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Procedia Computer Science 200 (2022) 934–943

Procedia Computer Science

www.elsevier.com/locate/procedia

3rd International Conference on Industry 4.0 and Smart Manufacturing

How to adapt lean practices in SMEs to support Industry 4.0 in manufacturing

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Abstract

Industry 4.0 promises to increase productivity and flexibility for the manufacturing industry, which translates into greater customer value and lower costs. Lean manufacturing has long championed principles and tools with a focus on value adding activities, elimination of waste and continuous improvement. Even the most successful lean manufacturing firms, in terms of efficiency and quality achieved through waste reduction, will acknowledge there is a lot of opportunity for improvement. This review evaluates how lean principles can support Industry 4.0 in pursuit of greater customer value and manufacturing excellence. Leveraging the opportunities that exist within Industry 4.0 umbrella of technologies can help to further reduce the nine wastes of lean. While large corporations have access to extensive capital markets and can capture economies of scale offered by leading edge technologies of Industry 4.0, small and medium sized enterprises (SMEs) with greater capital restraints face the challenge of justifying Industry 4.0 technologies and cannot risk being at the bleeding edge of technology. Using a case study of a small electronics manufacturing firm, the opportunities, challenges, and the implementation strategy for technology are examined. This paper finds that SMEs pursuit of process efficiencies and waste reduction can be best achieved through a focus on foundational digitalization & data management then taking a stepwise approach towards the cyber-physical systems of Industry 4.0.

Peer-review under responsibility of the scientific committee of the 3rd International Conference on Industry 4.0 and Smart Manufacturing

Keywords: Industry 4.0; lean manufacturing; lean 4.0; change management.

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Peer-review under responsibility of the scientific committee of the 3rd International Conference on Industry 4.0 and Smart Manufacturing
10.1016/j.procs.2022.01.291

1. Introduction

Lean manufacturing, a system that pursues continuous improvement and integration of labor with a clear focus on value adding activities and elimination of waste, has been widely recognized and accepted in manufacturing [1]. Introduction of cyber physical systems (CPS), and industrial internet of things (IIoT) into the manufacturing environment is making way for the fourth industrial revolution [2]. The 4th industrial revolution (Industry 4.0), also known as industrial internet, smart manufacturing, smart factory, and an integrated industry, is at the forefront of improvements related to higher flexibility and adaptability of production systems [3]. Both Industry 4.0 and lean manufacturing seek to increase productivity and flexibility [4]. Optimization targets of lean and digital manufacturing have attracted attention to research new improvement approaches in production systems that comes with the combination of these two systems.

The objectives of Industry 4.0 are in line with the goal of reducing lead times and costs, to steadily increase productivity, and enable continuous improvement cycles [5]. Industry 4.0 technologies are deemed as a strategy to make manufacturing process more efficient whilst improving product quality, but the process of integration of the technology into the existing production systems and the processes that the technology can support continues to evolve [6]. In the advent of wide range of new technologies, and varieties of terms, companies face a challenge in developing customized implementation plan [7]. This study evaluates potential opportunities for Industry 4.0 to make lean manufacturing more efficient.

This poses the following question: *What is the best approach for efficient manufacturing? Lean Manufacturing, Industry 4.0, Lean Manufacturing then Industry 4.0, or Lean and Industry 4.0 developed together?* This paper explores the proposed answers to this question, based on current literature, and discusses its implementation in an electronics company in Canada.

2. State of the art

2.1. Lean Manufacturing

Driven by limited access to resources, lean manufacturing is a systematic method of focusing on customer value, reducing waste and continuous improvement of standardized work through innovation. For the last three decades, lean management is one of the most widely used business strategy [8]. Mass production practices have been successfully challenged by lean production systems, delivering quality products while reducing non-value-added activities [9]. By focusing on value adding activities, application of lean can boost the performance of a company significantly [10]. Buer et. al. identified lean manufacturing as a process that is focused on elimination of wastes in production process through identification of unnecessary activities, streamlining of the process, and creation of standardized practices [4]. Lean manufacturing is mostly seen as a potential way to improve productivity and reduce cost in manufacturing companies [11]. Senkayas H. & Gursoy O. also noted that in many industrial enterprises, lean production techniques give significant benefits by elimination of waste, for improvement in efficiency, flexibility, and speed of response in production [12].

Mayr et al. identified value stream mapping (VSM), just in time (JIT), heijunka, total productive maintenance (TPM), visual management (VM), kanban, single-minute exchange of die (SMED), and poka-yoke as specific lean methods [10]. Just in time (or just in sequence) aims to make the right product, with the right quality, right quantity, and right cost available at the right time and place. Kanban ensures that a predefined stock level is maintained to ensure continuous material flow. Heijunka reduces wastes in form of overproduction by producing what is demanded by the customer. SMED targets reduction of downtime and cost that is caused by the setup process.

2.2. Industry 4.0

Bauer et al. referred to Industry 4.0 as an umbrella term for digital concepts such as Internet of things, big data, digital twin, data analytics, digital shadow, and cyber-physical systems. Industry 4.0 holds the promise of increased manufacturing flexibility, better quality, mass customization and improved productivity [13]. It allows companies to deal with the challenge of producing individualized product with higher quality, within a shorter lead time to market

[14]. Industry 4.0 includes a set of state-of-the-art technologies that are linked to the internet with the aim of making production systems more collaborative and flexible [9]. Davies et al. also noted that Industry 4.0 holds a promise of cost reduction and increase in efficiency [15]. According to Lu, Industry 4.0 is closely related to enterprise architecture, enterprise integration, cyber-physical systems, information and communications technologies, and internet of things [16]. Hofmann & Rusch identified key components in Industry 4.0 as cyber physical systems (CPS), internet of services, internet of things, and smart factory [3]. Table 1 summarizes the terms and technologies grouped under the Industry 4.0 umbrella.

Table 1. The 'umbrella' of Industry 4.0 Technologies categorized by those that enable connectivity, those that manage & analyse data, and those technologies integrated within a cyber physical system.

CYBER PHYSICAL SYSTEMS (CPS)	DATA MANAGEMENT	CONNECTIVITY
Automation *Virtual / Augmented Reality* *Advanced Robotics* *Unmanned Vehicles / Drones* *Additive Manufacturing* *Situational Awareness*	*Big Data* *Artificial Intelligence (AI)* *Machine Learning* *Machine Vision* *Blockchain* *Digital Twinning* *Knowledge Modeling*	*nG Connectivity* *Internet of Things* *Wireless Communications* *Satellite Communications* *Near Field Communications* *Cloud Computing* *Serial Communications* *4/20 (integrating old tech)* *Data Exchange* *Data Standards*

Fettermann & Tortorella noted that Industry 4.0 technologies are positively associated with lean production practices, and the concurrent implementation of the two technologies leads to a bigger improvement in performance [6]. The so-called fourth industrial revolution is based on an intelligent and completely automated production that has the capability of communicating with the major corporate players [17]. Industry 4.0 systems are flexible and allows for individualized and customized products [18].

The concept of Industry 4.0 is not limited to the direct manufacturing in the company, it comprises an overall value chain for providers, enterprise business function, services, and customers; it assumes broad support of an entire lifecycle of systems, series and products that are distributed organizationally and spatially to the extent that smart products can continue to provide useful data (such as can be used for preventive maintenance) during their lifetime. As a specialization of internet of things that is applied to manufacturing environment, Industry 4.0 assumes real time data collection, generating issue about handling, and analysis of huge data, with cybersecurity [18].

Buer et al. operationalize Industry 4.0 as the use of intelligent products and processes that allows autonomous data collection and analysis, including the interaction between products, customers, suppliers, and processes through the internet [4]. Piccarozzi et al. noted that the fourth industrial revolution is a broad field that includes production processes, data management, efficiency, competitiveness, and its relationship with customers [17]. Among other things, part of the vision laid out for Industry 4.0, by the Industry 4.0 working group, includes characterization of Industry 4.0 as a new level of socio-technical interaction that revolves around a network of manufacturing resources that will be self-configuring, sensor-equipped, knowledge-based, having the capabilities of controlling themselves in response to different situations, spatially dispersed, incorporating relevant planning and management systems [19]. But still researchers and practitioners have difficulty in establishing a standard set of elements that make up Industry 4.0, how the elements are related and where I4.0 is applicable [4]. Recommendations imply following basic tenets of lean, using 'data, testing and application' to evaluate where Industry 4.0 can improve lean procedures.

3. Integrating Industry 4.0 into Lean Manufacturing - Smart Factory (Lean 4.0)

Partial and often limited knowledge about lean production leads to misconception that the two approaches (Industry 4.0/smart factory and lean production) are not compatible [20]. Sony noted that lean management can contribute towards the implementation of Industry 4.0 but there is a shortage of studies that promotes the integration of Industry 4.0 with lean management [8]. Industry 4.0 will not make lean obsolete, rather both manufacturing systems will generate mutual dependency [21]. Doh et al. categorized two factors that play a major role in helping industrial organization meet the growing need for competitiveness, and delivery of high-performance products that meet quality standards at reduced production cost as: (1) Widespread application of automation technologies (Industry 4.0), and (2) adoption of lean philosophy, focusing on effectiveness, waste reduction and efficiency by emphasizing the important values that must be delivered to customers [22]. The methodologies for Industry 4.0 and lean manufacturing or six sigma initiative are mutually supportive [15]. Sanders et al. noted that the design principles of Industry 4.0 and lean management tools reveal a lot of opportunities for achieving synergies that is expected to result in successful implementation of interconnected smart factories in future [11]. To evaluate how lean production systems supports Industry 4.0, Wagner et al. focused on integration of technical perspectives of cyber physical system into an industrial environment [23]. For example, the cyber physical just in time delivery was described as an information technology system that is designed to support the just-in-time material flow process in lean production system. CPS just in time delivery aims at creating a gapless flow of information between manufacturing order, materials (delivery, stock, and consumption), and the supplier's automatic purchase order. Movement of every material is detected by sensors and recorded in the big data architecture. In the context of just in time, main parts of waste are work in process, safety stock, and overproduction. To reduce these types of wastes, every supplier will only produce what customer needs in small batches. Wagner et al. also identified cyber physical systems as the main key technology for Industry 4.0, and further noted that data acquisition and processing are the enabler of cyber physical systems [23]. Fig. 1. illustrates the relationship between elements of each technology involved in the Industry 4.0 revolution.

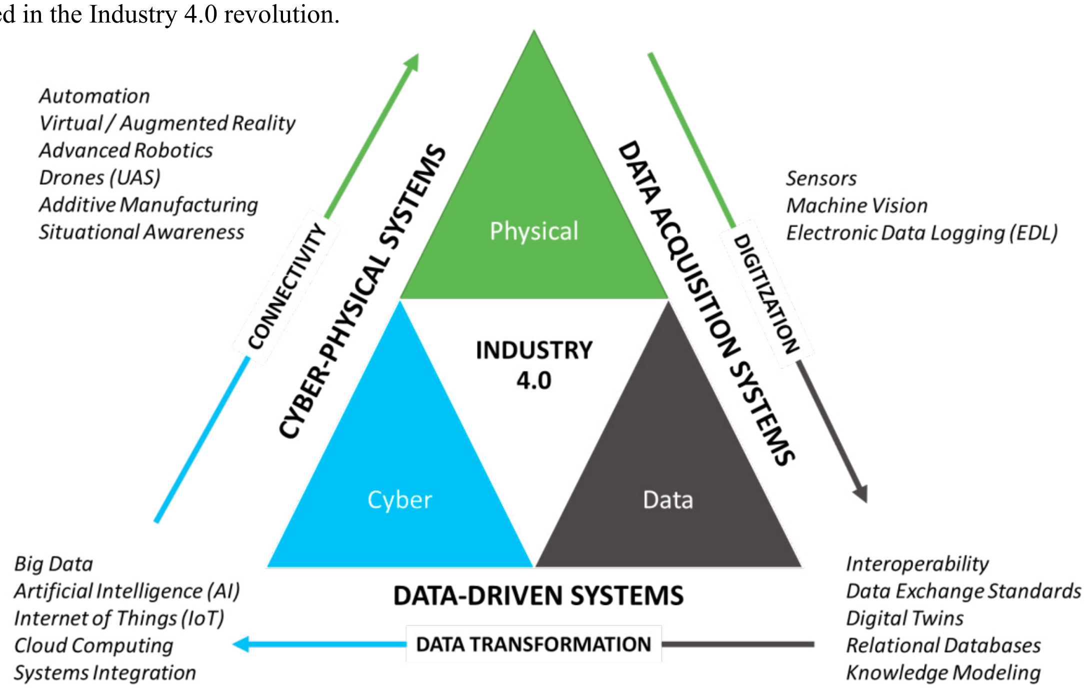

Fig. 1. Illustration of the interrelationship of Industry 4.0 and the process of digitizing the physical world, leveraging data, and optimizing the physical system through cyber-physical systems.

Previous studies show that there are mixed opinions about Industry 4.0. Vita, in a study about integration of lean manufacturing and Industry 4.0, and the impact on organizational performance used online questionnaires (from 212 companies) which measures the implementation level of lean manufacturing and Industry 4.0 [24]. Surprisingly, Vita found that although there is a positive and high correlation between Industry 4.0 and lean manufacturing, the impact of Industry 4.0, lean manufacturing, and that of the integrated approach are statistically non-significant. Malavasi & Schenetti noted that Industry 4.0 will either have a sustaining or a disruptive impact on lean performance [25]. Sustaining impact was referred to as a positive impact on lean performance, while disruptive impact refers to the radical change that Industry 4.0 is expected to bring. In a sustaining perspective, the authors identified internet of things and data analytics as sustaining elements for waste reduction. Similarly, advanced automation was identified as a sustaining element for Jidoka, cloud computing for just in time, human-machine interfaces for visual management, and interoperability for stable and standardized processes. Additive manufacturing was identified as a disruptive element for just in time; autonomous automation (CPS) was identified as a disruptive element for Jidoka, and manufacturing as service (maas) was identified as the disruptive Industry 4.0 element for stable and standardized processes. Based on previous work by Womack et al. [26], the authors presented a data model for comparison of lean principles and Industry 4.0, which is summarized in Table 2.

Table 2. Comparison of model principle for Lean 4.0 and Industry 4.0. Adapted from [25].

Adding Value		Mapping of the Value Stream		Ensuring Continuous Flow		The Pull Approach		The strive For Perfection	
Lean	Industry 4.0	Lean	Industry 4.0	Lean	Industry 4.0	Lean	Industry 4.0	Lean	Industry 4.0
Listen to the Client	Anticipate the needs of the Client	Focus in on value adding activities	Focus is on value adding information	Ensure flow of product	Ensure flow of data	Ensure Pull Production	Ensure pull of production and services	Improve Continuously	Transfer internet principles into manufacturing

From here, several areas of potential opportunities that are expected from the integration of Industry 4.0 with lean manufacturing includes:

Interconnectivity: through the Internet of Things (IoT), interoperable machines, sensors, and devices connect and communicate.

Information transparency: connection of data and information across the manufacturing process is hoped to allow for process optimization.

Technical assistance: through a real-time aggregation and analysis of process and system data, I4.0 is hoped to allow for a faster identification of issues, and implementation of appropriate decisions.

Decentralized decisions: connected system elements can autonomously make operational decisions. But exceptions, interferences, or conflicting goals, are elevated to a higher level of decision making.

Other potential areas of opportunities that exist in integration of Industry 4.0 with lean manufacturing includes:

- Mass-customization of products to suit customer’s demands.
- Greater resource efficiency, more efficient maintenance systems, reduced overheads, and accelerated development of improved and/or new products.
- Opportunities to access new markets and supply chains.

4. What is required for lean manufacturing processes to support Industry 4.0?

This study evaluates the requirement for integration of Industry 4.0 with lean manufacturing. Depending on the nature, and size of project, a production system may generate big data that requires cloud computing and storage systems. Reliable software systems are hoped to facilitate data analysis, and autonomous decision making. Sharma & Gandhi categorized four major perspectives in Industry 4.0 as: manufacturing process, software, devices, and engineering [21]. The devices include objects such as programmable logic controllers, portable devices, workstations, servers, automation devices, etc. The software includes control software, production management software, business management software, etc. Although some technological forces of Industry 4.0 are still not ready for use at this point, Industry 4.0 brings together technological forces that includes cloud computing, internet of things, big data analytics, augmented reality, robotics, additive manufacturing, machine-to-machine applications, and cyber security. Internet of things helps establish a value chain by provision of an avenue for machine-to-machine interaction over a network. Cloud computing provides a platform with high computational storage and network capabilities that enables interaction among various technologies. By leveraging mathematical modeling and virtual reality, augmented reality can improve business operation. Machine to machine interface is a platform that facilitates data recording and communication between sensors, industrial instrumentation, and software [21].

One of the critical issues for Industry 4.0 is that no generalized model exists for implementation of Industry 4.0 in most industries, which results in lack of clarity in tool usage in various phases of implementation of Industry 4.0. Davies et al. noted that Industry 4.0 provides the infrastructure to potentially improve lean/six sigma capability of an organization both at the enterprise, and operational level [15]. At the operational level, improvements that can be achieved by transmitting performance and operational data metrics through cyber physical systems in real-time includes production surveillance, electronic Kanban, data analysis, total productive maintenance, and virtual value stream mapping. For production surveillance, key metrics for production such as down time, production rates, and set up time can be automatically captured; through intelligent protocols, anticipated production problems such as performance deterioration and machine breakdowns can be communicated to production worker through handheld devices. For total productive maintenance, sensors help to detect when there is need for maintenance. Rather than relying on traditional Kanban cards, using electronic Kanban, upon sensing the need that the desired inventory level has been reached, a production order can be automatically sent to the downstream process [15]

5. Reducing waste through integration of Industry 4.0 and lean manufacturing

Waste reduction in production system is foundational for improved efficiency. To simplify production lines, all wastes, faults, delays, and any other wastes should be dealt with [12]. Even though no generalized model exists for implementation of Industry 4.0, a reasonable approach for the incorporation of Industry 4.0 is to evaluate how these technologies can help further reduce waste that lean manufacturing has had as a priority. Toyota Production System (TPS) seven forms of waste includes: over production, waiting for work, correction of mistakes (defects), conveyance (transportation), extra or wrong work (over processing), motion (movement) and inventory [23, 27]. Additionally, misplacement or misusage of human potential is sometimes also included as a waste [28]. Hence, with the identification of 'underutilization of human resources' as the 8th form of waste, the acronym TIMWOODS is often used to describe the waste in lean production systems.

Additionally, lean practitioners have considered energy and company politics as the ninth and tenth wastes. In this study, an assessment of the potential areas of improvement where Industry 4.0 can help reduce the different forms of waste is presented. The considered wastes (TIMWOODS + EP) are illustrated in Fig. 2.

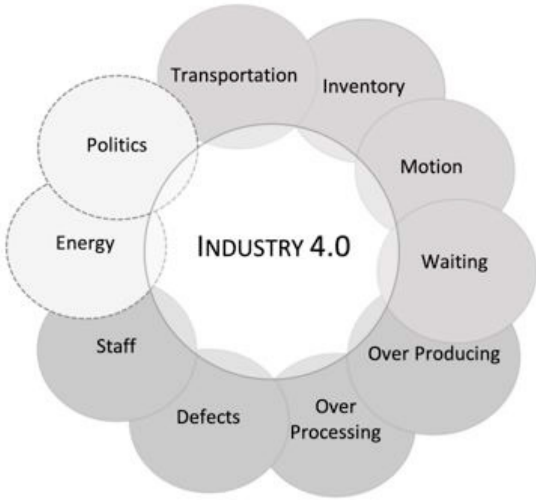

Fig. 2. Industry 4.0, the TPS wastes and 9th & 10th wastes (TIMWOODS + EP). Adapted from [23].

This study identifies the following as potential areas for improvement:

- *Transport*: electronic data logging (EDL), logistics optimization and regulatory requirements.
- *Inventory:* interconnected logistics and supply chain for asset tracking and inventory in response to demand / sales.

- *Movement:* movement detection systems may be used to analyze the degree of unnecessary movements, while robotics may be utilized where necessary for operational improvement
- *Waiting:* real time response to changes is hoped to result in optimization of processes to reduce waiting times.
- *Overproduction:* real-time takt time monitoring as demand changes will reduce the lag of over production.
- *Over processing:* near real-time response to changing customer preferences/demand/value (i.e., big data/market analysis) is hoped to help address the issue of over processing.
- *Defects:* real time detection of faults, and traceability to source (root cause analysis) is hoped to help ensure a quick identification of the source of defects either from process, parts, or personnel. This is hoped to also help in process improvement
- *Staff:* whether insufficient training, misalignment of compensation or underutilizing the expertise and talent, staff waste and the discretionary effort of human resources are a significant element in every organization. In transitioning to Industry 4.0 technologies, this report recommends that due respect be given to human dignity and privacy in all works of life.
- *Energy:* efficient consumption of energy reduces waste. Additionally, businesses are increasingly scrutinized on their energy use in terms of corporate social responsibility use and environmental leadership.
- *Politics / Resistance to Change:* successful implementation of lean and/or Industry 4.0 involves organization and cultural change.

Erboz et al. evaluated the applicability of Industry 4.0 on the seven types of wastes of the TPS system, and listed various smart components, cyber systems and physical smart network that may be applicable in reducing waste of lean through Industry 4.0 [29]. Examples of smart components and cyber systems to reduce waste of lean through Industry 4.0 includes: overproduction (auto-identification, additive manufacturing machines, intelligent control units and cyber-physical systems for production implementation); waiting (auto-identification, automated assembly lines, additive manufacturing machines, and cyber-physical systems to identify objects that are waiting); over processing (auto-identification, intelligent control units, and augmented reality, process analyzing tools, etc.); transport (auto-identification, human-machine interfaces, track and trace systems (i.e., GPS sensors), automated guided vehicles, cyber-physical systems to align demands to the layout, and to plan both parking and dynamic rerouting systems); defects (auto-identification, intelligent control units, automated assembly line, sensors, and cyber-physical systems to predict machine wear that will occur in future); motion (automated guided vehicles, autonomous robots, additive manufacturing and augmented reality devices, and process analyzing tools); inventory (auto-identification, additive manufacturing machines, and a cyber-physical system that can forecast inventory).

6. Case Study: How can a small sized enterprise begin to implement Industry 4.0?

Large well capitalized enterprises have access to significant resources and capital to capture economies of scale and the value of Industry 4.0, but SMEs face the scrutiny of a well-supported businesses case, cash flow analysis, net present value (NPV), and return on investment (ROI) for any investment, Industry 4.0 or otherwise.

Through the review with the company, the leadership team clearly indicated that an iterative approach towards Industry 4.0 was strongly preferred. Starting with a focus on defect wastes, the manufacturing firm was able to assess how Industry 4.0 could be implemented to deliver value and establish a foundation for subsequent Industry 4.0 technologies. Through value stream mapping (VSM), the current testing step of the manufacturing process was the bottleneck in the process. The equipment demonstrated a cycle time of 4:00 minutes, experiencing many false negatives and only determined conformity of the quality of the end-product using a pass-fail rule. Using the interrelationship and process of Industry 4.0 illustrated in Fig. 2, the test fixture data was found to be collected as a series of *.txt* file outputs stored locally on a computer but never used. The case study reviewed saw the firm take a Kaizen approach to the defect waste, and the testing technologies to improve quality.

The approach to the case study included: a 'Gemba walk', the development of a value stream map, the identification of production opportunities to reduce waste and upgrade to Industry 4.0. The case study focused on the waste associated to a testing fixture. Fig. 3 shows the current and future states of the product evaluation procedure. Meissner et al. noted that digitization and Industry 4.0 have a strong influence on production environment [30]. Presently, the firm in this case study has a localized system of recording test results, which are visually analyzed by an operator so that corrective actions are performed for any failed test.

The 65 steps of the test process were digitized as an optical pass/pass/failure based on measured reading within tolerances, however the .txt file offered no ability to enhance and analyze the data. As part of the case study, the 15,568 .txt files were parsed into a database and a basic review of the aggregate data is performed. The average number of 4-minute tests conducted per product was 2.5, for a total cycle time of 10 minutes per product.

Being a small size company, transitioning all processes to Industry 4.0 technology is not possible nor justified from the business perspective. However, a stepwise approach that focuses on digitization and the connectivity of processes was well received by the company as a strategic approach. While describing examples of use cases to combine Industry 4.0 with lean production, Kolberg & Zuhlke described a scenario in which machines send failures directly to smart operators and call other systems to repair the fault [31].

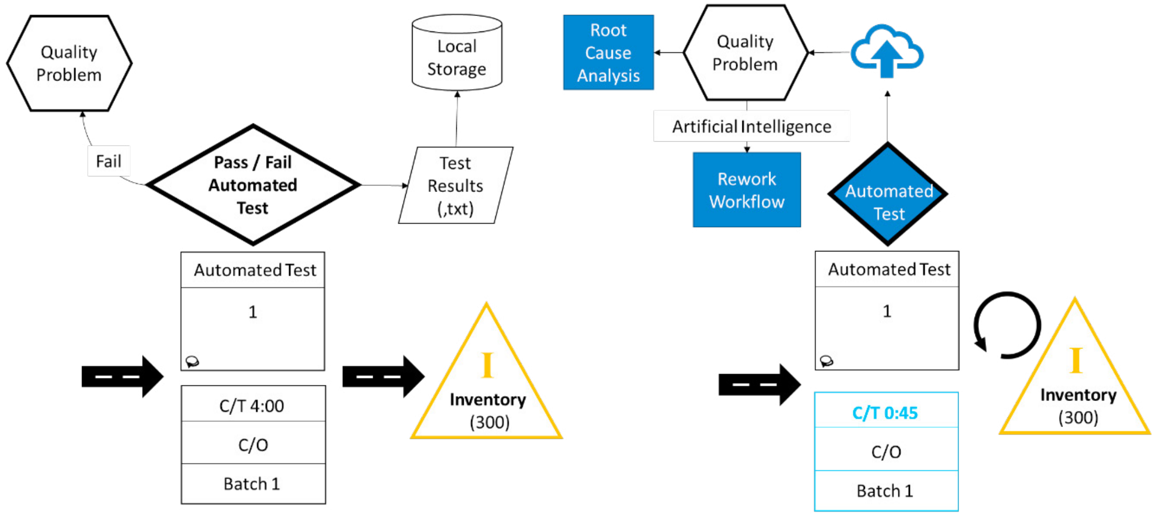

Fig. 3. Product test evaluation. *Left:* current state. *Right*: forecasted future state with stepwise upgrade to Industry 4.0.

6.1. Expected benefits from the stepwise upgrade of the functional tester to Industry 4.0 technologies

The proposed future state includes a new test fixture that outputs test results into a relational database that is connected to the cloud where analytics of test data will enable root cause analyses of products that failed the test to identify the source of defects in the production process. Additionally, for the products that failed, the results can be analyzed to determine an optimized workflow for product rework. Beyond the future state contemplated in the case study, the cloud managed relational database will serve as the foundation for implementation of cyber physical systems that could possibly automate required rework. Table 3 below compares the current state and the proposed future state for the test step of the production process. Note that the company in the case study is incorporating a more advanced testing system that is hoped to help reduced the waste associated with waiting for the cycle time to complete.

Table 3. Comparison of the current state and the expected future state for the test fixture.

	CURRENT STATE	FUTURE STATE
Test Type	• OCR pass/fail • UCS & LCS	*To be determined*
Cycle Time	• 4:00 min/ test	Est.: 00:45 min/test
Results	• 65 test steps • Pass / Fail • First fail	• Pass / Fail • Full test run • Full results

	• False negatives	
Output	.txt file, by serial number, for each test at first fail	Real time SQL database
Data Management	Local storage	Cloud storage
Analysis	Operator-> Pass/Fail	• Results -> AI -> rework workflow • Results -> Root cause analysis • Data visualization • Six Sigma

6.2. Managing the ninth waste of politics & resistance to change when transitioning to Industry 4.0.

The issue politics as the ninth waste is a significant consideration for any organization implementing lean or Industry 4.0 either separately, or in parallel. Successful implementations require organizational and cultural change. To mitigate the challenges of change, the company employed the ADKAR Model for organizational change [32]. As the pace of technological change continues to increase, organizations are faced with a seemingly continuous need to change to remain competitive. As suggested by this report, an SME's path toward Industry 4.0 is likely a series of successive implementations of select technologies, all of which will require some degree of organizational change with the risk of excessive waste from politics and resistance to change.

7. Conclusions

Then, *what is the best approach for efficient manufacturing?* From our review of all the factors that businesses need to consider, the best answer therefore is: "*E: it depends*". Through the literature and case study, it can be concluded that there are many factors for a firm to consider. Mainly, the ones highlighted here are the size of the organization, the business case financial, the ease of access to capital, and the internal politics of organizational change. In the presented case study, a stepwise approach that focuses on the foundations of digitalization and connectivity provides a path toward Industry 4.0 adoption.

Regarding the potential answers discussed in this paper, the strengths and limitations of their implementations have been presented. Lean principles and tools lead to improved productivity through waste reduction. The core tenant of lean is continuous improvement which is founded in the belief that there is always potential for more improvements. Industry 4.0 technologies have the potential to enable manufacturing firms achieve a significant leap in improvements. However, in both cases, SMEs may face capital limitation and business decisions that constrain full adoption, hence the best approach for efficient manufacturing is relative to each firm and must be analyzed as such. A universal approach for efficient manufacturing is a complex goal, possibly unattainable. Future research should aim at facilitating simulating scenarios in which either approach, lean or Industry 4.0, is implemented, thus supporting firms decision-making regarding this issue, specially SMEs.

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