Information systems in Industry 4.0: Mechanisms to support the shift from data to knowledge in Lean environments

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Abstract

The paradigm that presently emerges in the organizational context, known as Industry 4.0 (I4.0) promises to bring principles of connectivity and flexibility to the companies that embrace it. However, it is known that the adoption of the Lean philosophy was absorbed by the industrial environment, with results that proved to be exuberant, considering the simplicity of the tools. In this way, the I4.0 implementation must be prepared to preserve the existing manufacturing systems. MES systems will be decisive in the foundation of the I4.0 paradigm. They are capable of eliminate information silos, introduce knowledge management practices and data visualization mechanisms. Thus, their documentation is an organizational pillar, with BPMN and UML being able to guide it. However, BPMN is also likely to be applied in capturing tacit knowledge, which can be a foundation for the constitution of knowledge repositories, impacting organizational excellence. This work aims the creation of guidelines that facilitate the implementation of I4.0 strategies in Lean industrial environments. Some applications aligned with the I4.0 paradigm and with the Lean philosophy were developed and contemplated and considering the evidence reported in the literature, a Lean 4.0 framework oriented to the shop floor is proposed.

Keywords

Industry 4.0, Lean Manufacturing, BPMN, MES, Data Visualization.

1. Introduction and motivation

The future of Small and Medium-sized Enterprises (SMEs), this being a large part of the Portuguese business fabric, depends heavily on their ability to respond to the expectations of their customers, managing to maintain a competitive advantage (Mayr et al., 2018; Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018). On challenging markets, organizations have to test themselves, carrying low production costs and high quality products (Hoellthaler, Braunreuther, & Reinhart, 2018). In this way and to achieve this competition's gain, it is necessary that organizations work constantly to improve their processes, and make some effort to bring celerity, regarding innovation and processing times, and mutability/flexibility to adjust to the new manufacturing environment (Hoellthaler et al., 2018; Moeuf et al., 2018).

Industry 4.0 is the new world wave also called as Fourth Industrial Revolution. This paradigm is more and more "in the spotlight of researchers, economic policymakers and manufacturers" (Tortorella, Giglio, & van Dun, 2019). Cyber-physical systems (CPS) and Internet of Things (IoT) are crucial applications which Industry 4.0 pretends to implement in the companies' shop floor. The considered industry 4.0' s execution system is a set of connected CPS building blocks with decentralized control and high level of connectivity, allowing the traceability, monitorization and optimization of production processes (Rojko, 2017). Although, Industry 4.0 introduces new opportunities that may disturb the conventional approach to production planning and control (Moeuf et al., 2018).

Lean Production was cultivated by Toyota and suffered a widely spread among the western industry in the last decades, especially in automotive sector (Meissner, Müller, Hermann, & Metternich, 2018; Tortorella & Fettermann, 2018). This philosophy is seen as a continuous learning and improving system with a human-centered approach (Meissner et al., 2018; Tortorella & Fettermann, 2018). Lean manufacturing ideologies can simply be applied in manufacturing systems with a low level of mass customization, since it is more practicable to standardize and coordinate processes (Hoellthaler et al., 2018).

Industry 4.0 can have a huge impact in bringing Lean to a whole new level of excellence (Meissner et al., 2018). Nevertheless, the full implementation of the I4.0 paradigm is still distant, but it is imperative to portray the size and core obstacles of that transformation which could mean a change of the outlook of the production and the manufacturing shop floor, pointing also to disrupting new business models grounded on IoT (Nakayama, de Mesquita Spínola, & Silva, 2020). With the Fourth Industrial Revolution excitement many technology vendors persuaded companies to flinch their digital conversion journeys, however a proper process, culture and technology alignment was not having into account (Romero, Flores, Herrera, & Resendez, 2019). Majority of manufacturers, SMEs in specific, are able to just digitize certain areas of their procedures, such as the customer relationship management (CRM) or production planning and control (Manufacturing Requirements Planning has a huge weight in here) (Ghobakhloo & Fathi, 2020).

The transitioning toward Industry 4.0 requires: (i) the removal of functional silos (Ghobakhloo & Fathi, 2020; Wilkesmann & Wilkesmann, 2018); (ii) openness and a supportive culture to change- where the cultivation of a Digital Culture is promoted (Romero et al., 2019); (iii) standardized processes and their understanding (through mapping) (Mayr et al., 2018); (iv) collaborate knowledge management (Ghobakhloo & Fathi, 2020); (v) supply chain integration (Xu, Xu, & Li, 2018); (vi) data transparency across the entire value chain (Ghobakhloo & Fathi, 2020); and (vii) digital skills (from capturing system specifications, through their architecture and design, to their implementation) (Enke et al., 2018; Xu et al., 2018)

Despite the relevance of the topic, the literature has highlighted the lack of scientific work capable of adequately investigate the mechanisms that can contribute, preserving the manufacturing systems that already exist (particularly regarding to lean production practices), to implement the industry 4.0 paradigm in the manufacturing industry, especially in the small and medium enterprises' universe. It is precisely this gap that is at the root of the motivation, leading to the development of this research project. It has the purpose of identifying, analyzing and, consequently design a framework which groups a set of factors that can support the implementation of Industry 4.0 in manufacturing lean environments. To carry out this research, a company belonging to the chemical industry was taken as the basis of the study. The results obtained were duly generalized so that guidelines could be built for the implementation of the new context in a higher universe, being it the manufacturing industry.

2. Research question and methodology

There is an emerging need for companies to implement mechanisms that will allow them to own a shop floor 4.0. Nowadays, Industry 4.0 (I4.0) is the new wave of the industry and promises to bring flexibility, and connectivity. While in the 1990s, Western industry was the target of the Lean wave that, with its low-tech and simplistic principles, managed to bring out impressive results, it is now time to see implemented cyber-physical systems capable of connecting the virtual world to the physical one. These systems are capable of conceding to act to anomalies almost in real time and offer the capacity of the company to adapt to market fluctuations, and consequently constitute a real pull system. Hence, I4.0 brings tools which make possible mass customization, thus having a greater capacity of companies to satisfy the requirements of their customers.

However, the first system architectures that appeared because of this concept, are considered high-tech solutions, which poses several obstacles to companies regarding their implementation. Therefore, it is necessary to establish principles and guidelines for the business universe to be able to adopt the I4.0 mechanisms in a focused and simple perspective, with the awareness that existing systems must be preserved. For that reason, the following primary research question urges:

Q: What mechanisms should organizations adopt in order to establish (first in the shop floor) the context of Industry 4.0?

This research was based on the design science research (DSR) methodology, which is motivated by the desire to develop the environment by the launch of new and innovative artefacts, having although in account the procedures for constructing these artefacts (Hevner, 2007). This methodology is primarily a problem-solving paradigm (Hevner, March, Park, & Ram, 2004; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2014), where the artefacts' creation depends on existing kernel theories, which means that explanatory, predictive, or normative theories support design theories and it is demonstrated how such theories can be placed to practical use, using for that, researcher's experience, creativity, intuition and problem solving capabilities (Hevner et al., 2004). Regarding to DSR activities, Drechsler et al. (2016) determines four cycles that are part of the DSR development phases: the relevance cycle, the rigor cycle, the design cycle and the change and impact cycle. Hevner et al. (2007) have proposed a scheme similar to the above one, although the change and impact cycle was not included. Drechsler et. al (2016) suggested, in order to capture, in a more realistic way, the dynamic nature of artefact design for dynamic real-world contexts, a fourth cycle (change and impact cycle).

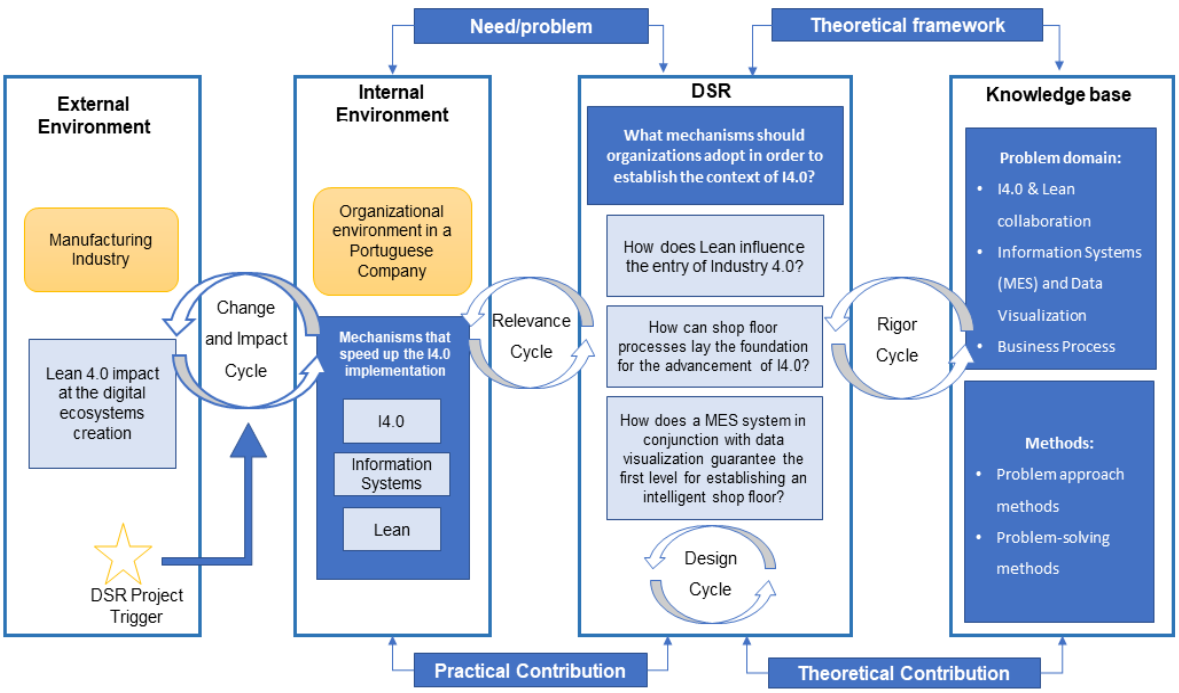

Figure 1- Research Framework based on DSR

They proposed this one more, to distinguish an artefact's direct application context from the surrounding socio-technical system within which the immediate application context is a subsystem. In a static perspective, the extra cycle promotes researchers to distinguish the immediate artefact effects from those it may have on the external context. On the other hand, and in a dynamic point of view, the extra cycle encourages researchers to turn out to be more aware of dynamics in the external organizational or societal context and to make sense of cope with these dynamic forces within a research project's scope.

The present research was based on DSR, and the three constituent elements concern: (i) the environment (internal and external) characterized by an organization environment in a Portuguese Company (for the internal one) and the manufacturing industry (for the external one); (ii) the knowledge base, which will backing the theoretical groundwork and also (iii) the research process that will be conducted and it is represented in Figure 1.

3. Structure and Main results

The dissertation was structured into three parts, which make a group of seven chapters. **Part I** includes the general introduction, as well as the motivation of the research; the state of the art on what concerns to research focus; the objectives described by research questions and the methodology carried out, concluding with the presentation of the dissertation structure. **Part II** groups Chapter II to Chapter VI, where a set of scientific papers is presented. Four of them are in international conference proceedings and one is submitted to a scientific journal. Figure 2 pretends to summarize all the contributions related to these five papers. To finalize, **Part III** incorporates the general discussion and some final considerations, gathered by the results obtained from the five scientific works. Beyond that, the limitations of the study and future work are presented.

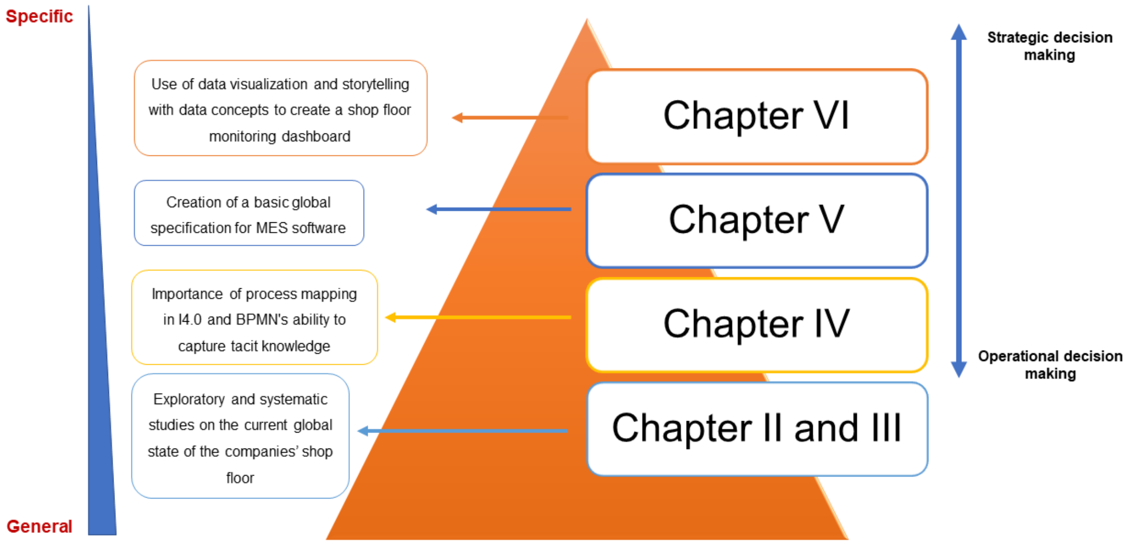

Figure 2- Scientific works' structure

3.1 Chapter II- The bilateral effects between Industry 4.0 and Lean: proposal of a framework based on literature review

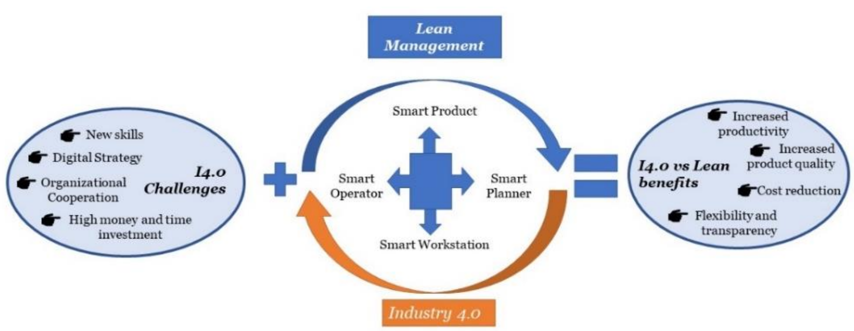

Figure 3- Lean 4.0 Shop Floor Framework

The first chapter aim was to analyze the challenges and obstacles of an implementation of an Industry 4.0 strategy and how the Lean philosophy could be useful in reaching the answers to those challenges. It was possible to identify that while I4.0 supports connectivity, flexibility and, therefore, responses to volatile and increasingly demanding markets, integrating information systems to support process and unceasing data flows, Lean holds up continuous improvement in a logic of eliminating waste, acting primarily on production and material processes and flows. In this line of thought, an exploratory literature review was carried out and an evaluation of the impact of Lean on I4.0 was made.

Thus, according to the literature it was possible to realize that it is necessary, when implementing a high-tech paradigm as industry 4.0, to preserve the existing manufacturing systems, in order to establish a gradual change. There is also a consensus in the literature that, in order to obtain higher levels of performance when the new paradigm is instituted (I4.0), Lean must be at the base, and the company in question must already present some maturity of Lean practices in its processes. In this way it is possible to integrate technologies in standardized and robust processes. A Lean 4.0 shop floor framework emerged therefore (see Figure 3), establishing four important players, the smart product, the smart planner, the smart operator, and the smart workstation. In this framework, the bilateral effects between the two concepts (Lean and Industry 4.0) are demonstrated, considering the challenges brought about by I4.0 and the possible consequent improvements.

3.2 Chapter III- Industry 4.0 as an enabler of Lean Practices: A systematic literature review

Table 1- I4.0 vs. Lean Matrix: the contributions of I4.0 technologies on the Lean practices

	Just-in-Time	VSM	Heijunka	Jidoka	Kaizen	Andon	Kanban	KPI's	TPM	SMED	Poka Yoke	Visual Management	5S's
CPS	x	x	x	x	x	x	x	x	x	x	x	x	
IoT	x	x	x	x	x	x	x	x	x	x	x	x	
Big Data Analytics	x	x	x	x	x	x	x	x	x	x	x	x	
Cloud Computing	x	x	x	x	x	x	x	x	x	x	x	x	
3D Printing	x									x			
Virtual Reality	x	x	x		x								x
Augmented Reality	x	x	x	x	x	x	x	x	x	x	x	x	x
Robotics	x	x		x	x		x		x	x	x		x
Artificial Intelligence			x			x							

It was possible to verify in Chapter II that the contribution of I4.0 to lean was at an advantage, because of the number of works developed. Chapter III, based on a systematic literature review, intends to respond to the confluence of Lean with Industry 4.0. This is, therefore, a work that intended to continue the previous one, using a more methodical approach.

I4.0 can possible, in order to respect the already stated shop floor (because of the lean wave among western industry), usufruct of the existing tools (updating them) and of the thinkers' promotion, with origin in the lean philosophy. Because of its high-tech solutions, I4.0 needs to be capable of being simple. Lean is a low-tech approach, but their results were above what was expected, so there is a huge necessity of preserve what there is already and, if it is possible, try to make it better. This review allowed to create a matrix (see Table 1) whose axes represent the technologies and/or practices of each of the concepts (Lean and I4.0) in order to establish those Lean tools that already have practical and/or theoretical evidence. It was possible to underline some well-known tools that saw their update to the virtual world, such as Kanban, VSM, Poka Yoke, Andon, visual management, KPIs. All tools considered as those with more application have a huge influence of data, which, with the introduction of technologies, made the instruments become more dynamic, with sufficient capacity to support decision making and the ability to allow action in almost real time in the face of abnormalities. Control and action in real time in the face of problems occurring, on the shop floor, allows to severely reduce waste, which is the focus of Lean. Since the focus on the human being was also evidenced, with the Lean purpose also, it is to be expected that connectivity provided by I4.0 affords knowledge sharing, on-site training with greater application (even if virtual) and even greater involvement of more operational staff in the management and decision-making process directed to the manufacturing processes. Here, the need to acquire more technological and out-of-the-box skills is highlighted.

Broadly talking, I4.0 can severely bring Lean to a new level of excellence, fomenting the innovation, considered to be a kind of a difficulty denoted for this philosophy. The promotion of teamwork involvement in Lean practices, with human beings as the focus of the approach, provides I4.0, on the other hand, with a mindset capable of being open to the changes that this paradigm requires, such as greater organizational cooperation with a view to achieving goals that become common.

3.3 Chapter IV- Organizational Knowledge in the I4.0 using BPMN: a case study

Chapter IV arises with the necessity of taking careful the application of technologies that should not be frivolous, since a good understanding and documentation of shop floor processes is highlighted in order to integrate technologies in robust and consistent processes. In addition, another key issue has been considered here, in the case of the workers' tacit knowledge. This knowledge is never enough (or if it is considerably in a low percentage) to be captured by the organization, which causes it to lose knowledge of core processes when workers leave. Industry 4.0, in addition to the high level of turnover that may be seen, also requires an easier and more efficient learning process for newcomers to the company.

There are some issues making difficult to transfer and share of knowledge, such as the struggle for operators in putting their knowledge into words, the absence of standardization to capture and document knowledge, the considered extreme time recognized by employees to spend on documentation and, above all and most importantly, the use by workers of their knowledge as a guarantee to remain relevant and indispensable in their workplace (Fast-Berglund, Thorvald, & Billing, 2018).

From a knowledge point of view, process orientation is vital to deliver task appropriate knowledge in the organization's operational business processes context (Sarnikar & Deokar, 2010). Furthermore, knowledge is broadly well-known for being the enhancer of long-term growth, development and existence of competitiveness in any enterprise. And nowadays, there is a great amount of information and knowledge that is extremely valuable and is not made externalized or formalized, resulting in not being used by other individuals and sometimes it can even be lost for the enterprise (Kalpic & Bernus, 2002).

For this reason, Business Process Management, already recurrent in the analysis of processes, was applied, using BPMN 2.0, to capture tacit knowledge, resulting in representative models of work instructions, which formed a small repository of organizational knowledge. But in addition to capturing knowledge, process modeling allows the assess to their status and the integration between people, information systems and resources, which supports the establishment of a software specification capable of meeting shop floor requirements.

To conclude Business Process Modelling can be applied in order to institute the knowledge management in a company. Furthermore, it also serves as a tool to study all the gaps in the enterprise's processes. With the perception of these gaps BPM can help improving organization's industry 4.0 environment, as well as to facilitate the acquisition and transfer of knowledge. Although it is important reveal the difficulty in applying changes in organization's processes. The documentation of these processes it is important in order to facilitate people adaptation to workstations. Knowledge management can mitigate the revolt to change felt by people in general by creating a more transparent and balanced climate in which everyone can know everything.

3.4 Chapter V- Shop floor data in Industry 4.0: study and design of a Manufacturing Execution System

Chapter V appears considering the business process analysis carried out by the chapter IV. It is known that, today, the major deficiencies that exist in companies that move them away from the reality of I4.0 are the lack of data capture in real-time and also the programs of the manufacturing systems to which suppliers do not allow access, or if they make it possible, they intend to grant this access only through a large amount of money (Yao et al., 2019). This concern causes the existence of information islands. In addition to this and, presented as two major barriers to the industry 4.0 paradigm, are the lack of process standardization and the lack of architecture and systems integration skills (Raj, Dwivedi, Sharma, Beatriz, & Sousa, 2020).

Since the Manufacturing Execution System is the software closest to the shop floor and with which it interacts, companies are interested in acquiring a distributed information system capable of establishing a continuous information flow without the existence of information islands being a problem. The integration of this system also provides the ability to construct a database structure which may further allow a more flexible data analysis, facilitating the data visualization, having consequences in the decision-making process.

This scientific work is settled in the specification of an information system aligned to the shop floor. This information system, normally called the Manufacturing Execution System, allowed to establish a database (through the UML class diagram) somewhat generalized, capable of supporting the most basic functions of a company's shop floor. Features such as guaranteeing the collection of equipment data, justification for stoppages, requesting maintenance actions and notifications when stopping, are system features and are represented in the appropriate UML use case diagram, that is supported by the UML class diagram (see Figure 4).

The design of the MES system also included knowledge management, thus creating, now, a basis for the installation of a knowledge management system (this is provided by the Tasks Bank class illustrated by the UML class diagram represented in Figure 4) that can refer to the use of BPMN as a tool to capture this same knowledge. As previously mentioned, a base for the primary data of a factory floor was designed and a view was exemplified, which is made up of KPIs relevant to most organizations. These KPIs are capable of being calculated based on the data structure represented by the class diagram.

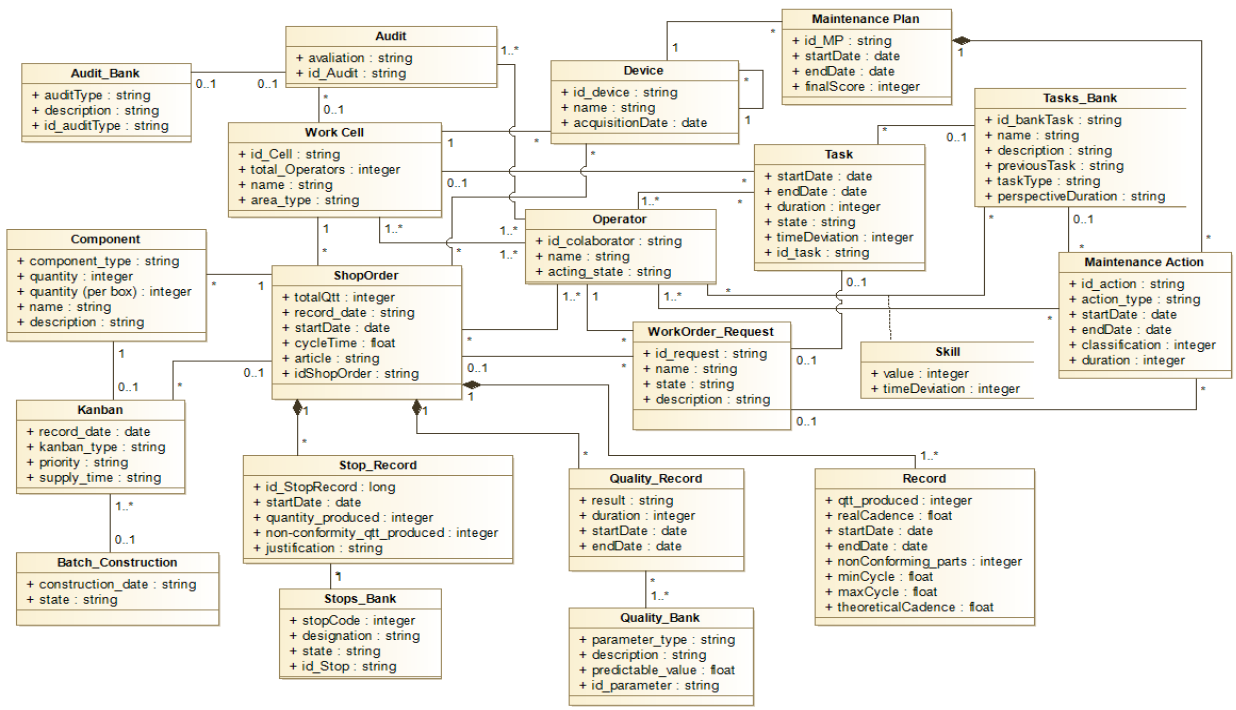

Figure 4- MES class diagram

3.5 Chapter VI- Shop floor data in Industry 4.0: study and design of a Manufacturing Execution System

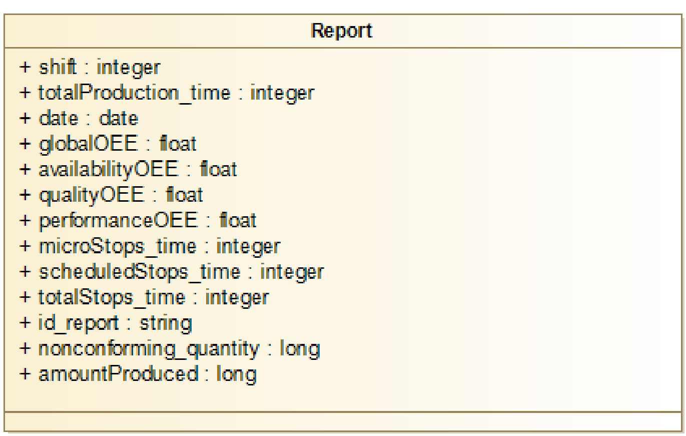

Figure 5- Report class diagram (view)

With a view to representing these same KPI's (see Figure 5), chapter VI appears, using data visualization and storytelling with data as a way of communicating information (data collected that are later processed by statistical analysis tools) for the user. The Power BI software was applied here, revealing itself as a capable and user-friendly tool, whose transmission of information works through the creation of dashboards. I4.0 causes the collection of an exuberant volume of data, which can bring noise, disrupting the manager's decision-making process. Therefore, there is a need to use approaches capable of transmitting information in a more focused way and aligned with the company's strategy. Storytelling with data

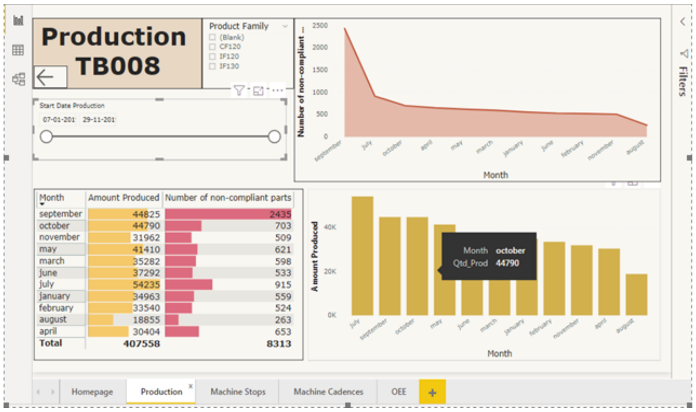

Figure 6- Production Bookmark

Figure 7- Overall Efficiency Effectiveness Bookmark

intends, in a "storyteller" way, to bring to the context of data visualization the display of indicators in a more precise and oriented way.

Figure 6 and 7 show two bookmarks that constitute the dashboard. It is important to highlight that this interface was conceived in order to communicate the actual state of a workstation cell.

For the construction of the dashboard to be possible, firstly an analysis of problem, including the software, was carried out, through its modelling in Unified Modelling Language (UML).

After this modelling and after understanding the data generated, exporting them to Excel was essential to better understand the problem. Through Power BI Software Power Query, several transformations were possible, obtaining a fact table of relevant information.

This table was built using M and DAX language and, in the end, the application of graphic elements was done, creating the final dashboard.

In the “Production” (Figure 6) bookmark the user can find the total amount of parts produced by the station and the total number of non-compliant parts. And the “OEE” (Figure 7) bookmark displays the station efficiency levels, calculated by the concept of Overall Equipment Effectiveness. Here, the OEE Availability, OEE Operator/Performance and OEE Quality are calculated along time and the multiplication of the three allows us to obtain the global value (OEE Global).

4. Discussion and final considerations

The company that served as the basis for this research had presented some determining characteristics for this investigation to follow in the direction currently displayed. This is a company belonging to the group of small and medium-sized companies. It exhibits very low digital maturity and its entire shop floor is covered by Lean practices. It currently has many software programs created inside doors to satisfy different tasks, however they are not integrated, creating silos of information. The company in question intends to start a deeper digitization process (thus increasing digital maturity), with the purpose of building a digital ecosystem on the shop floor.

By analyzing the literature, it is understood that most companies belonging to the group of small and medium-sized companies in the manufacturing industry are currently in the same situation as the company used as a case study. To this question, it is highlighted the issue of information silos created due to the isolated use of software created to satisfy a specific need (Yao et al., 2019).

Thus, all the results that have been derived from the different scientific works and that have been properly generalized, may constitute part of a digital strategy for the manufacturing industry. In this way, the cycle of impact and change is fulfilled, represented in the methodology used in this research, and the adaptability of the artefact outcome in an external environment is achieved (this being the expansion of the internal environmental context, thus constituting the manufacturing industry for small and medium-sized enterprises).

Figure 8 presents a representative diagram of the construction of the results obtained in the five scientific works, thus offering a framework that establishes a first step towards the beginning of digitalization, creating a Lean 4.0 shop floor.

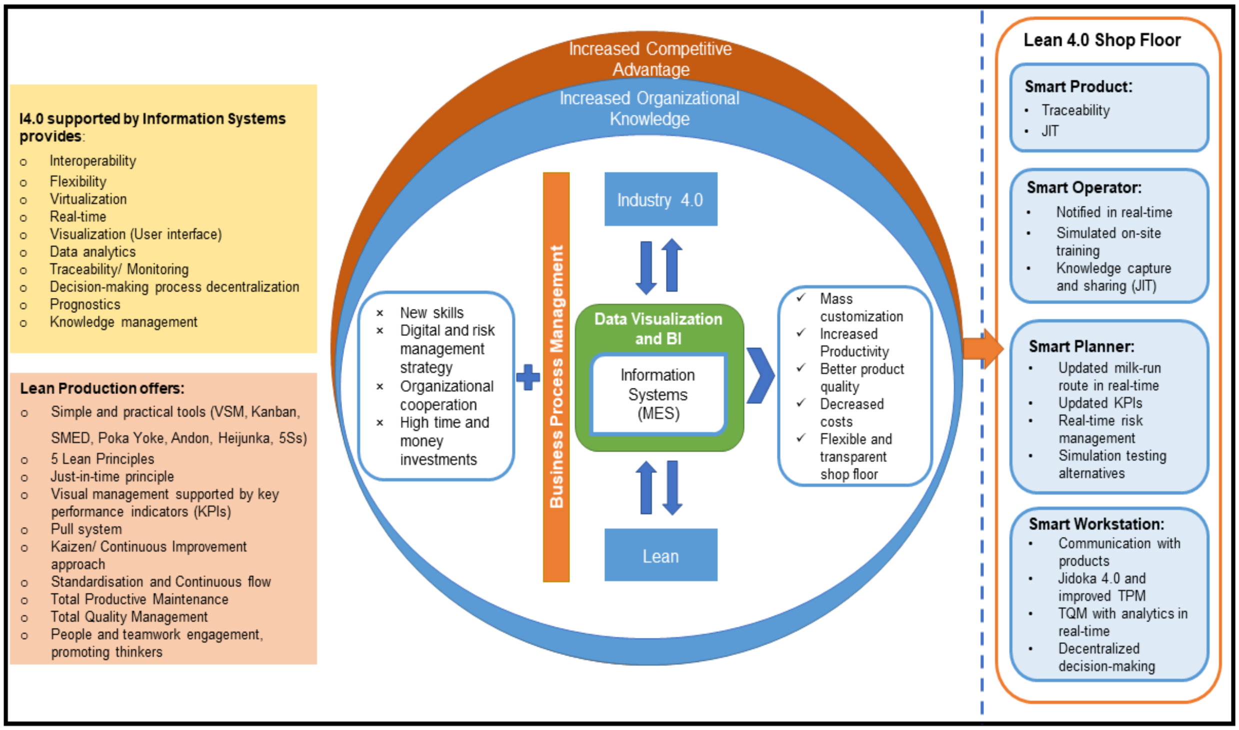

Figure 8- Artefact: Framework for a Lean 4.0 Shop Floor

Since the investigation started with the detachment of two major areas, Lean and Industry 4.0, it is necessary to clarify what each area can bring to the establishment of a digital ecosystem, since the most propitious access of the I4.0 was evidenced together with Lean techniques and a pre-established Lean maturity in the company's shop floor. Following this thought, it is understood that the most relevant characteristics that I4.0 can bring are based on its ability to connect different equipment and systems, track and monitor products and resources in real time, which offers greater flexibility in control of them, contributing to an almost instant action to possible problems that may arise. Its ability to maintain monitoring in real time, also offers a basis for the constitution of interfaces capable of establishing KPIs' visualization that constitute the basis for decision making by the operational management. In addition to this, the ability to collect data on the variables of the equipment belonging to the shop floor, together with the data analysis systems, establishes the possibility of creating prognoses regarding the troubles in the equipment, as well as regarding the level of demand from the market. It is important to note again that in order for these characteristics to become effective, information systems will have a primary role, with the MES being more focused on covering the shop floor and therefore being the focus of this research. This type of system is capable, in addition to connecting the entire shop floor (providing information about it in real time), of creating, sharing and storing knowledge, establishing a good foundation for the birth of a knowledge management system.

On the other hand, Lean already denotes tools and techniques widely used on manufacturing floors that are quite simple to use, with promising results. Total Productive Maintenance (TPM) and Total Quality Management (TQM) encompass a set of Lean principles and techniques that make them easier to apply on the shop floor, ensuring preventive equipment maintenance and higher product quality. However, it should be noted that these methodologies (TPM and TQM), like the Lean philosophy, not only have tools (Poka-Yoke, Heijunka, Andon, etc.) included, but are also based on fundamental principles, such as the 5 Lean principles, the pull system, Just-in-Time, continuous flow and standardization. From its basic principles (5 principles), the Lean philosophy denotes a strong integration of employees in all applied strategies, always promoting their cooperation in them, with a view to their involvement and empowerment. It was perceived through the research, that Lean can give rise to solid foundations for the introduction of I4.0. Not only does it bring widely used tools already in a widespread industrial environment, but also principles that focus on consumer requirements, eliminating waste and on employees and their involvement in processes and new strategies.

The introduction of the I4.0 paradigm is referred to by the academia as a concept that currently requires pre-established guidelines that allow its effective integration in any company. They are the acquisition of new digital capabilities (namely software architecture, process mapping and programming), and the creation of a digital strategy that allow the distribution of goals in cascade form to all levels of a company and the conception of a risk management strategy, so that preventive actions against possible problems are properly aligned and prepared. In addition, cooperation at all organizational levels is necessary, so that the initial objectives created in the digital strategy become common to everyone in the company. As in any project, the investment of money and time are essential, and in this case, they are high, since it is essential to invest in new equipment, new capacities, and adapt the strategy as the project progresses.

Once the pre-established guides for the introduction of I4.0 were internalized and acquired, it was possible to prove that BPM offers strong consonance for the creation of a solid foundation for this new paradigm. The mapping of all shop floor processes is crucial since the alignment of all resources must be idealized with the new strategy to be implemented. In aligning I4.0, it is essential to ensure the integration of the entire digital level with the operational level, and this will only be possible and effective if the processes are properly "free" of waste. For this, we have the connection of BPM with Lean, which, analyzing the processes in a methodical way, intends to eliminate their waste, making them more efficient. Still in the area of I4.0, BPM's capacity to capture tacit knowledge was verified, originating repositories of organizational knowledge. This characteristic will allow, in addition to preserving the capital of organizational knowledge, to facilitate the entry and integration of new members, as well as to enable and support the increased rotation of people that the I4.0 paradigm may require.

In order to integrate I4.0 into the companies' Lean shop floors, it was noticed by the research that the information systems will be pivotal, namely the MES, which is the system most capable today of interacting with the shop floor and transmitting the information resided in him to higher management levels. For the MES to be effective, a strong specification mapping must be carried out and the Lean tools already present on the factory shop floor, have the possibility to upgrade to the digital level. The way of communication of this type of software can undergo a great change through the data visualization (using BI tools) that can take advantage of the data storage in real time and thus show KPIs capable of providing a more integrated view of the state of the shop floor. Thus, it is possible to assist managers at the operational level in making decisions more effectively. All this integration and union of efforts aims to achieve objectives, such as the guarantee of mass customization, increased productivity, better quality of products, cost reduction, as well as the manifestation of a more flexible and transparent shop floor, able to respond to possible changes and problems that may occur, in a quicker way.

The MES system will act as the link between the Lean philosophy implemented in the company and I4.0 that is about to enter. This system will be able to share a large amount of information on the shop floor (creating transparency and flexibility) and, in addition, provide a basis for sharing, storing and creating knowledge. Thus, it can be concluded that all this integration will increase organizational knowledge, which currently favors the competitive advantage of any company.

The exemplification of all this integration is demonstrated by the Lean 4.0 shop floor, where four elements are revealed, the smart product, the smart workstation, the smart planner and the smart operator. The smart product monitors and shares information at all stages of its production, and can even take advantage of the JIT logic (being in the right place at the right time), while having the ability to communicate with the equipment around it. The smart operator, in addition to being notified in real time about the productive status, can also benefit from the distribution of knowledge (in JIT format) provided by MES (can help with troubleshooting). Another advantage is the on-site training that takes benefit of simulation, augmented and virtual reality (AR and VR). Smart planner will take advantage of updated KPIs, real-time risk management (with solutions capable of being applied in time for problems to arise) and also the ability of the simulation (in conjunction with AR and VR) to evaluate flow alternatives. In addition, the update of the milk-run route provided by smart products will act in the readjustment of planning. The smart workstation will benefit from an entire 4.0 maintenance, where preventive and even predictive actions can be performed (through Jidoka 4.0 and analytics). These actions can be promoted through constant communication with the products and, in addition, the entire performance of the station can be verified through KPIs, updated in real time, providing a more decentralized decision making.

5. Limitations of the study and future work

This research has important contributions, although it is not exempt from limitations. Given the exploratory nature of the study and the fact that the data collection is restricted to just one Portuguese company, it is important to extend the framework's application to other enterprises to establish general validation.

Given the exploratory atmosphere of this study, several remarks have come light which can be recognized as further areas to research.

- Since it was mentioned by the literature that the implementation of I4.0 depended on a certain level of Lean maturity, it would be interesting for future research to establish frameworks capable of measuring this characteristic. Thus, it would be possible to understand what minimum value would be expected from this lean maturity to implement the I4.0 paradigm.
- It is also suggested the digitization of Lean tools and their evaluation and analysis in a practical context, in order to access the advantages of this digital update, as well as difficulties in its implementation.
- For the relationship between Lean and I4.0, a greater and more in-depth analysis of the benefits of Lean principles and techniques that can help in the implementation of an I4.0 paradigm is suggested, thus increasing knowledge about the influence of Lean on I4. 0.
- It is also suggested as a future work the digital implementation of a system of capturing tacit knowledge based on BPMN notation / language, creating repositories of organizational knowledge on the shop floor.
- In this research, it is also recommended that the specification and architecture of the MES created here be applied in practice, preferably in several shop floors, in order to understand the implementation difficulties, such as the practical validation of this software architecture.
- Finally, it is proposed that the created dashboard be evaluated by a greater variety of users, in order to make the interface the friendliest possible. In addition, it is suggested that an analysis should be carried out into which performance indicators will be the most preferred and indicative in the I4.0 environment.

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Leonor Teixeira graduated in Industrial Engineering and Management, received a MSc. degree in Information Management, and a PhD in Industrial Management (Information Systems area), in 2008, from the University of Aveiro, Portugal. She is currently an Assistant Professor of the Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT) at the University of Aveiro. She is also a researcher (Integrated Member) at the Institute of Electronics and Telematics Engineering (IEETA) and collaborator at Research Unit on Governance, Competitiveness and Public Policies (GOVCOPP) of University of Aveiro. Her current research interests include Industrial Management in general, and in Information Systems applied to Industry in particular. She has over 200 publications in peer-reviewed journals, book chapters and proceedings, and has several communications at international scientific conferences, some of which as invited speaker. She serves as a member of Program Board and Organizing Committees for several Scientific Committees of International Conferences and has collaborated as reviewer with several journals. She is associated with IIIS, IEEE Society and APSI/PTAIS