementations have experienced rapid improvements in data accessibility, computational power and connectivity, all made possible using sensors, cloud computing, the Internet of Things (IoT) and Artificial Intelligence (AI) [21]. As a result, there has been an increase in the use of Data Analytics – affectionately called "Big Data," or data collected automatically – to drive business strategies and make solid, fact-based decisions. With more manufacturers generating data at higher rates than previously possible, Big Data Analytics has become a hot topic for manufacturers of all sizes. That's where LSS comes in. Basic data mining techniques such as clustering, association, prediction, classification and process mining algorithms help organizations reach correct and optimal decisions in various stages of LSS. Now, as companies are upgrading to digital operations, the appropriate LSS tools can be applied to expand on initiatives that companies have already started. Most companies have responded to this evolution by "turbo charging" every process-driven operation supported by Big Data that is guided by LSS practitioners [18]. My only hope is that companies do not misunderstand and overestimate their new capabilities and assume they no longer need LSS tools! In reality, when aligning IoT and Industry 4.0 with LSS methodologies, these tried and true tools are made even more relevant. *Why is this?* The need for an established quality process is not going away. Furthermore, these tools empower dynamic and efficient analyses of complex and not-so-complex processes, enabling organizations to better leverage vast amounts of data [6]. This way, companies of all sizes can easily make operations more efficient, improve business intelligence, identify strategic initiatives and provide better products and services to their customers. We all know the cliché…knowledge is power [17]. In this context, that cannot be more true. Managers and employees with knowledge in LSS are better positioned to take an active role in ensuring new technologies are incorporated into their operations in meaningful ways. The large amount of data collected by Industry 4.0 innovations will not do anything for a company if it is not *cleaned and formatted* so it can be *properly analyzed* to provide *informed, actionable insights* that can improve a business. A linguist will always be needed to translate and share the unique story only data can tell us. Therefore, for any operation, it is crucial to start with an LSS framework from the beginning and watch the data-driven transformation emerge, evolve and thrive in the competitive business climate that now demands real IoT decisions. Charles Darwin said it best: "It is not the strongest species that survive, nor the most intelligent, but the most adaptable." The principles of how to run a production line, find defects and bottlenecks, increase capacity, remove waste or work more efficiently, etc., are still part of manufacturing operations [31]. How to modify operations in this new environment is where the adaptation comes into play – by combining what we have learned about manufacturing in the last few decades with all the new benefits of Industry 4.0. Using advanced analytics to solve the same manufacturing challenges we've faced for years just accelerates our ability to reach operational and business excellence [21]. LSS practitioners know where and how to collect data, translate raw data into practical and interesting stories, provide targeted information and develop actionable strategies in response to collected data. Their role will not be diminished because of the massive data available. Instead, their skillset will be needed now more than ever as they are able to guide decision-making around much larger volumes of data better, faster. More importantly, their skillset enables them to sift through Big Data in ways that can be overwhelming for the untrained. Just imagine – what used to be accomplished with a laptop and Minitab [19].

Lean Six Sigma 4.0 The integration of Lean Six Sigma [40], methodology focused on process variability reduction and standardization, with Lean Thinking [41], approach which aims to reduce wastes, has created Lean Six Sigma [32]. These two disciplines have proven to be especially successful when working together [31], and the great success in a variety of industries has led to the fact that its application is not limited to the manufacturing area but is extended to service and public administration industry [42]. Given the growing demand for patient-oriented and efficient health services, Lean and Six Sigma methods are now increasingly used also in hospitals [39], [43], [44], [45], where are used also mathematical advanced models already applied by the authors for different industrial application [45]. Other individual researches [31] have been done in exploring how Lean Six Sigma could be applied to accelerate the process of extracting key insights from Big Data and also how Big Data could bring new light to projects requiring the use of Lean Six Sigma, but the potential to execute LSS was not completely developed. In Toyota Production System Ohno (1988) [46] already introduced between the important pillars also automation with Just in Time: hence automation in production has played an important role and Industry 4.0 allows to advance in this field.

5. CONTINUOUS AND RADICAL CHANGE

Like Lean, Industry 4.0 focuses on business processes. Industry 4.0 involves business process automation and data exchange using the Internet of Things (IoT), cloud computing, analytics, machine learning and artificial intelligence. Some have broadened Industry 4.0 to include a variety of newer technologies including 3D scanning, additive manufacturing, blockchain, augmented reality, virtual reality, and drones [37].

Continuous: Usually, applying Industry 4.0-associated technologies dramatically improves an existing business process. Using VSM provides a higher rate of sustainable success. This includes digitalization, such as replacing paper-based procedures with a digital workflow and mobile devices.

Radical: Occasionally, Industry 4.0 and related technologies enable a more radical digital transformation or a new business model. An example of a new business model is equipment as a service. Rather than purchasing an asset, a company can rent it with a service-level agreement that employs condition monitoring using IoT and analytics for predictive maintenance.

Applying Industry 4.0 typically involves continuous types of improvement and, only occasionally, radical approaches. This report focuses on the continuous improvement.

Digitalization Enhances Continuous Improvement Industry 4.0 includes data acquisition, analytics, and collaboration that enable faster consensus building among the kaizen event members and improved speed of execution [23]. Kaizen teams are often thwarted by a lack of data for analysis that impedes collaboration and blocks progress – particularly with Six Sigma. Industry 4.0 involves technologies to overcome each of these impediments using:

- Automated data collection with IoT
- Data management in cloud platforms

- Advanced analytics for problem identification
- Automated business processes that ensure compliance with the change

VSM Can Identify Industry 4.0 Applications
Use VSM to identify practical applications of advanced technologies [18]. After creating the "as is" version of the graphical map, the team looks to identify waste and eliminate it. Industry 4.0 adoption enables examination of the value stream map for process automation with the newer technologies mentioned previously. This VSM approach provides a repeatable methodology for evaluating and adopting technology with clear business benefit and user support [15].

ARC Advisory Group clients can view the complete report at ARC Client Portal. If you would like to buy this report or obtain information about how to become a client, please Contact Us by aligning Lean and Six Sigma with Industry 4.0 technologies, manufacturers can drive continuous improvement, maximise efficiency and enhance customer value.

The data and digital technologies labelled as *Industry 4.0* (I4) – or *Fourth Industrial Revolution* (4IR) depending on your preference – have been evolving for many years [49]. But perhaps not as long as Lean and Six Sigma approaches, which were "born" in manufacturing and have more often been applied in factory operations.

All have their devotees, often with very different types of expertise. SAP hosted a vivid discussion facilitated by *The Manufacturer* between senior leaders in construction, automotive, aerospace, electronics, materials and printing sectors to consider the implications of Lean and Six Sigma on I4 and vice versa [53].

This experienced group considered how Lean and Six Sigma could enhance and be enhanced by the take-up and benefits of I4. Peaceful co-existence is not an option. Six Sigma is probably the best known, data-driven quality programme. New powers to analyse vast quantities of structured data from I4 technologies are already being exploited by Six Sigma practitioners. It seems that while I4 data will inevitably increase the impact not just of Six Sigma but of quality programmes generally, which could create tensions with existing tools and techniques [52]. So, practitioners of Six Sigma could be challenged to adopt and adapt to I4 or be overtaken. The potential synergies between I4 and Lean generated heated discussion in the SAP forum. Lean is of course an employee-led continuous improvement regime, whereas I4's advances were often considered to be from technocrats. The common ground is people – workforce and customers.

The scope therefore of new connections identified under the banner of I4 is comprehensive, and they all impact the way people do things including responding to customers.

These I4 connections include:
- Products; from predictive maintenance and accelerated product improvement to automated re-supply
- Assets; from improved health and safety management to optimized service delivery
- Fleet; from performance optimization and usage based billing to compliance management
- Infrastructure; from optimized energy usage to security and safety management
- Markets; from dynamic agri-product pricing to individualized marketing

The potential for positive influences of I4 on Lean continuous improvement and Six Sigma control are clear; but what about the roles of Lean and Six Sigma in accelerating the application of I4 and return on investment?

The SAP forum of senior manufacturers identified three key factors that will determine the speed and direction of change:
1. Lean should ensure that customer engagement is connected by I4
2. Lessons need to be learned from recent history to ensure I4 is embraces them
3. Implementation of new digital technologies needs to be risk managed

Where once only our computers, phones and gadgets were connected to the internet, the internet of things (IoT) is now making it a truly connected world. Cars, appliances, road signs, weather stations, pollution detectors, medical patients, even farm animals – if anyone or anything can have a sensor put on it, it can be a part of IoT [22]. IoT is part of what is called Industry 4.0, or the fourth major upheaval in the history of industry. It is most associated with manufacturing but can be applied to many other industries.

Industry 4.0 involves the following factors:

- The rapid increase in the amount of data, computational power and connectivity (IoT is a major driver in this area)
- The increased use of data analytics to drive business strategy
- The emergence of machine learning and artificial intelligence
- Advances made in transferring digital instructions to the physical world (obviously, another big IoT area)

6. USES OF IOT

What all this means for businesses is the ability to gather information from objects and people in the "real world" through sensors that share information with each other as well as being connected to the internet [56]. The data gathered from the IoT will mean even more information for organizations to use in streamlining operations. For example, it can help supply chain managers know where trucks, trains and ships are in the supply route, as well as the amount of inventory in a warehouse. For healthcare operations, sensors worn by patients can transmit real-time data on their physical condition to medical professionals far away. It's also the technology behind the invention of autonomous cars [27]. By 2020, projections call for 26 billion devices to be connected to the IoT.

7. LEAN SIX SIGMA AND IOT

As with all things involving data, the challenge has moved from collecting and storing data to figuring out the best ways to put it to use. That's where the tools and techniques of Lean Six Sigma can come into play [31].

With the IoT, the amount of data available will grow even larger than it already is today. For example, retailers will have finely grained information on customers' buying habits. Manufacturers will have details on every phase of any process. Transportation officials will have a better grasp on where problems are occurring in a city and how to allocate tax dollars to improve roadways and provide better public transportation [29]. However, before it can be used, data must be cleaned and formatted in a way that it can be analyzed for the type of insights that can improve a business [19]. That's the first step in any Lean or Six Sigma process – analyzing the data to find out where an operation stands and what changes need to be made. By aligning IoT and Industry 4.0 with Lean Six Sigma methodology, organizations can better leverage vast amounts of data to make operations more efficient and provide better products and services to customers [51].

8. APPLYING LEAN SIX SIGMA

In a way, IT should be viewed as another channel to gather data. Turning that data into actionable business intelligence still requires a consistent and successful strategy. That means using proven methods such as Lean Six Sigma [22]. Six Sigma focuses on eliminating defects in a process. Lean focuses on cutting out waste in a process by keeping only those steps that add value to the end user. With the big data that IoT will provide organizations, the tools and techniques provided by Six Sigma are more important than ever [31]. For example, studies have already been done on applying Lean Six Sigma to supply chains. Managing supply chains have become more complex and competitive, with businesses now having a global reach and all of them are trying to beat each other on providing the best service [16].

Fig. 2. Industry 4.0

In this study, researchers found that a "Lean Six Sigma approach in global supply chain using Industry 4.0 and IoT creates an ideal process flow that is highly optimized as well as perfect and free from defects and wastage.". While only a theory, the study provides a blueprint for those wanting to couple Lean Six Sigma quality control and continuous process improvement with the potential of IoT and Industry 4.0.

9. THREE AREAS OF FOCUS

Businesses and consultants have started to dig deep into the use of Lean Six Sigma and the expansion in the amount of available data. The demand for quality control and process improvement is high. Otherwise, organizations might find themselves lost in a forest of data.

In The Manufacturer, a website that focuses on the manufacturing industry, three areas were identified where Lean Six Sigma can accelerate implementation of new technologies:

- Ensuring that customer engagement remains forefront as organizations move into Industry 4.0
- Using the lessons learned from previous advances in technology to optimize the use of IoT
- Using risk assessment in the implementation of IoT and Industry 4.0

IoT and Industry 4.0 offer businesses advantages in data collection and potential business intelligence. However, the need for a quality process to be in place has not diminished. Managers and employees with knowledge in Lean Six Sigma continuous process improvement are better positioned to take an active role in ensuring that new technologies are incorporated into an operation in a meaningful way. They also will understand that no leap forward in technology will give an organization an advantage without having a solid process in place, such as the framework provided by Lean Six Sigma.

REFERENCES

[1] Schwab K., Davis N. (2018) "Shaping the Fourth Industrial Revolution", Book ISBN–978-1 944835-14-9.

[2] Pieroni A., Scarpato N., Brilli M. (2018). Performance Study in Autonomous and Connected Vehicles, an Industry 4.0 Issue. Journal of Theoretical and Applied Information Technology January 2018, Vol. 96 No.2 E-ISSN 1817-3195 / ISSN1992-8645.

[3] Pieroni A., Scarpato N., Brilli M. (2018). Industry 4.0 Revolution in Autonomous and Connected Vehicle A non-conventional approach to manage Big Data. Journal of Theoretical and Applied Information Technology January 2018 Vol. 96 No.1 E-ISSN 1817-3195 / ISSN1992-8645.

[4] F. Guadagni et al., (2017). RISK: A Random Optimization Interactive System Based on Kernel Learning for Predicting Breast Cancer Disease Progression. In Bioinformatics and Biomedical Engineering: 5th International Work-Conference, IWBBIO 2017, Granada, Spain, April 26--28, 2017, Proceedings. Part I, I. Rojas and F. Ortuño, Eds. Cham: Springer International Publishing, 2017, pp.189–196.

[5] A. R. D. Accardi and S. Chiarenza. (2016). Musei digitali dell'architettura immaginata: un approccio integrato per la definizione di percorsi di conoscenza del patrimonio culturale Digital museums of the imagined architecture: an integrated approach. DISEGNARECON, vol. 9.
[6] M. Pennacchiotti and F. M. Zanzotto. (2008). Natural Language Processing Across Time: An Empirical Investigation on Italian," Springer, Berlin, Heidelberg, pp. 371–382.
[7] R. Beccaceci, F. Fallucchi, C. F. Giannone, F. Spagnoulo, and F. M. Zanzotto. (2009). Education with 'living artworks' in museums," in CSEDU 2009 – Proceedings of the 1st International Conference on Computer Supported Education, 2009, vol.1.
[8] Arcidiacono, G., De Luca, E.W., Fallucchi, F., Pieroni, A. (2016). "The use of lean six sigma methodology in digital curation", CEUR Workshop Proceedings.
[9] M. T. Pazienza, N. Scarpato, and A. Stellato. (2009). STIA*: Experience of semantic annotation in Jurisprudence domain. In Frontiers in Artificial Intelligence and Applications, 2009, vol. 205, pp. 156–161.
[10] M. Bianchi, M. Draoli, G. Gambosi, M. T. Pazienza, N. Scarpato, and A. Stellato. (2009). ICT tools for the discovery of semantic relations in legal documents. In CEUR Workshop Proceedings, 2009, vol. 582.
[11] G. Boella, L. Di Caro, L. Humphreys, L. Robaldo, P. Rossi, and L. van der Torre. (2016). "Eunomos, a legal document and knowledge 148 management system for the Web to provide relevant, reliable and uptodate information on the law. Artif. Intell. Law, vol. 24, no. 3, pp.245–283, Sep.2016.
[12] V. Morabito (2015). Big Data and Analytics for Government Innovation. Big Data Anal. Strateg. Organ. Impacts, pp. 23–45, 2015.
[13] Zanella Andrea, et al. (2014). Internet of things for smart cities. IEEE Internet Things J. 1.1, pp. 22–32.
[14] F. Fallucchi, E. Alfonsi, A. Ligi, and M. Tarquini. (2014). Onto logy driven public administration web hosting monitoring system, vol. 8842.
[15] M. Bianchi, M. Draoli, F. Fallucchi, and A. Ligi. (2014). Service level agreement constraints into processes for document classification. In ICEIS 2014 - Proceedings of the 16th International Conference on Enterprise Information Systems, 2014, vol. 1
[16] D. Zhang, L. Zhou, and J. F. Nunamaker Jr. (2002) A Knowledge Management Framework for the Support of Decision Making in Humanitarian Assistance/Disaster Relief. Knowl. Inf. Syst., vol. 4, no. 3, pp. 370–385, Jul. 2002.
[17] F. Fallucchi, M. Tarquini, and E. W. De Luca. (2016). Knowledge management for the support of logistics during Humanitarian Assistance and Disaster Relief (HADR), vol. 265.
[18] A. D'Ambrogio et al. (2017). Use of integrated technologies for fire monitoring and first alert," in Application of Information and Communication Technologies, AICT 2016 -Conference Proceedings, 2017, pp. 1–5.
[19] Scarpato N., Pieroni A., Di Nunzio L., Fallucchi F, 2017, "E-health IoT Universe: A Review", International Journal on Advanced Science, Engineering and Information Technology, Vol. 7 (2017) No. 6, pages: 2328-2336, DOI:10.18517/ijaseit.7.6.4467.
[20] Iazeolla, G., Pieroni, A., D'Ambrogio, A., Gianni, D. (2010). A distributed approach to wireless system simulation. 6th Advanced International Conference on Telecommunications, AICT 2010, art. no. 5489830, pp. 252-262.
[21] D'Ambrogio, A., Gianni, D., Iazeolla, G., Pieroni, A. Distributed simulation of complex systems by use of an HLA-transparent simulation language. (2008). Asia Simulation Conference - 7th International Conference on System Simulation and Scientific Computing, ICSC 2008, art. no. 4675405, pp. 460-467.
[22] Iazeolla, G., Pieroni, A., D'Ambrogio, A., Gianni, D. (2010). A distributed approach to the simulation of inherently distributed systems. Spring Simulation Multiconference 2010, SpringSim'10, art. no. 132.
[23] Bocciarelli, P., Pieroni, A., Gianni, D., D'Ambrogio, A. (2012). A model-driven method for building distributed simulation systems from business process models (2012) Proceedings – Winter Simulation Conference, art. no. 6465106.

[24] D'Ambrogio, A., Gianni, D., Risco-Martín, J.L., Pieroni, A. (2010). A MDA-based approach for the development of DEVS/SOA simulations. Spring Simulation Multiconference 2010, SpringSim'10, art. no. 142.

[25] Gianni, D., D'Ambrogio, A., Iazeolla, G., Pieroni, A. (2008) Producing simulation sequences by use of a java-based generalized framework. Proceedings - EMS 2008, European Modelling Symposium, 2nd UKSim European Symposium on Computer Modelling and Simulation, art. no. 4625266, pp. 171-176.

[26] D'Ambrogio, A., Iazeolla, G., Pieroni, A., Gianni, D. (2011). A model transformation approach for the development of HLA-based distributed simulation systems. SIMULTECH 2011 - Proceedings of 1st International Conference on Simulation and Modeling Methodologies, Technologies and Applications, pp. 155-160.

[27] Iazeolla, G., Pieroni, A. (2014). Energy saving in data processing and communication systems. Scientific World Journal, art. no. 452863.

[28] Cardarilli, G.C., Di Nunzio, L., Fazzolari, R., Pontarelli, S., Re, M., Salsano, A. (2011), "Implementation of the AES algorithm using a Reconfigurable Functional Unit", ISSCS 2011 – International Symposium on Signals, Circuits and Systems, Proceedings, art. no. 5978668, pp. 97-100.

[29] Cardarilli, G.C., Di Nunzio, L., Fazzolari, R., Re, M., Lee, R.B. Integration of butterfly and inverse butterfly nets in embedded processors: Effects on power saving (2012) Conference Record - Asilomar Conference on Signals, Systems and Computers, art. no. 6489268, pp. 1457-1459.

[30] Sanders A, Elangeswaran C, Wulfsberg J, (2016). "Industry 4.0 implies Lean Manufacturing: research activities in Industry 4.0 function as enablers for Lean Manufacturing", Journal of Industrial Engineering and Management, - 9(3): 811-833.

[31] Fogarty D, (2015). "Lean Six Sigma and Big Data: continuing to innovative and optimize business process", Journal of Management and Innovation, Fall 2015 1(2).

[32] Arcidiacono G, Costantino N, Yang, K, 2016, "The AMSE Lean Six Sigma Governance Model", International Journal of Lean Six Sigma, Vol. 7, Issue 3; pp. 233-266, doi: 10.1108/ IJLSS-06-2015-0026

[33] Gijo, E.V., Antony, J., Reducing patient waiting time in outpatient department using lean six sigma methodology (2014) Quality and Reliability Engineering International, 30 (8), pp. 1481-1491.

[34] Hicks, C., McGovern, T., Prior, G., Smith, I., Applying lean principles to the design of healthcare facilities (2015) International Journal of Production Economics, 170, pp. 677-686.

[35] Moraros, J., Lemstra, M., Nwankwo, C., Lean interventions in healthcare: Do they actually work? A systematic literature review (2016) International Journal for Quality in Health Care, 28 (2), pp. 150-165.

[36] Walshe, K. Pseudo Innovation: The development and spread of healthcare quality improvement methodologies (2009) International Journal for Quality in Health Care, 21 (3), pp. 153-159.

[37] Van Der Meulen, F., Vermaat, T., Willems, P., Case study: An application of logistic regression in a six sigma project in health care (2011) Quality Engineering, 23 (2), pp. 113-124.

[38] W. Gao et al. (2015). ""The status, challenges, and future of additive manufacturing in engineering". Computer-Aided Design 69, page. 65–89.

[39] Arcidiacono G, Wang J, Yang, K, 2015, "Operating room adjusted utilization study", International Journal of Lean Six Sigma, Vol. 6, Issue 2; pp.111 – 137, doi: 10.1108/ IJLSS-02-2014-0005

[40] Arcidiacono G, Calabrese C, Yang K, 2012, "Leading processes to lead companies: Lean Six Sigma", Springer, ISBN 978-88-470-24922.

[41] Womack J, Jones D. (2003). "Lean Thinking". New York, NY: simon &Schuster.

[42] Arcidiacono G, Matt DT, Rauch E, 2017, "Axiomatic Design of a Framework for the Comprehensive Optimization of Patient Flows in Hospitals", Journal of HealthCare Engineering, Vol. 2017, Article ID 2309265, 9 pp. doi: 10.1155/2017/2309265

[43] Walshe, K. Pseudo innovation: the development and spread of healthcare quality improvement methodologies. Int J Qual Health Care 2009; 21: 153-159.

[44] Brandao de Souza, L., (2009). "Trends and approaches in Lean healthcare". Leadership in Health Services 2009; 22: 121–139.
[45] Arcidiacono G, Berni R, Cantone L, Placidoli P, 2017, "Kriging models for payload-distribution optimization of freight trains", International Journal of Production Research, Vol. 55, No. 17, 48784890, doi: 10.1080/00207543.2016.1268275
[46] Ohno T, (1988). "Toyota Production System: beyond large-scale production", Cambridge, Mass: Productivity Press.
[47] Spath D, Ganschar O, Gerlach S, Hämmerle M, Krause M, Schlund S., (2013). "Produktionsarbeit der Zukunft". Stuggart: Fraunhofer erlag.
[48] Wan J, Cai H, Zhou K, (2015). "Industrie 4.0 Enabling technologies", International Conferences on Intelligent Computing and Internet of Things (ICIT), IEEE 2015, Harbin, China, 135-140.
[49] Giorgetti A, Cavallini C, Ciappi A, Arcidiacono G, Citti P, (2017). "A holistic model for the proactive reduction of non-conformities within new industrial technologies", International Journal of Mechanical Engineering and Robotics Research, vol. 6(4), pp. 313317.
[50] Sodhi, H.S., Singh, G., and Mangat, H.S., "Optimization of end milling process for d2 (die steel) by using response surface methodology", Journal of Production Engineering, 2014, Vol.17, No.2., pp. 73-78.
[51] Sodhi, H.S., and Singh, B.J., (2014), "Parametric optimisation of CNC turning for Al-7020 with RSM", International Journal of Operation Research, Vol. 20, No.2, pp. 180–206.
[52] Sodhi, H.S., and Singh, H., 2013. "Parametric Analysis of Copper for Cutting Processes Using Turning Operations Based on Taguchi Method", International Journal of Research n Mechanical Engineering & Technology, Vol. 3, No. 2, pp. 202-204.
[53] Sodhi, H.S., Dhiman, D.P., Gupta, R.K., and Bhatia, R.S., (2012), "Investigation of Cutting Parameters for Surface Roughness of Mild Steel n Boring Process Using Taguchi Method", International Journal of Applied Engineering Research, Vol. 7, No. 11.
[54] Sodhi, H.S., Singh, D. and Singh, B.J. (2019) 'An empirical analysis of critical success factors of Lean Six Sigma Indian SMEs', nt. J. Six Sigma and Competitive Advantage, Vol. 11, No. 4, pp.227–252.
[55] Sodhi. H.S., Singh, D., and Singh, B.J., (2019), "Developing a Lean Six Sigma conceptual model and to Implementation: a case study", Industrial Engineering Journal, Vol.12, No.10, pp. 1-19.
[56] Balkrishna Eknath Narkhede, (2017)," Advance manufacturing strategy and firm performance An empirical study n a developing environment of small- and medium-sized firms ", Benchmarking: An international Journal, Vol. 24 ss 1 pp. 62 – 101.

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