Implementation of Digital Tools for Lean Manufacturing: An Empirical Analysis

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Abstract. Purpose: The literature on Lean Manufacturing and Industry 4.0 has identified a strong link between the two paradigms and a positive impact on operational performances. Industry 4.0 offers digital tools to support LM tools and practices. However, empirical and in-depth analyses to validate such propositions are still scarce in the literature. Therefore, the observation of the implementation of Industry 4.0 tools for Lean Manufacturing with a focus on the factors needed for properly introducing them in firms is the next logical step to further strengthen this area of research. This study aims to understand the required factors needed to take into consideration for a successful implementation of the tools in the manufacturing process. **Methodology:** We rely on multiple case studies performed in 6 Italian Manufacturing companies that adopt digital tools for Lean Manufacturing. **Findings:** Our findings highlighted the central role of skills, the need for a specialized team to oversee the implementation in addition to better formulation of the tool's offerings by the suppliers through successful case studies. We also tried to connect individually each tool with the operational performance it aims at improving .

Keywords: Lean · Digital tool · Implementation · Industry 4.0

1 Introduction

The literature on Lean Manufacturing (LM) and Industry 4.0 (I4.0) has started to pay increasing attention to their combined effect rather than to each one individually. Academicians and practitioners have identified a strong link between LM and I4.0 and a positive impact on operational performances [1]. The combination of these two paradigms in the industrial field in practice is represented by the challenge of implementing I4.0's technologies into existing LM systems, with the necessary adjustments to business processes. However, the expected performance improvements seem to justify this effort, even if not all firms are still aware of that. In evaluating the main challenges of the implementation of I4.0, according to [2], academicians should put their efforts to better understand "how I4.0 technologies impact processes, products, and services of firms".

The implementation of digital tools for LM as a part of the digital transformation process is a challenge in the digital era. Many enterprises seem reluctant to start a digital

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transformation process. It is becoming increasingly important to understand the needed requirements for the adoption of digital tools.

To fill this knowledge gap, this study aims at understanding empirically:

"What are the factors needed for properly introducing the digital tools in manufacturing companies?". In addition, we try to answer the knowledge gap highlighted by [3] that called for associating digital tools to corresponding operational performances.

2 Theoretical Background

The literature review confirms that when applied together, I4.0 and LM improve greatly operational performances [4–6]. It is also shown empirically in the work of [4, 7] who surveyed companies in European and Brazilian contexts about the level of implementation of both LM and I4.0 and how this contributes to their performances. High adopters of lean are the ones most likely to apply I4.0 technologies, whereas low adopters of lean are less inclined to adopt I4.0 technologies, and former ones achieve greater operational performances compared to the latter ones.

Those studies confirm the support I4.0 gives to LM in improving operational performances but do not dwell on how this is possible. Empirical case studies were done in this context postulating that I4.0 offers digital tools for Lean, and through them, performances are improved. Those studies, however, focus on few lean digital tools such as the e-kanban [8, 9] and VSM 4.0 [10, 11]. The literature emphasizes heavily the role of sculpting skills whether technical ones or analytical ones to face the new era of I4.0 and its rapidly growing technologies [12–17]. With this research, we will try to see empirically whether this is the main factor for companies or there are other factors as well.

Based on the literature, a list of a more comprehensive set of tools was developed: E-Kanban, E-Poka Yoke, E-Andon, Value Stream Mapping software (VSM 4.0), OEE software, Computerised Maintenance Management Software (CMMS), KPI dashboard, Root Cause Analysis software, Cause and Effect Diagram software, S.M.A.R.T. Goals software, Mind Mapping software, RFID trackers, Handsfree Radio Data Terminals, 3D Factory Simulation software, Collaborative Manufacturing, GPS fleet tracking, Real-Time Production Monitoring software, Collaborative Robots, Virtual Reality, Real-Time Machine Monitoring, Real-Time Inventory tracking, and I-bin.

3 Research Methodology

We decided to conduct an explanatory multiple case study. The scope here is the identification of relationships and relevant variables in a limited number of realities. This allows us to create initial knowledge for academicians and practitioners who are facing the challenge of digitization.

The selection of cases was made among the Italian participants of a survey developed by the Lean Excellence Center at Politecnico di Milano (reference omitted for peer-review) which showed a particular commitment to digital tools adoption. We have grouped the participants into high and low implementers based on the number of tools

they implement. The case study follows a holistic approach, which considers a single unit of analysis corresponding to the implementation process of digital tools.

We followed a theoretical sampling approach, thus collecting information that will support the results of our survey analysis and refine them by identifying "polar types" from the different firms of the initial survey sample. Indeed, this approach generally reinforces the generalization of results and enables a comparative analysis of findings. Using the "heterogeneity approach" for the selection of cases, we searched for different cases representative of different sizes, different sectors (all belonging to the manufacturing environment) but at the same time, we selected homogeneous cases as in Italian manufacturing companies. Though it might reduce the possibility to generalize findings, it assures that confounding variables do not cause variation [18] (Table 1).

We have designed semi-structured interviews based on a set of pre-determined questions. All the interviews were recorded (after receiving permission from respondents) and then transcribed. The transcripts, together with notes taken during and after each interview, were collected and stored in a dedicated database. We have archived this information in a well-organized structure to make it ready for the coding phase. This process mainly involved content analysis performed to identify relations or patterns or to contribute to the development of the theory. Indeed, transcripts together with the team's observations, external documents, notes, and precedent survey answers, ensured data triangulation. The coding process has been conducted manually by the authors, to ensure inter-code reliability [19]. We followed a two-steps coding procedure. In the first-round coding, the authors have done the coding of each text interview separately, and then a comparison was done between the coders. The interview model has been divided into 6 main sections:

1) Organization structure description that includes the role of the interviewees in the company, their definition of I4.0, and whether their company's culture is "just Lean", or "just I4.0" or "Lean 4.0" exploiting the relationship between the two paradigms.
2) Digital tools adoption level: it was asked whether company size, sector and type of process affect the digital tool implementation process and the reasons why they implemented the digital tools they are using
3) Guidelines for digital tools implementation and the decisional process and feasibility analyses undertaken by the company before implementing a specific digital tool.
4) Obstacles to digital tools implementation process we asked the interviewees the reasons why their company did not decide to implement the digital tools.
5) Performances impacted by digital tools adoption: both positive, neutral, and negative of each of the implemented digital tools on the various operational performances
6) Insights for future development: we asked the interviewees to share, based on their experience, some insights to improve digital tools providers' offer

Table 1. Interviewees information sum-up

Implementers	Case	Size	Sector	Operating model	Production type	Role of interviewee	Tools currently implemented	Tools to be implemented
High	A	Small	Packaging	B2B	High volume, Low variety	Lean Six Sigma Improvement Facilitator	5	7
High	B	Medium	Healthcare	B2B	High volume, High variety	Head of Continuous Improvement	4	5
High	C	Medium	Furniture	B2C	Low volume, High variety	Lean Specialist	13	8
High	D	Large	Automotive	B2B	Low volume, High variety	Digital Manufacturing specialist	8	2
Low	E	Small	Machining	B2B	Low volume, High variety	Quality Manager	3	3
Low	F	Small	Pressure equip	B2C	Low volume, High variety	Operations Director	1	3

4 Discussion

The first finding of case study analysis is the confirmed bi-directional relationship between LM and I4.0 discussed in the existing academic literature. All the practitioners have confirmed both the enabling effect of Lean on I4.0 implementation [7, 20, 21] and the empowering effect of I4.0 on Lean [8, 9]. We report in Table 2 a summary of the factors that companies take into consideration to properly implement the digital tools according to the various interviewees. All the investigated case studies in this work confirmed the agreed statement of LM as a prerequisite of I4.0 confirming the corresponding academicians' theory [7, 22, 23] also in the practitioners' field.

Table 2. Implementation factors for digital tools

Implementation factors	Company					
	A	B	C	D	E	F
Change of mentality	x	x	x		x	x
Suppliers involvement	x	x	x		x	x
Freedom in decision making					x	
Investment in personal knowledge		x	x		x	
Incremental change	x	x	x			
Adequate information system			x	x		
Ad hoc division for LM	x	x		x		
Presence of cross-functional team to foster digitalization		x		x		
People Involvement	x	x	x			

Moreover, most of the interviewed firms started using the traditional Lean tools (such as Kanban, Andon, and Poka-Yoke) and then updated them with the corresponding digital version.

4.1 Contributing Factors and Decision Making

Given the fact that LM provides the right culture to the company to embrace the digital transformation, a very important element is the people factor. Indeed, one commonality that emerged among the high implementers, but not among the low implementers, is the presence of an ad hoc division inside the company fully dedicated to digitization projects. In some cases, the team was composed of the previous LM team, while in other cases, it was created in recent years using an interdisciplinary approach of young profiles. This peculiarity is aligned with [18], who observed a case in which a new business division was created to provide I4.0 solutions based on LM competencies. Also, Kaizen and Multifunctional Team are often considered as "soft" LM techniques [1, 24], however, the analyzed case studies prove that their contribution to I4.0 adoption can be very effective, confirming the hypothesis of [18]. Therefore, future research can also concentrate the attention on the enabling effect of "soft" Lean practices on companies' digitization process.

Seeing the digital tools for LM as resources, we can use the Resource-Based-View [25] according to which these two types of resources can bring a positive synergistic effect to operational performances. However, because of the case studies analysis, an additional resource should be introduced in this model: this third resource is represented by the people factor. For all the interviewed firms, skilled people are seen both as the main facilitator and as the main difficulty for the implementation of digital tools. Therefore, the central role of people emerged both as a well-known pillar of the Lean paradigm but also as a basis for I4.0 adoption. Indeed, I4.0 technologies aim to support people's work rather than replace them [26, 27] by converting workers' activities without value-added into value-added ones [21]. Considering this concept and the Resource-Based-View by [28], skilled people within the company fit all the requirements of the resources which are: valuable, rare, imperfectly imitable, and un-substitutable/unique. We can conclude that the commitment of people is more evident among high implementers than low ones, and its effect seems to have a positive contribution to the digitization intensity, as observed by [29] stating: "The change can only come with the involvement of the operational staff".

Moreover, the perception of the contextual factors' impact (especially company size, sector, and type of process) among the interviewed firms is various. Indeed, it is not possible to find a different perception on contextual factors' impact between high and low implementers or between SMEs and large companies interviewed. Most interviewees (both high and low implementers) have stated that the type of process had an impact on the selection of type and number of digital tools to be implemented.

While the existing literature investigating the possible barriers for non-implementation of digital tools [26, 30] is mainly focused on the SMEs which seem the most vulnerable in this sense, none of the small-medium firms has cited the limited financial availability as a reason for non-implementation, while the most common reason was represented by the internal resistance to change showed by workers, confirming the perspectives of [26, 31, 32].

Both high and low implementers agree on the importance of people training to successfully introduce new technologies. The training should be both technical and cultural, a very important aspect to introduce digital tools is the understanding of the "importance of data" [29] and thus the creation of "Digital Culture cultivation" [33].

In particular, the low-experienced firm in Lean 4.0 (Company E) perceived that the main barriers to the introduction of I4.0 in manufacturing firms are related to internal challenges such as lack of skilled operators and culture for the change, while the digital transformation of Company F is mainly limited by strategic and operative issues [33, 34]. On the contrary, the most cited barrier among high implementers is the uncertainty of such investments that usually do not have reliable ROI values.

Therefore the maturity stage in the digitization rather than the company size or sector is relevant, confirming the independence of contextual factors in the adoption of the digital tools [2, 4, 9].

To start the digitization process, an internal "Digital Culture" should be developed [33]. Modern company processes require a certain degree of maturity in innovation methods and tools for digitization and companies usually need external help to explore these possibilities [32]. This support is not only related to the knowledge of the existence

of available technologies but mainly related to the knowledge of how to make them functional in real production systems.

Indeed, low implementers seem not to be able to sustain this cultural change alone, therefore, they ask the support of external entities (first the digital tools providers, but also universities and consultants) in the implementation and installation of the digital tools, but also the training of the employees affected by the change.

4.2 Supplier Side

Both families of implementers asked for a revision of current digital tools offerings, by changing the structure of the product, marketing strategy, and price. The increased modularity of software will help firms in the gradual adoption of digital solutions starting from strategic modules to then integrate all other systems. Moreover, the possibility to customize the offer concerning the characteristics and operations of the firm seems to be a value-added for most companies interviewed by avoiding buying systems that the company does not truly need, negatively influencing the company's perception of digitization. Finally, all interviewees recognized great benefits in receiving case study examples dealing with similar context applications and highlighting the results obtained from the implementation of digital tools, to assess the effects of the digital projects in advance.

4.3 Tools and Operational Performances

We report in a tree (see figure below) a tree associating the tools with the operational performance it tackles. In general terms, we can see that Productivity is recognized as the most positively impacted performance. Regarding the individual relations between performances and used instruments, this observation is necessary to, we can see that almost all the performances have at least one association; in particular, the positive ones are the most noticeable, suggesting a general performance satisfaction of digital tools users.

A positive association has emerged between the E-Kanban adoption and the reduction of Lead Time by Company C, between the OEE software and the Real-Time Production monitoring adoption by Companies A, D, and E, with a significant increase in Productivity and between the Real-Time Inventory tracking adoption and an improvement in warehouse management, by Company C.

Many manufacturers indicate that the integrated systems of MES (Manufacturing Execution System) and ERP (Enterprise Resource Planning) can immediately communicate anomalies or breakdowns as well as calculate KPIs.

This is in line with the scientific works by [8, 35] who show that Smart Machines empower the production capability using displays with graphical user interfaces connected to the production line and the MES.

It is remarkable the positive effects observed by Company D due to the usage of RFID to reduce human errors as well as to increase the traceability of items in the Warehouse Management, aligned with the concept of Poka-Yoke 4.0 by [36].

In addition, Company B has notified the benefit of 3D Factory simulation and Virtual Reality to allow the company to try out different layout configurations through a virtual walk in the simulated environment, already observed by [18, 37].

5 Conclusion, Future Research, and Limitations

In conclusion, this research sheds the light on the three main areas the academic and practitioners' fields should focus on for the proper implementation of digital tools for LM. The first is sculpting the skills of the operators for the use of the digital tools and limiting their resistance to change and this could direct governments and companies into investing in education and skills formation. The second is dedicating a team in the company to oversee the implementation of the tools. The third one instead is the effort digital tools suppliers should put on to modify their product offerings in such a way to highlight empirically how the tools could be used and implemented through successful case studies. This result confirms the academic request for empirical validations of the use of digital tools [1]. In addition, the research sets the first step into answering the gap identified by [4] that calls for associating each performance to each tool to guide the company into adopting the tools according to the needed improvement. This research surely presents some limitations. Having relied on only 6 Italian manufacturing companies, the results are neither enough to be generalized nor can they be in their current form extended to other industries. Future research of ours will try to expand on those limitations to ensure more generalizability of the results (Fig. 1).

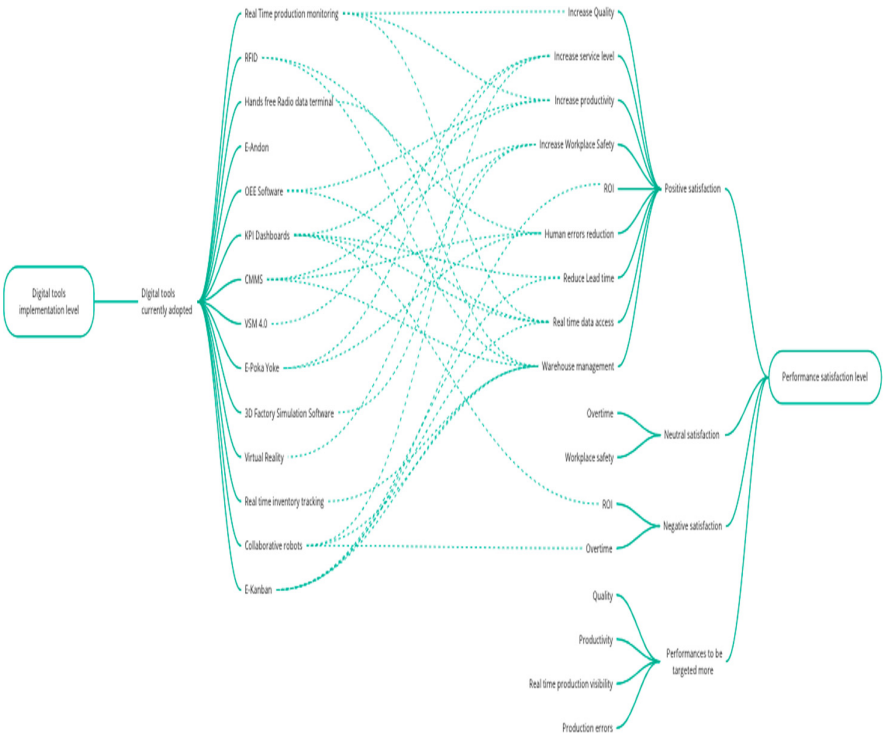

Fig. 1. Association performance-tool

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