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Modeling: Integration of Lean and Technologies of Industry 4.0 for Enterprise Performance

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Abstract: Lean manufacturing has been used by companies for decades to achieve their objectives. In today's context the introduction of industry 4.0 technologies has become imminent. However, the way these two paradigms can be mixed up in a common approach is yet not mature. Previous attempts to combine Lean and industry 4.0 have been led in literature. In this paper, we show our positioning and a global methodology of modeling that we undertake. The study of the relationship is shown in this document based on case studies reviewed in the literature. Initial modeling of influence will help in the gradual building of the global methodology. An example of Kanban and digitalization is depicted. The target is to illustrate the possible ways of combination of these two performance paradigms who lead implementation of Lean and industry 4.0 technology transformation.

Keywords: Industry 4.0 technologies, Lean, performance optimization, Kanban, integration.

1. INTRODUCTION

Companies are constantly seeking solutions and improvements to remain competitive. Being able to understand the challenges that they might be facing on, internally and externally, allows researchers to narrow down the solutions to be proposed. Implementing lean solutions and leading digital transformations belongs to those performance (Ghobakhloo and Fathi, 2020; Valamede and Akkari, 2020).

Lean manufacturing focuses on the elimination of every non-value-added activity on the process. This philosophy has existed for more than 70 years. It is also known as Toyota production systems (TPS) as it was first originated in this automotive company (Pereira et al., 2019). The TPS principle is based on a house, which structure constitutes the focal points for lean implementation (Vinodh and Joy, 2012). Jidoka and Just in Time (JIT) represent the pillars and the objective is to achieve the highest quality, minimum cost, and time process.

Lean is supported throughout the application of tools and methodologies. The tools that commonly applied by enterprises (called: hard lean tools) are: Value stream map (VSM), 5s, Total productive maintenance (TPM), Kanban, Single-minute exchange of die (SMED), cellular layout, visual management, standardization of work, Just in time (JIT), and continuous flow (Neves et al., 2018; Panwar et al., 2018; Alkhoraif et al., 2019).
Nevertheless, the implementation of Lean seems not enough in today's industrial challenges to ensure high performance (Shahin et al., 2020). Technologies and digital era become important factor to consider to overcome them.

Here, the introduction of new technologies can help to push these already proven useful tools to meet the objectives of current demand.
Industry 4.0 is a strategic initiative introduced by Germany at the Hannover Messe in 2011. The goal of the initiative is the transformation of industrial manufacturing through digitalization and exploitation of potential of new technologies (Sodhi, 2020).
Industry 4.0 is the answer to the market demands, individualization of products, volatility, energy and efficiency. This new era of industry 4.0 raises the new challenges that enterprises need to tackle in order to remain competitive (Bartodziej, 2017). How to lead digital transformation successfully is yet a question.
This paper attempts to analyze the connections between lean tools and industry 4.0 technologies in a global perceptive of implementation. Integrating enablers, lean tools, and industry 4.0 technologies to reach specific objectives to have a general perspective to select the correct elements.
The global cartography of the possible connections between lean and industry 4.0 technologies aims to integrate those concepts.
Quantifying the effect that the combination of two concepts can have on the performance of enterprises can represent the next step.

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2. LITERATURE REVIEW

2.1 Lean manufacturing tools

Lean has been proved to be effective in different industries and manufacturing sectors, for instance: Textile, aerospace, pharmaceuticals, and health care (Panwar et al., 2018; Possik, 2019).

The impact that the application of lean tools has in the performance of the company has been proved by many practitioners and researchers over the years (Ramadan, 2019; Majiwala et al., 2020). Individually, each tool has the objective to aid the company to achieve their strategies. According to the objective of the company, the lean tool to be implemented should be chosen.

VSM is a well-known diagnosis tool that supports on the identification on non-value-added activities in the process (Valamede and Akkari, 2020). Once the required added values activities identified, the elimination of those judged as NVA (non-value-added) can be done employing other lean tools such as 5s, cellular layout, total productive maintenance (TPM), Sigle minute exchange of die (SMED), Heijunka, Jidoka, Poka-Yoke and Visual Management (Tripathi et al., 2021; Trubetskaya et al., 2022).

Kanban is a tool that promotes the movement of materials through customer purchase orders with the just-in-time vision. In summary, it is a pull system that aims to reduce inventory by producing only what is being requested (Valamede and Akkari, 2020)

Companies are aware of lean benefits; most of them have already adopted lean tools as part of their improvement process (Bittencourt et al., 2021).

Lean is a philosophy; hence, the success of its deployment is not only limited to the application of previously mentioned tools (Possik, 2019), but is also their sensitivity to the economic undergoing context and the relevant choice according to circumstances.

2.2 Industry 4.0 technologies

Inside the fourth industry revolution, are several technologies that are leading the digital transformation, for example, Internet of Things (IoT), Cloud computing, Smart sensors, RFID, Digital Twin, 3D printing, collaborative robots (Cobots), big data, augmented guided vehicles (AGVs) These technologies bring flexibility to the company.

Industry 4.0 represents more than a set of new technologies. It is important to adopt the right management and the relevant approach of deployment. Horizontal and vertical integration and the connection of the physical and virtual word, will allow real-time data flow, for a better communication thought the supply chain (Sony, 2018). More informed decisions can be made in the process, due to the availability and the information recorded by this integrated technology.

The applications of these technologies are various, they can be applied to solve problems from bottlenecks, idle times, customization or your product portfolio. According to (Rossini et al., 2019), many manufacturers do not have Information and Communications Technology (ICT) structure mature enough to support Industry 4.0, which, rather than digitizing processes, will conclude into a dysfunctional system.

The objective that the company is looking to achieve plays an important role when implementing industry 4.0. Hence, the methodology varies according to the circumstances of the enterprise.

2.3 Lean and Industry4.0: Combined Studies

Ciano (2020) conducted a series of surveys to professionals implementing industry 4.0 with lean tools. This work has proved that two paths exist, in which these two methodologies can converge. First, where industry 4.0 aids to improve the existent lean tools running on the companies, the second where the implementation of industry 4.0 technologies needed lean tools to be deployed to reach the expected operational results. The empowerment effect is not strictly Industry 4.0 supporting Lean. In some cases, an early introduction of industry 4.0 shows the need of applying lean tools to be obtained better results (Mayr, 2018; Ciano et al., 2020). In the following table, we pointed out some studies that have worked on various combinations.

Table 1. Lean techniques impacted by Industry 4.0

I4.0 Technologies	Lean tools	Outcome
Digital twin	Cotinuous Improvement	Powerful simulation tools allow manufacturers to test their assumptions in the virtual world prior to implementing them in the physical world. (SAGE Automation, 2019)
IoT	Customer value activities	Internet of Things manage information of transported goods allowing real-time status informing delivery time to the customer. (Sanders,2016)
E-kanban/real-time-data.	Kanban	E-kanban system recognizes missing and empty bins automatically via sensors and triggers replenishment.(Ghobakhloo,2019)
Big Data	Preventive Mantainance	Big data and related activities with preventive mantainance improve transparency of systems (Tortorella et al., 2021)
Augmented reality	Elimination of waiting time (waste)	Augmented/Virtual Reality adaptive technology will be beneficial in improving workers' capabilities and minimizing idling in the production process together with data (Lai,2019).

The implementation of IoT allows access to real-time information, which can lead to a better control of the activities having the possibility of eliminating the waiting time leading to the reduction of the lead time (Lai et al., 2019).

The number of papers describing the benefits of the adoption of industry 4.0 technologies integrated with Lean is normally higher since it is natural for researchers to focus on the influence that new technologies have as it is the new disruptive change.

However, Industry 4.0 works in tandem with Lean rather than replacing it. The organizational empowerment and sense of responsibility that the implementation of lean visual management brings to the company is the one of benefits of lean (Bhattacharya and Ramachandran, 2021). Therefore, a minimum maturity in Lean is advised, before introducing digitalization (Buer et al., 2021; Salvadorinho and Teixeira, 2021)

3. PROBLEM STATEMENT

The selected papers often demonstrate that indeed there is an undeniable relationship.

Although, it is not mentioned how these tools and technologies should be selected or the effect is when they are combined. Most articles focus on whether there is a relationship, leaving aside how and what is needed for a successful combination (Buer et al., 2021; Cifone et al., 2021).

A previous research demonstrates the importance to go beyond binary assessment (Zouggar and Vallespir, 2021).
Among the first analysis, we got various binary relationships from literature as summarized in the table 2. It shows the possible links without any methodological approach.

Table 2. Industry 4.0 and Lean matrix influence

Industry 4.0 / Lean	IoT	Cloud	Big Data	AGVs	Autonomous robots	AR/VR	Additive manufacturing	Digital Twin
Kanban	x	x	x	x		x	x	x
Poka-Yoke	x	x	x	x	x	x	x	
SMED	x			x	x	x	x	
VSM	x	x	x			x		x
5s	x			x	x	x		x
Ucells (Lean-Layout)				x	x	x		x
TPM	x	x				x	x	x
Heijunka	x	x	x			x		

4. METHODOLOGY

The methodology employed in this paper starts by empirical observations. Academic publications, study cases and conducted surveys were analyzed to understand the applicability on the subject.
The papers consulted (as part of the investigation on the links between Lean and technologies of industry 4.0) were obtained from scholarly databases such as Elsevier, Scopus, Springer, Web of Science and Emerald. The key words in the searches were: Industry 4.0 and Lean implementation, Industry 4.0 and Lean study cases, Industry 4.0 and Lean literature review.
It is important to note that the type of cross analysis seen in table 2, are useful as a first approach to understand the relationship that lean and I4.0 technologies have.
Thus, it is imperative to clarify the reaction that occurs. Not only showing if there is an influence as usually done. But going beyond and attempting to model the influence.
Many elements need to be considered to obtain the desired result. Which requirements are needed to succeed in the implementation? How to select the correct tool and technology according to the company's objectives?
The successful combination of these tools and technologies cannot be fully grasped without considering the environment and elements that the company possesses. As well as the results that are obtained when and while the combination is being made. Analyzing the context and understanding the starting point before considering the implementation of any tool is crucial.
Hence, this paper aims to get one step closer to model the nature of each relationship between lean tools and industry 4.0 technologies and the benefit that these tools have when working together.

5. INDUSTRY 4.0 AND LEAN INTEGRATION: MODELING THE INFLUENCE

Boston Consulting Group says that manufacturers who have successfully deployed both ideas have reduced conversion costs by 40% in 5 to 10 years (SAGE Automation, 2019), proving that the introduction of industry 4.0 will not overshadow Lean.

The steps of our analysis methodology are as follows and are summarized in figure 1.

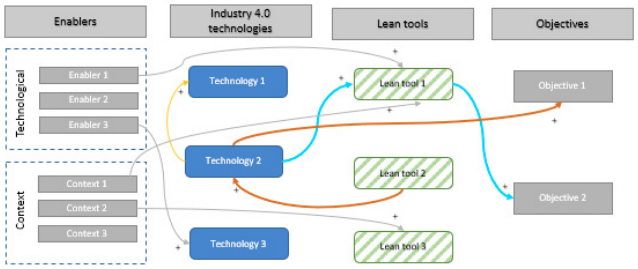

Figure 1. Methodology to analyze the integration of lean and I4.0

5.1Enablers identification

The enablers specify what aspects need to be considered before implementing any of these methodologies (IT maturity, management involvement, human cross skills, …). This supports the company to know in what situation it stands and, in a second time, serves as a milestone to define the domains where it needs to put more effort of evolution. They are divided into axes and can be broken down more in detail.
Lean can be considered as a facilitator for industry 4.0 introduction, along with other requirements. Top management commitment, employee's engagement and partner cooperation are crucial for a successful implementation of lean (Flores, 2018; Maginnis, 2020). The implementation of any new methodology and technology becomes easier when the workforce and top management have cleared the scope and realistic objectives.

5.2 Context evaluation

Considering the context is an essential part of successful implementation. The selection of industrial contexts (engineer to order, assembly to order, manufacture to order, manufacture to stock) was done through a literature review and case studies, which allowed to understand what contexts are more likely to adopt which tools. This, to indicate in the model the influence of the context when deciding to implement certain tools or technologies. Previous work proceeded in our research Lab (Possik, 2019) allows to get closer ideas to introduce in our model.

5.3 Lean Tools identification

The lean tools that are most frequently mentioned in the literature consulted due to their affinity to integrate with Industry 4.0 technologies were selected for our study. The benefits and objectives of these tools were also considered to achieve the expected result.

5.4 Industry 4.0 technologies selection

Through the analysis of 41 publications on industry 4.0 and, in some cases, the combination with Lean, a graph was constructed showing the frequency with which these technologies were mentioned in each article. In this way it was possible to narrow down the selection to analyze their combination with lean (represented by arrows) in the figure of the methodology.

5.5 Objectives achievement

Based on the benefits that the adoption of lean and Industry 4.0 technologies have brought to companies, we have selected the objectives most frequently mentioned in academic articles, in relation to these production methodologies and tools. The objectives selected to include in this model are quality, reduction of production costs, visibility and traceability in the processes, flexibility, and lead time reduction (Possik, 2019; Ionel et al., 2020; Majiwala et al., 2020)
The empirical research on the influence of these two approaches, as shown in table 2, allows the development of the targeted implementation methodology. Consequently, companies can use it as guideline to reach their operational objectives, clarifying the path and steps that need to be considered. It becomes a decision aided tool where the manager can check its enablers contributing to his performance, the context to tackle, the lean tools and technologies that are a priori in his strategic business plan and perceive through the model how they interact to contribute to the various operational objectives. We use the objectives proposed by Possik (2019) to model the influence. Indeed, operational performance to improve the production flow is the scope of this study and the objectives will show the global influence.

6. KANBAN AND TECHNOLOGIES OF INDUSTRY4.0: MODELING INFLUENCE

In this part, Kanban, as a part of lean tools, is selected to demonstrate the results on the combination with industry 4.0 technologies. Figure 2 shows the influence of the combination of Industry 4.0 technologies (I4.0) and Kanban, based on what was found in (Mayr, 2018; Santos, 2020; Valamede and Akkari, 2020). We chose intentionally Kanban, because it is a worldwide used lean tool often mentioned in literature (Trubetskaya et al., 2022).
We show how technologies of industry 4.0 can augment the performance of Kanban. As we can see, each combination results in different benefits. The benefits can be translated into operational objectives such as process time reduction or cost reduction (Possik, 2019).

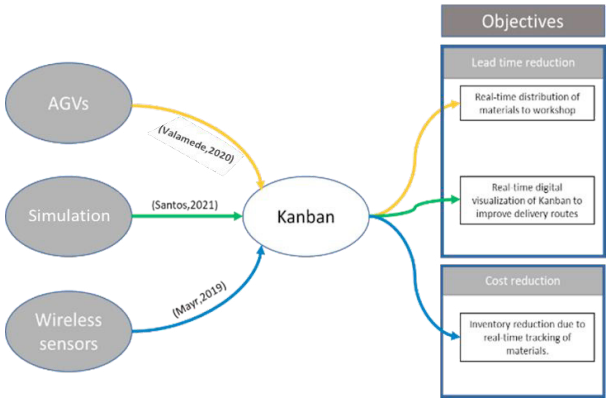

Figure 2. Modeling the influence of industry 4.0 technologies on Kanban improvement.

The results of merging a technology with Lean are not limited to a single benefit. The combination of Kanban with simulation can test the delivery routes, and simulate the process with different demands. We can improve production parameters by simulating different demands, analyzing the benefits and challenges that may arise (Santos,2020; Valamede and Akkari, 2020). Therefore, the decision maker may interact and test different production scenarios.

Kanban digitization, often called Kanban 4.0 or E-Kanban uses software connected to the process with the help of sensors and cloud. The connection permits to launch purchase orders automatically to the supplier and monitor the level of work in progress warehouses.

6.1 Kanban and AGVs

One of the multiple ways of industry 4.0 to complement Lean is with the usage of automatic guided vehicles (AGVs). Accordingly, with receiving instructions, AGV calculate the optimal path to complete the task giving their autonomy and mobility (Zhang, 2017).
The integration of this transfer means for the delivery of materials from the warehouse to workstations or between workstations at the moment becomes interesting for availability (Valamede and Akkari, 2020).
For the purpose of this paper, the study of the influence of AGVs focuses only on Kanban. However, there are various lean tools that can benefit of the implementation of AGVs.

6.2 Kanban and wireless sensors

The application of wireless sensors attached to the materials on the production floor, permits companies to constantly monitor the work in process and increase the transparency of the consumption of materials. The comparison with the actual demand enabled the reduction of the inventory translated into cost reduction (Mayr, 2018).
The introduction of industrial sensors for the real-time monitoring of production volumes enabled the company studied in (Ghobakhloo, 2020) to decrease unfinished work in the process as well as problems for reprioritizing tasks to adapt to the demand. It enhanced the work flow by enabling work-in-process (WIP) restrictions, tracing lead times and examination of workflow.

6.3 Kanban and simulation

Industry 4.0 technologies can help to test the behavior of Lean before implementing them. This is particularly the case of simulation. There can be more than one solution to a problem in the company, therefore to test these possible solutions with a simulation software results useful when choosing the right one. Having at the same time a positive relationship with specialized training of the workforce, augmenting the possibilities of a successful Lean and I4.0 implementation (Devi, 2020).
The expected demand for each Kanban station needs to be entered in the simulation system for it to exit the most efficient supply route and number of operators required not to overpass the maximum lead time. The cost, lead time of the company can be positively impacted when the Kanban calculation and parametrization are simulated and provided by optimized systems (Santos et al., 2020).

What was described above is an example of linkage study. The remaining task is the analysis of the huge cartography with various relationships to objectives and showing the sensitivity to the enablers surrounding company context before going in the transformation.

The gap reminds on the search of a holistic integration of Lean and industry 4.0 technologies: Which elements are needed to be considered, how companies can be prepared (applying readiness tools, enablers to consider) to integrate compound solutions to improve their performance and remain competitive, etc. stay issues to be solved. The expectation of the research work under development is to produce a global cartography and step-by-step guidelines in each macro category of analysis of figure 3 to provide the decider with a gradual way in their lean implementation and technologies deployment for digital transformation.

7. CONCLUSIONS

The literature review conducted in this paper clarifies the benefits of integrating Lean and industry 4.0. It clarifies the benefits and objectives that can be achieved with this combination.

Further research needs to be focus on the readiness elements that companies have to considerate to assure the successful deployment on new technology together with Lean. For instance, the details of the possible enablers, the content of the various elements of contexts and the modeling of influence among Lean and industry 4.0 technologies is yet under development to consider the most elements for a correct implementation. Analyzing the areas and elements that play an important role in the company to obtained better results would be possible thanks to the global cartography that we aim to provide.

However, there are many elements that are still missing in the literature, such as tools considered as soft lean that help in the adoption of new technologies and serve as enablers to achieve the ideology of horizontal and vertical integration in Industry 4.0. We intend to clarify the set of lean tools and the set of technologies to build a coherent and global approach for assisting managers of production in gradual and parallel Lean and Industry 4.0 transformation.

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