Universidade de Aveiro Departamento de Economia, Gestão, Engenharia Industrial e Turismo
2020

Juliana Pereira Salvadorinho

SISTEMAS DE INFORMAÇÃO NA INDÚSTRIA 4.0: MECANISMOS DE APOIO À TRANSFERÊNCIA DE DADOS PARA CONHECIMENTO EM AMBIENTES LEAN

INFORMATION SYSTEMS IN INDUSTRY 4.0: MECHANISMS TO SUPPORT THE SHIFT FROM DATA TO KNOWLEDGE IN LEAN ENVIRONMENTS

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia e Gestão Industrial, realizada sob a orientação científica da Doutora Leonor da Conceição Teixeira, Professora Auxiliar do Departamento de Economia, Gestão, Engenharia Industrial e Turismo da Universidade de Aveiro

Dedico este trabalho àqueles que, de uma forma austera ou não, são incentivados a acreditar superiormente na persistência, ao invés da genialidade.

o júri

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agradecimentos

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palavras-chave

Indústria 4.0, Produção Lean, Manufatura Lean, Gestão de Processos de Negócio, BPMN, Sistemas de Informação, MES, Visualização de dados.

resumo

O paradigma que atualmente emerge no contexto organizacional, conhecido como Indústria 4.0 (I4.0) ou Quarta Revolução Industrial, promete trazer princípios de conectividade e flexibilidade às empresas que a adotam. A Indústria 4.0 potencia a eficácia no ajuste em tempo real aos requisitos dos clientes, através da constituição de um chão de fábrica inteligente e capaz de responder de forma flexível e customizada às mudanças do mercado.

Contudo, durante as últimas três décadas, sabe-se que a adoção da filosofia Lean foi absorvida pelo meio industrial, com resultados que se demonstraram exuberantes, tendo em conta a simplicidade das ferramentas.

Deste modo, a implementação I4.0 deve ser feita no sentido da preservação dos sistemas de manufatura já existentes, procedendo, desde que possível, ao seu upgrade numa base de excelência Lean.

Conta-se que os sistemas de informação serão decisivos na fundação do paradigma I4.0. Destes, os sistemas MES, com maior conexão ao chão de fábrica, tenderão a ser alinhados com as práticas já existentes, contribuindo, através da sua conectividade, para a introdução de práticas de gestão do conhecimento e mecanismos de visualização de dados. Na fase de especificação e arquitetura destes sistemas, o entendimento dos processos será crucial. Assim, a documentação dos mesmos é um pilar organizacional, estando o BPMN e a UML capazes de a orientar. Porém, e a somar à sua utilidade na ilustração de processos, o BPMN está igualmente passível de ser aplicado na captação de conhecimento tácito, o que por si pode ser uma base para a constituição de repositórios de conhecimento, contribuindo para a excelência organizacional.

É neste contexto que o presente trabalho se insere, tendo como objetivo a criação de linhas orientadoras e mecanismos que facilitem a implementação de estratégias I4.0 em ambientes industriais Lean. A metodologia adotada passou, primeiramente, por uma exaustiva revisão da literatura, por forma a encontrar possíveis efeitos bilaterais entre tecnologias I4.0 e ferramentas lean. De seguida, contemplou-se o desenvolvimento de alguns aplicativos alinhados ao paradigma I4.0, enquanto motor tecnológico, e à filosofia Lean, enquanto ferramenta de eliminação de desperdícios e/ou criação de valor. Das diversas experiências de desenvolvimento em contexto industrial e considerando as evidências reportadas na literatura o presente estudo propõe uma framework Lean 4.0 orientado ao chão de fábrica.

keywords

Industry 4.0, Lean Production, Lean Manufacturing, Business Process Management, BPMN, Information Systems, MES, Data Visualization.

abstract

The paradigm that presently emerges in the organizational context, known as Industry 4.0 (I4.0) or Fourth Industrial Revolution, promises to bring principles of connectivity and flexibility to the companies that embrace it. Industry 4.0 enhances the efficiency in adapting in real time to the customers' requirements, through the establishment of an intelligent shop floor capable of answering in a flexible and customized way to market changes.

However, during the last three decades, 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, proceeding, whenever possible, to upgrade them on a Lean excellence basis.

It is said that information systems will be decisive in the foundation of the I4.0 paradigm. Of these, MES systems, with greater connection to the shop floor, will tend to be aligned with existing practices, contributing, through their connectivity, to the introduction of knowledge management practices and data visualization mechanisms. In the specification and architecture phase of these systems, understanding the processes will be crucial. Thus, their documentation is an organizational pillar, with BPMN and UML being able to guide it. However, and in addition to its usefulness in the processes' mapping, 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.

It is in this context that the present work is implanted, aiming at the creation of guidelines and mechanisms that facilitate the implementation of I4.0 strategies in Lean industrial environments. The adopted methodology first went through an exhaustive literature review, in order to find possible bilateral effects between I4.0 technologies and lean tools. Then, the development of some applications aligned with the I4.0 paradigm, as a technological engine, and the Lean philosophy, as a tool for eliminating waste and / or creating value, was contemplated. From the various development experiences in an industrial context and considering the evidence reported in the literature, this study proposes a Lean 4.0 framework oriented to the shop floor.

Contents

List of figures

List of tables

List of abbreviations

AR	Augmented Reality
BI	Business Intelligence
BPM	Business Process Management
BPMN	Business Process Model Notation
BPR	Business Process Reengineering
BPs	Business Processes
CPS	Cyber-physical systems
CRM	Customer Relationship Management
DMCP	Daily Mold Change Plan
DSR	Design Science Research
DT	Digital Twin
ERP	Enterprise Resource Planning
ESs	Enterprise Systems
FMEA	Failure Mode and Effect Analysis
HMIs	Human-Machine Interfaces
I4.0	Industry 4.0
IC	Intellectual Capital
ICTs	Information and Communication Technologies
IoT	Internet of Things
IT	Information Technology
JIT	Just-in-Time
KM	Knowledge Management
KPI	Key Performance Indicator
LA	Lean Automation
LIM	Lean Information Management
LM	Lean Manufacturing
MES	Manufacturing Execution System
MRP	Material Requirements Planning
MRP II	Manufacturing Resource Planning
OEE	Overall Equipment Effectiveness
OL	Organizational Learning
OMG	Object Management Group
OPC	Open Platform Communications
PLC	Programmable Logic Controller
RFID	Radio Frequency Identification
SCADA	Supervisory Control and Data Acquisition
SMED	Single-minute exchange of dies
SMEs	Small and medium-sized enterprises
TPM	Total Productive Maintenance
TPS	Toyota Production System
UML	Unified Modelling Language
VR	Virtual Reality
VSM	Value Stream Mapping
WIP	Work in Progress

Chapter I- General Introduction

I.1 Introduction and motivation

I.2 State of the art

I.3 Objectives and research methodology

I.4 Dissertation structure

I.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., 2018a; A. 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; A. 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 (A. 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-centred 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 (Material Requirements Planning (MRP) as well Manufacturing Resource Planning (MRPII) have a huge weight in here) (Ghobakhloo & Fathi, 2020).

The transitioning toward Industry 4.0 requires:

- the removal of functional silos (Ghobakhloo & Fathi, 2020; Wilkesmann & Wilkesmann, 2018);
- openness and a supportive culture to change- where the cultivation of a Digital Culture is promoted (Romero et al., 2019);
- standardized processes and their understanding (through mapping) (Mayr et al., 2018);
- collaborate knowledge management (Ghobakhloo & Fathi, 2020);
- supply chain integration (L. Da Xu, Xu, & Li, 2018);
- data transparency across the entire value chain (Ghobakhloo & Fathi, 2020);
- digital skills (from capturing system specifications, through their architecture and design, to their implementation) (Enke et al., 2018; L. Da 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, analysing 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.

I.2 State of the art

I.2.1 Industry 4.0 and Lean Production

I.2.1.1 Industry 4.0

The term "Industry 4.0" (I4.0) came from a German government project in 2011, in which a strategy (involving a high level of technology) for the digitization of the manufacturing industry was promoted (Martinez, 2019; Rojko, 2017; Savastano, Amendola, Bellini, & D'Ascenzo, 2019). Smart manufacturing, industrial internet, smart factories, and smart production can be considered synonymous, despite having different geographical roots, however the meaning is the same given to the initial one of Industry 4.0 (Savastano et al., 2019).

The fourth industrial revolution is allowing the progression of embedded systems to cyber-physical systems (CPS), which, using machine-to-machine communication, Internet of things and CPS technologies, know how to bring together both virtual and physical spaces (Sony, 2018; L. Da Xu et al., 2018). The inherent focus of industry 4.0 is the integration of digital industrial ecosystems, providing end-to-end digitization (L. Da Xu et al., 2018).

CPS consist of several built-in devices that are networked to detect, monitor, and activate physical elements in the real world. CPS do not intend to unite the two worlds, physical and virtual, but rather to guarantee their intersection (Monostori et al., 2016). These systems are capable of accomplishing agile and dynamic production requirements and aim to increase organization's efficiency and effectiveness (Sony, 2018).

Horizontal integration across entire supply chains, strong vertical integration around all levels of a company and digital engineering transparency across the value chain are features included in I4.0 (Bahari, Jafni, & Ismail, 2018).

According to Telukdarie et al. (2019a), Alcácer et al. (2019) and Unver et al. (2013), a fully integrated enterprise must bridge the technical gaps between all its levels and all its systems. For that, a scheme of an automation pyramid is presented (Figure 1), where the first level (the most operational one) is based on process control, using for that the Supervisory Control and Data Acquisition (SCADA), which is constituted by Human-Machine Interfaces (HMIs) and Open Platform Communications (OPC). The second level is centred on the Manufacturing Execution System (MES), responsible for plant control, and the third one is focused on Enterprise Resource Planning (ERP), with a more business high level strategy. Telukdarie et al. (2019) establish that Business Intelligence (BI) can be assumed as the last one level, however it was understood by this present research that in all levels managers can benefit from business intelligence tools, having dashboards to monitor the processes' evolution, from the lowest level of the business to the highest. For that reason, it was launched an all vertical opportunity to introduce this practice (see Figure 1).

Industry 4.0 technologies could boost the accomplishment of particularly high-performance levels, even though they necessitate structural adjustments in organizations' modus operandi which creates an extra test for its acceptance (Rossini, Costa, Tortorella, & Portioli-Staudacher, 2019).

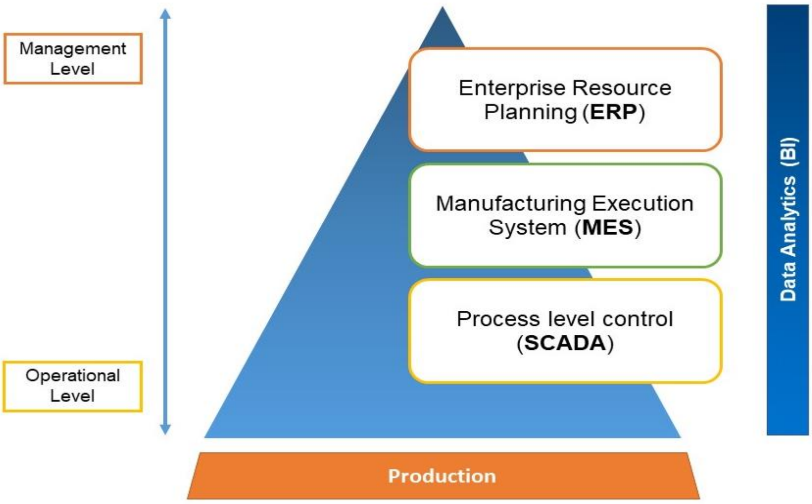

Figure 1- Data Automation pyramid based on Information Systems

I.2.1.2 Lean Manufacturing

Lean manufacturing tools and techniques have been widely implemented through the world during the past two decades (Yeen Gavin Lai, Hoong Wong, Halim, Lu, & Siang Kang, 2019). Its simplicity and effectiveness were the incentives why it became so famous in 1990s (Kolberg & Zühlke, 2015; Tortorella & Fettermann, 2018; Tortorella, Rossini, Costa, Portioli Staudacher, & Sawhney, 2019).

It is particularly accepted that Lean was developed from Toyota Production System (TPS), which was started by Taichi Ohno at Toyota as a means to increase the competitiveness of the automotive company production competences (Kale & Parikh, 2019; Kolberg & Zühlke, 2015; Pekarčíková, Trebuňa, & Kliment, 2019; Yeen Gavin Lai et al., 2019).

Thinking about the TPS scheme (see Figure 2) (a Lean's vision), standardized work and smooth production using Heijunka are at the foundation. The first pillar is characterized by the Just-in-Time principle, producing precisely what is required when the user wants it, and the second is based on Jidoka's technique (perceiving irregularities in the process) (Rosin, Forget, Lamouri, & Pellerin, 2020; Wagner, Herrmann, & Thiede, 2017). At the core are the principles of continuous improvement, employees and teamwork involvement, as well as waste reduction. Lastly, at the TPS house's highest point are the purposes of improved quality, shortest potential costs, lowest cycle time, best protection for employees and superior employee enthusiasm (Rosin et al., 2020; Wagner et al., 2017).

The main concepts related to Lean are reduction of manufacturing wastes (Haddud & Khare, 2020; Kale & Parikh, 2019; Kolberg & Zühlke, 2015; Tortorella, Giglio, et al., 2019), continuous flow relied on the pull approach adoption (Haddud & Khare, 2020; Tortorella & Fettermann, 2018) and continuous improvement (Kolberg & Zühlke, 2015; Tortorella & Fettermann, 2018). All these concepts settle in the customer's perspective identification of value.

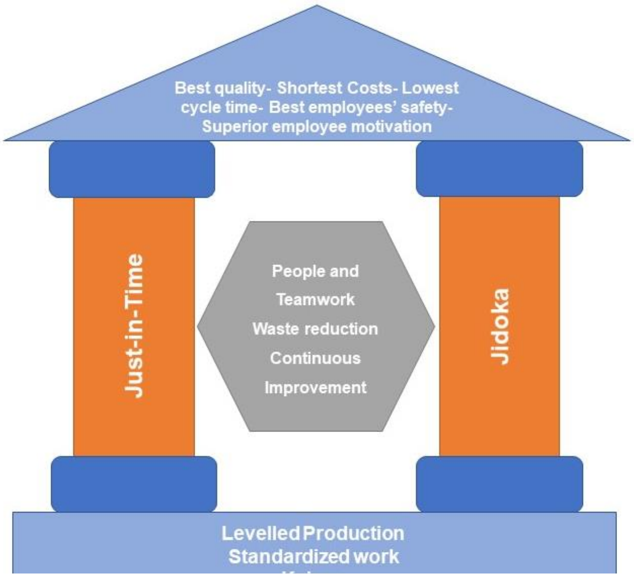

Figure 2- TPS House (adapted from Wagner et al. (2017)

The understanding of Lean Production System has expressively grown during the last decades, moving from an exclusive shop-floor practice-oriented methodology to an integrated and contingency-founded value system. Besides, lean has been extending its influence from single firms to entire supply chains (Rossini, Costa, Tortorella, et al., 2019; Tortorella, Giglio, et al., 2019).

Nevertheless, fluctuations in production procedures, buffer stocks or cycle times necessitate painstaking alterations of Kanban cards. Consequently, in the line of this thought, the suitability of Lean Production for future shorter product life cycles is inadequate (Kolberg & Zühlke, 2015). It appears that Lean Production achieved its limit, since strong variations in market demands are in dispute with required levelled capacity utilization. Its rigid arrangement of production and established cycle times are not advisable for individual single-item production (Kolberg & Zühlke, 2015). On the other side, Industry 4.0 concedes the launch of smart and dynamic production systems and the mass production of extremely personalized products (Tortorella, Giglio, et al., 2019).

I.2.1.3 Lean 4.0

The Lean Automation (LA) subject (integration between Lean Production practices and Information and Communication Technologies) date from the beginning of 1990s and its main goals are to achieve higher variability and smaller information flows to gather future market demands (Tortorella & Fettermann, 2018). Although, the current tactics are exclusive solutions which have to be tailored to personal needs (Tortorella & Fettermann, 2018).

The connection between Lean Production and information and communication technologies has been highlighted even more, with the appearing of the Industry 4.0 wave in companies. Some authors have already claimed about the envisioned benefits for the manufacturers, since this integration could mitigate recent management difficulties and contribute to increase performance standards (Tortorella, Rossini, et al., 2019). Researchers denote that I4.0 will not be emerged as an industrial revolution if it is not combined with Lean Manufacturing (Sony, 2018).

Few studies have been carried out to explore the link between Lean Manufacturing (LM) and Industry 4.0. That is why research academia still lacks published frameworks which can sum up this integration. Hence, the perception of the area of LM and I4.0 is yet immature (Sony, 2018).

I.2.2 Data, information and Knowledge

According to Zins (2013), data can be assumed as the raw material for information and information can be considered as the raw material for knowledge.

Some authors describe data as information but in numerical arrangement or just simply consider it as one or more symbols which signify something (Ahmed-kristensen, 2014; Sanders, 2016; Zins, 2013). Information, on the other side, is seen as a flow of messages (Nonaka & Lewin, 1994; Sanders, 2016; Tsoukas & Vladimirou, 2001) or is just defined by data surrounded by a context (Ahmed-kristensen, 2014).

Data is irrelevant if not inspected according to manufacturing actor requests and centred on business vocabulary. The similar data can come up with separate connotations or benefits from one task to another, hence it is vital for an initial understanding to convert raw data into valuable information (Nantes & Nantes, 2019).

Since information is a flow of messages, knowledge is conceived by that exceedingly flow of information, attached in the values and commitment of its possessor (Nonaka & Lewin, 1994a; Tsoukas & Vladimirou, 2001). This understanding emphasizes that knowledge is essentially related to human action. It is still conceived that knowledge is the result of a synthesis mixture in the psyche of the aware person and survives simply in his or her mind (Zins, 2013). Hence, knowledge is adequately assimilated information which revises the individual's mental collection of information and promotes his development (Zins, 2013).

The combination of data and knowledge allows computerized thinking, the incorporation of artificial intelligence, and the establishment of decision support systems to assist workers at distinct decision levels (Nantes & Nantes, 2019).

Industry 4.0 enabling technologies in SMEs are difficult to implement, however, the companies may improve their dissemination of data, information and knowledge applying their current technologies in a structured way (Sandbergs, Stief, Dantan, Etienne, & Siadat, 2019).

I.2.3 Business Processes: The shop floor skeleton

The I4.0 paradigm brings to the forefront the need to create digital ecosystems, which in turn requires the creation of new software and systems predisposition architectures and the preadaptation of existing business processes. As such, Business Process Reengineering has already emerged in this sense, with a view to remodelling processes, so that the best use of the new technologies brought by I4.0 is gathered (L. Da Xu et al., 2018; Yao et al., 2019).

Business processes (BPs) convert system inputs into required system outputs by the use of system resources (Kalpič & Bernus, 2006). They can also be seen as a group of one or more associated practices or activities which together comprehend a business objective, usually within the context of an organizational structure, characterizing functional roles and relationships (Chinosi & Trombetta, 2012; Kovačić, Bosilj-Vukšić, & Lončar, 2006; Ouali, Mhiri, & Bouzguenda, 2016).

The Business process management (BPM) is a subject that offers control of an environment constituted by business processes in order to increase agility and operational performance in an organization (Chinosi & Trombetta, 2012). BPM emerged from a Business Process Reengineering exodus and a merger of tools associated to total quality, Six Sigma and strategic management culture (Kaziano & Dresch, 2020).

BPM is used to backing business processes using for that methods, techniques, and software design. Besides, it is a topic capable of enact, manage and explore operational processes which involve people, applications, files and other sources of information (Neubauer, 2009). Hence, the intention of BPM is to make parallel business processes with the company's strategic planning, goals, normalize corporate processes and accomplish a better throughput and efficiency (Kaziano & Dresch, 2020).

Business Process Modelling is different from Business Process Management since the first one is the endeavour of representing processes of an enterprise, and it is usually performed by business analysts and managers (Chinosi & Trombetta, 2012). This one is a subject which tools offers users the capacity of performing "what-if" analysis and the capability of detecting and mapping no-value moves, costs and process performance. The goal is to develop AS-IS and TO-BE models of business processes which represent the actual (for AS-IS) state and the future (for TO-BE) state (Kovačić et al., 2006).

The Business Process Model Notation (BPMN) is the standard code used by Business Process Modelling to create Business Process Models. A model is a group of elements depicted in some well-defined and documented shape. Hence, modelling is an abstraction process of the real world into a strict representation, where the relevant facts are articulated with some formalism (Kalpič & Bernus, 2006).

BPMN was originally published in 2004 as a graphical notation and, since there was an increasing of adoptions from companies and the growing interest upon this notation, OMG (Object Management Group) adopted the language as a standard in 2006 (Chinosi & Trombetta, 2012).

Experts come to an agreement that a good comprehension of BP guarantees the survival of the organization (Ouali et al., 2016). Moreover, very complex and process-oriented nature of business has led organizations to use process modelling tools to manage this complexity and improve the performance of the organization in quality and quantity (Kovačić et al., 2006; Ouali et al., 2016).

Despite all the benefits regarding productivity, adaptation to markets' requirements and efficiency, the academia found that business process modelling is effective in supporting other areas such as knowledge management (Bosilj-Vukšić, 2006). If business processes are modelled and captured, hence, they are part of codified intellectual capital of the organization. Besides, company's knowledge processes should be a part of business process repository and this repository ought be used for knowledge creation, sharing and distribution (Kovačić et al., 2006).

I.2.4 Information Systems on the shop floor

Enterprise information systems are constituted by computers, software, people, processes and data and play a critical role in manufacturing organizations by backing the business processes, information flows and analytics (Soujanya Mantravadi & Møller, 2019).

Information systems will be critical to achieve the smart manufacturing state, since they are capable of providing interoperability and traceability to the enterprise (Soujanya Mantravadi & Møller, 2019).

Enterprise systems (ESs) aim at mixing data and business processes throughout an organization, although to integrate cross-functional business processes, the business units of the organization must be in unceasing contact and cooperation (Ebrahimi, Ibrahim, Razak, Hussin, & Sedera, 2013).

However, it is important to assume that ESs are socio-technical shifts rather than simply software applications, in that way if the implanted procedures in an organization are not in harmony with the adopted ES, conflicts will urge (Ebrahimi et al., 2013). With the ES adoption, organizations must move from a function-based organizational structure to an unified process-oriented structure (Ebrahimi et al., 2013; Sauer, 2014). Hence, for a fruitful ESs Integration an analysis, evaluation and complete understanding of business processes before the change are critical, otherwise, it will be almost impossible a high operational and strategic impact's outcome (Javidroozi, Shah, & Feldman, 2020).

According to Figure 1 (see I.2.1.1.), the smart factory will be established by the integration of three main levels. At the top of pyramid will stay Enterprise Resource Planning (ERP), which is a system that performs the planning of human and material resources in a company (M. Hoffmann, Büscher, Meisen, & Jeschke, 2016). This kind of systems have automated high-level business processes which incorporate production and supply planning, although most of the decisions almost not reach the operational level (shop floor level) (C. Huang, 2002). That is why Manufacturing Execution System (MES) exists right below ERP, since it was necessary to bridge the gap between planning systems, i.e., ERP and controlling systems (e.g. sensors, Programmable Logic Controllers (PLCs)) (Soujanya Mantravadi & Møller, 2019). MES functions as information hubs (Sauer, 2014) and allows the transfer of data between automation and ERP, preventing data errors during manual input, increasing speed of reporting and replacing repeated manual operations. These tasks, consequently, enhance business processes and deliver visibility of information (Ricken & Vogel-Heuser, 2010). MES core activities are operations, quality management, inventory and maintenance operations. The support ones consist in information management, safety management, document management, configuration management, conformity management and irregular deviation management (Yue, Wang, Niu, & Zheng, 2019).

The last level presented in Figure 1 is mainly associated to the Supervisory Control and Data Acquisition (SCADA) system which has the main aim of controlling conditions and system states for the period of operation to avoid critical problems or malfunctions in the production flow (M. Hoffmann et al., 2016). It is a system mostly constituted by sensors, Programmable Logic Controllers (PLCs) and Human-Machine Interfaces (HMIs).

Information systems are focused to capture, store and process data and, consequently, to generate knowledge which may be used by several stakeholders within an enterprise or among different networked enterprises. Hence, it is often approved that cooperative information systems deliver a fortitude for the integrated information infrastructure (Lezoche, Yahia, Aubry, Panetto, & Zdravković, 2012).

I.2.5 Business Intelligence and Data Visualization

The development of Internet, Internet of Things (IoT), big data, cloud computing, artificial intelligence and new Information and Communication Technologies (ICTs) has been created a whole new capacity of connectivity which generates a large volume of various data (including structured and unstructured data) (Qi & Tao, 2018).

Most organizations are currently faced with the existence of silos of information, that is, fragmented systems (software) and isolated scattered on the shop floor (Yao et al., 2019). In this way, the information systems' integration and the creation of connected interfaces are crucial, in order to achieve the maximum of cooperative information systems and the building of digital ecosystems. Visualization urges as a key characteristic that offers the capacity of having a perspective of how everything is connected.

If it is easier to collect data with the technologies advancements, it is difficult to extract and to process useful information from such massive and dynamic databases (Choi, Chan, & Yue, 2017).

Business Intelligence (BI) involves technologies, processes and propositions which make available acquiring, storing, retrieving and examining data for better decision making (Stecyk, 2018; Surbakti & Ta'A, 2017).

BI groups a set of steps and tools indicated to implement it in small and medium enterprises: (i) the first step settles in the identification of the sources and the nature of information in the enterprise; (ii) the second step consists in organizing data in tabular form (mostly using Power Query) and preparing a data model; (iii) then, it is essential the application of data analytics (with Excel or Power BI); (iv) the visualization and the preparation of reports finally urges after these steps, with posterior sharing all over the enterprise (Stecyk, 2018).

Data visualization appears to be an easy and speedy way to transmit messages and exemplify convoluted things, facilitating the people's interpretation, since humans are tailored to find patterns in the whole thing they see (Ali, Gupta, Nayak, & Lenka, 2016). Its goal settles in the recognition of interesting patterns and correlations (Ali et al., 2016).

Visualization has the potential to communicate information and a new concept is getting high attention, being its name visual storytelling or storytelling with data (S. Chen et al., 2015). Academia have been recently creating authoring tools to build stories and deliver visual support for storytelling (S. Chen et al., 2015).

Thus, it is already assumed in the academia that big data (the result of an enormous amount of data collected on the shop floor), with the data subsequently processed, can lead to the new strategy of competitive advantage establishments in companies (Kamoun-Chouk, Berger, & Sie, 2017). Data visualization in conjunction with analytics is the source of transformation of something raw into something with value. This can be summarized as the conversion of data into information, allowing decision-makers to create a more valuable knowledge about the company's state, and consequently a more valued intellectual capital (Surbakti & Ta'A, 2017).

I.3 Objectives and methodology

I.3.1 Objectives

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?

The main research question was addressed, however there was a need to establish three other more specific questions. These same concerns take place in a time perspective of the investigation, where, first, the contact with the current state of the industry was recognised (shop floor mostly Lean). Then some issues regarding the “skeleton” of the shop floor was having into account (shop floor processes) and, finally, the information system capable of make a bridge to Industry 4.0’s concept, always in a perspective “from data to knowledge”, allowing at the end, to create a framework of steps to integrate the new paradigm.

The occidental industry suffered from an extensive adoption of lean practices in the last three decades (Rossini, Costa, Tortorella, et al., 2019). The goal of Lean is aligned with a streamlined process flow where a systematic and visual approach is used to reduce waste (Rossini, Costa, Tortorella, et al., 2019) and increase flow via extensive employee involvement and continuous improvement, always recognizing value from the customer’s point of view (Haddud & Khare, 2020; Kamble, Gunasekaran, & Dhone, 2020; Tortorella, Pradhan, et al., 2020). Industry 4.0 (I4.0), driven by the principles of connectivity, settles its decentralized decision-making process on decentralized architectural models (Soujanya Mantravadi & Møller, 2019a). According to Savastano, Amendola, Bellini, & D'Ascenzo (2019), I4.0 brings the creation of cyber-physical systems that interconnect physical components with digital ones, varying any operation depending on the context (L. Da Xu et al., 2018). Numerous authors have already stated that since several shop floors were completely converted to Lean, it was time to pay attention to the combination of the two aspects, Lean and I4.0, with the arrival of the I4.0 context. Industry 4.0 is capable of improvement but in a mostly technical approach which does not replace the value-based mind set of lean (Meissner et al., 2018a). For this reason, urges the following more specific research question:

Q1: How does Lean influence the entry of Industry 4.0?

The processes are the core of one organization processes and for managing them it is vital to know how they are performed inside the organization and how they are linked to each other (Ongena & Ravesteyn, 2016). Business Process Management (BPM) subject is considered to be a way to gain and sustain competitive advantage (Niehaves, Poeppelbuss, Plattfaut, & Becker, 2014). This methodology allows companies to adapt more easily to the endlessly changing requirements of the market and its customers, since it enables development and continuous improvement of corporate strategies (Neubauer, 2009). Because of that, the modelling and documentation of processes are a matter of concern regarding their maturity within the organization (Ongena & Ravesteyn, 2016). The management of business processes in the I4.0 context will have significant requirements across the entire value-added chain (Halaška & Šperka, 2019). Therefore, the following specific question emerges:

Q2: How can shop floor processes lay the foundation for the advancement of Industry4.0?

Information systems will be critical tools to accomplish the two main pillars of Industry 4.0, interoperability and traceability (Soujanya Mantravadi & Møller, 2019; Rojko, 2017). There is a consensus in academia that the smooth integration between Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES) is the key to achieve a smart shop floor (Rojko, 2017). MES is a type of system used to track, inspect, and alert in real-time all that occurs on the shop floor, ranging from raw materials to final products (Coito et al., 2019). Since MES is the software closest to the shop floor and with which it interacts, companies are attracted in acquiring a distributed information system capable of establishing a continuous information flow without the existence of information silos being a problem. Hence, the last specific question is launched:

Q3: How does a MES with data visualization guarantee the first level for establishing an intelligent shop floor?

In order to study everything that was said in each of the segments, these questions (Q1, Q2 and Q3) were broken down as shown in Figure 3.

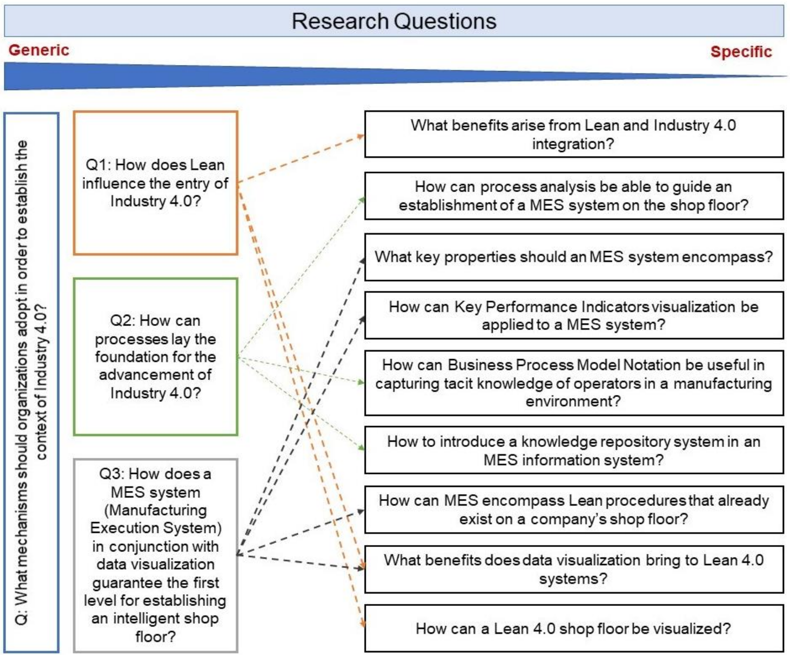

Figure 3- Research Questions

I.3.2 Methodology

I.3.2.1 About Design Science Research

Agreeing with Simon (1996), in his seminal book "The Sciences of the Artificial", "Everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (as cited in March & Storey, 2014).

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).

A good design science research often starts by recognizing and representing opportunities and difficulties in an actual application environment which involves people, organizational system, and technical systems that co-operate to work to achieve a goal (Hevner, 2007)

According to Peffers et al. (2014), the methodology chosen has some rules that need to be followed, they are: (i) an artefact has to be created in order to guide the resolution of a problem;

(ii) the artefact must be relevant to carry out the solution of an up to know unsolved and crucial business problem; (iii) the usefulness, quality and effectiveness of the artefact must be subject to evaluation; (iv) the research must demonstrate a contribution capable of being verifiable and, in addition, the search for rigor both in the development of the artefact and in its evaluation must be paramount; (v) the creation of the artefact must be a research process based on existing theories and knowledge to discover and align a solution to a defined problem; and finally, (vi) the research must be communicated to the appropriate audiences effectively.

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. Figure 4 portrays a scheme of DSR, as well as the cycles that compose it and the way these cycles are related.

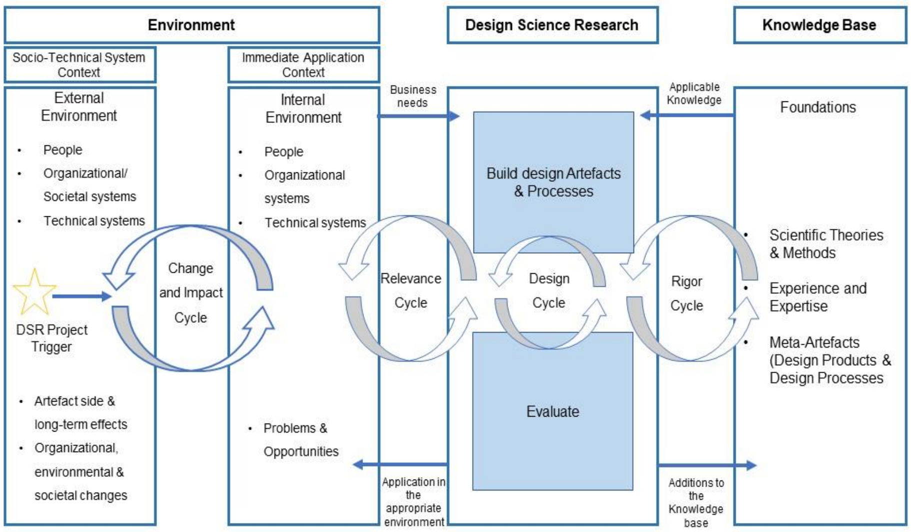

Figure 4- DSR cycles

Source: Adapted from Drechsler et al. (2016)

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). 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. They, actually, give an example with a mobile healthcare IT app in which the app itself, the doctors and patients that use the app would be the direct application environment, while the healthcare system (the surrounding environment) and the corresponding country's society in need of improved healthcare would constitute the external context/environment.

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.

I.3.2.2 Design Science Research in the Investigation process

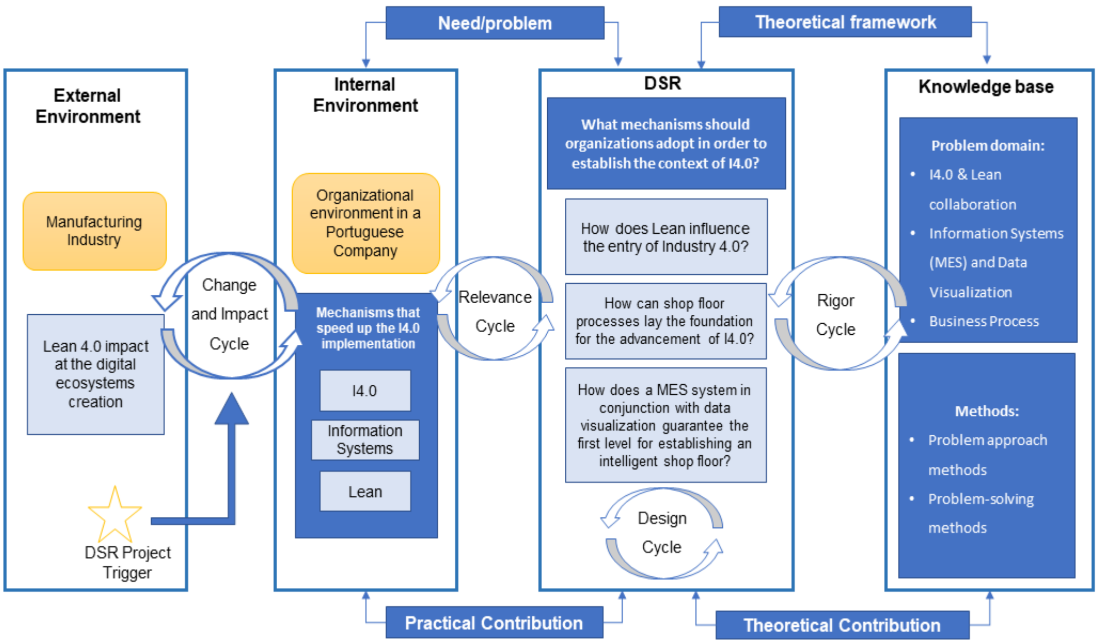

Figure 5- The Research Framework based on DSR

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 5.

The purpose of this work is to find foundations that support and answer the general research question "What mechanisms should organizations adopt in order to establish (first in the shop floor) the context of Industry 4.0?", and for that reason the research process began with a literature review. The literature review carried out made it possible to understand the limits of the existing theoretical research space, lack of knowledge, as well as tools that, if properly implemented, could offer a better understanding of the phenomenon in question. These tools have been integrated into the rigor cycle. The revision also made it possible to divide the general question into other questions (as already noted in the previous point), allowing the use of several approaches, which goal is to fulfil all the proposed objectives.

In order to answer the numerous questions derived from the general research question, a method was carried out, as can be seen in the Figure 6. This method consisted, after reviewing the literature, of data collection, supported by direct observation in a business environment, informal interviews and even documental analysis, regarding the enterprise's software and archive. After data is collected, it was necessary to carry out an analysis and processing of the data. In this way, as most of the acquired data was of a qualitative scope, and in order to carry out tools known for the literature review, in addition to content analysis, modelling languages were used - Business Process Model Notation and Unified Modelling Language. And because it was necessary making some connections to the company's database, a Business Intelligence tool was applied (Power BI desktop).

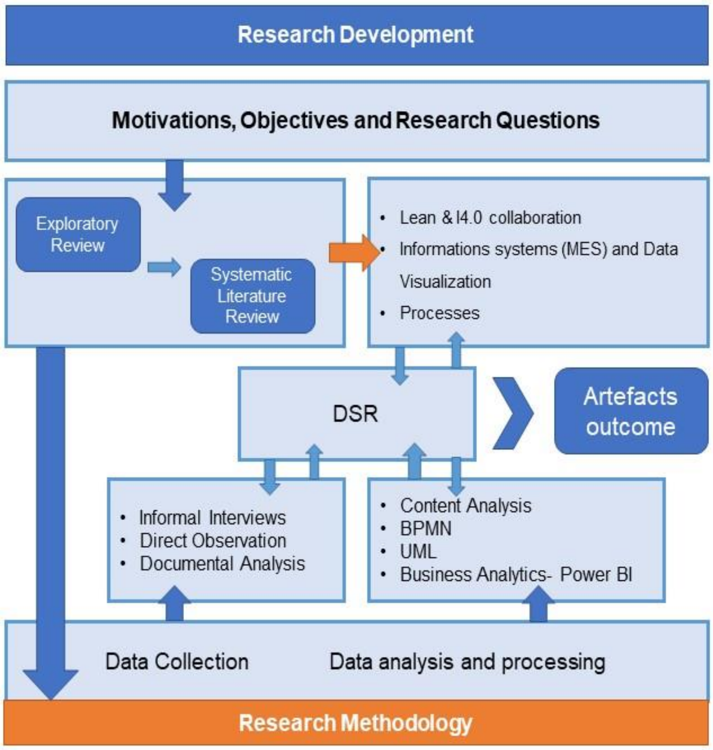

Figure 6- Research Development supported on Design Science Research

The structure of the dissertation will be presented and justified in the following subsection that follows.

I.4 Dissertation structure

The present dissertation is structured into three parts, which make a group of seven chapters. More details about each part will be described above.

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 7 pretends to summarize all the contributions related to these five papers.

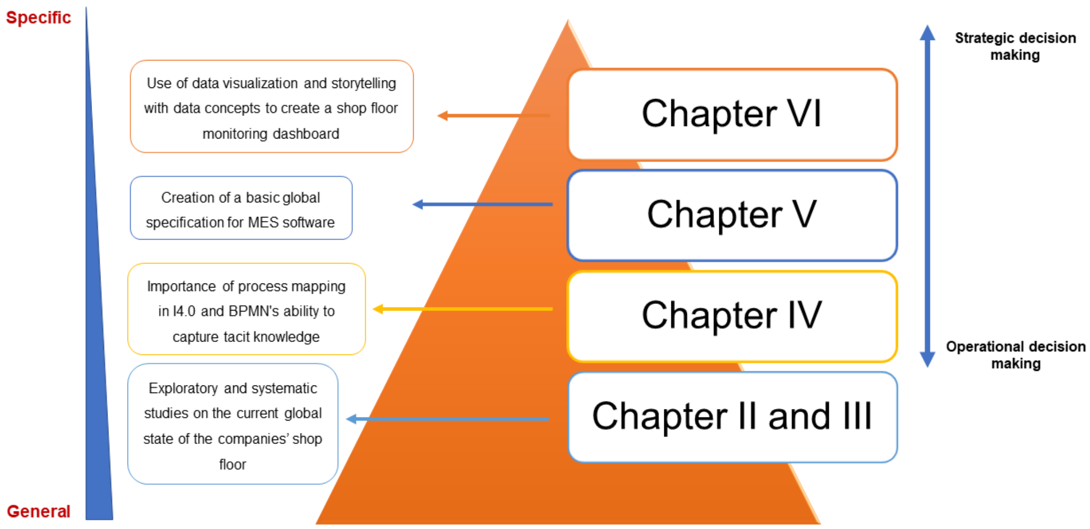

Figure 7- Scientific Works' Structure

The aim of the first scientific paper described in **Chapter II** was to analyse the challenges and obstacles of an implementation of an Industry 4.0 strategy and how the Lean philosophy can 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. The results culminated in a proposal of a Lean 4.0 framework, capable of summarizing the bilateral benefits of both practices (Lean and I4.0) and demonstrate a Lean 4.0 shop floor suggestion.

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 where the theoretical or practical evidence of the combination of I4.0 technologies with Lean principles and/or techniques is recognized. For this, a combination of the most relevant I4.0 technologies and the most relevant Lean practices, in the universe of selected articles, had to be conducted.

Chapter IV is a case study carried out in the organization belonging to the chemical industry previously mentioned where it was pretended to take advantage of business process models, using for that the Business Process Model Notation, to represent the knowledge associated with the tasks of operators on the shop floor. This aims to transform the tacit knowledge of these employees in explicit knowledge (creating a knowledge repository). Moreover, through the analysis of these models it was possible to identify gaps and weaknesses in the enterprise's processes, helping in the constitution of a posterior design of a Manufacturing Execution System for the shop floor (the next work).

The motivation for **Chapter V** was the essential need of establishing a Manufacturing Execution System software specification and the corresponding conceptual model (using the Unified Modelling Language) capable of filling the key processes of a shop floor, eliminating isolated information cores. Foundations of Chapter IV were used here since the strategy was carried out using the same company as a case study. The designed specification focuses concerns such as interoperability, knowledge management and data visualization, which are key characteristics considered by academia as being essential in I4.0 and preponderant to establish a successful shop floor software.

Chapter VI had its aim in carrying the Chapter V to the visualization world. Since a database architecture was created in the previous chapter, again in the same company, and ever since the organization had a shop floor software (an information silo) which data was not recognized or even used, the goal was to process this data and give it a friendlier aspect, using for that concepts like visualization and storytelling with data. Industry 4.0 brings the necessity of using the organization's data in order to bring value to the company's business and become the decision-making process easier. The result was a dashboard which offers an informative overview to the user.

Table 1 was created to summarize the state of all the scientific works developed.

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.

Table 1- Scientific works integrated in the dissertation

Chapter of dissertation	Scientific works
II	Salvadorinho, J. & Teixeira, L. (2020). The bilateral effects between Industry 4.0 and Lean: proposal of a framework based on a literature review. *5th North American International Conference on Industrial Engineering and Operations Management (IOM),* Detroit, USA (accepted)
III	Salvadorinho, J. & Teixeira, L. (-). Industry 4.0 as an enabler of Lean Practices: A systematic literature review. *International Journal of Production Research* (submitted)
IV	Salvadorinho, J. & Teixeira, L. (2020). Organizational Knowledge in the I4.0 using BPMN: a case study. *International Conference on Enterprise Information Systems* (CENTERIS), Vilamoura, Algarve, Portugal (accepted)
V	Salvadorinho, J. & Teixeira, L. (-). Shop floor data in Industry 4.0: study and design of a Manufacturing Execution System. 20ª *Conferência da Associação Portuguesa de Sistemas de Informação,* Porto, Portugal *(CAPSI) (undergoing review)*
VI	Salvadorinho, J., Teixeira, L., & Sousa Santos, B. (2020). Storytelling with Data in the context of Industry 4.0: A Power BI-based case study on the shop floor. *HCI International Conference,* Copenhagen, Denmark. (accepted)

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

Reference

Salvadorinho, J. & Teixeira, L. (2020). The bilateral effects between Industry 4.0 and Lean: proposal of a framework based on a literature review. *5th North American International Conference on Industrial Engineering and Operations Management (IOM),* Detroit, USA (accepted)

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

Abstract

Industry 4.0 (I4.0) is a paradigm based on connectivity, real-time information flows, and decentralized decision-making processes. Lean is a traditional management practice that aims to promote processes that can increase value and minimize waste. Despite these practices appearing in different ages, and with different motivations, the mission that guides them culminates in the same purpose - to increase the level of operational and organizational efficiency. Information Systems (IS), particularly MES and ERP systems, in addition to representing ISs of choice for I4.0, represent data aggregating systems and facilitators of standardization and automation of the processes inherent to these two practices (Lean and I4.0). The present work, based on the literature review, proposes a Lean 4.0 shop floor framework with the main bilateral effects between Industry 4.0 and Lean, based on the challenges established by I4.0 and with the contribution of IS.

Keywords

Industry 4.0; Digitization; Information Systems; Lean Manufacturing

II.1 Introduction

Industry 4.0 (I4.0) is driven by the principles of connectivity and grounds its decision-making processes on decentralized models (Soujanya Mantravadi & Møller, 2019). According to Savastano, Amendola, Bellini, and D'Ascenzo (2019), I4.0 promotes the creation of cyber-physical systems that interconnect physical components with digital elements, thus being able to operate at different time and space scales (L. Da Xu et al., 2018).

The manufacturing organizations' shop floor represents the appropriate scenario for the convergence of physical and digital space, in the I4.0 context (Tao & Zhang, 2017). According to Sony (2018), an industrial organization that integrates the cyber and the physical is considered a Smart Factory, with a predominance of flexible production systems, useful in reconfiguring planning using the principles of digitization. For the interconnection of these components, in addition to emerging technologies, such as the internet of things (IoT), artificial intelligence, cloud computing, among others (Sony, 2018; Telukdarie & Sishi, 2019), the literature identifies the Information Systems (IS) as key tools in the context of this industrial revolution. Within the several types of business IS, the Manufacturing Execution System (MES) represents the one that allows connecting, through Programmable Logic Controller (PLC) and sensors, the events that occur on the shop floor with the events planned and normally stored in the highest level integrated systems, as is the case with Enterprise Resource Planning (ERP), and, in this way, supporting the decision making (Soujanya Mantravadi & Møller, 2019). However, to materialize the MES in the context of industry 4.0, it is important, at first, to understand the whole process and ensure that it is robust. In most industrial environments, employees are not properly aligned with the company's information flow, even though they are treated as productive resources. From a management perspective, there is a lack of online information on processes, materials and equipment (Oborski, 2018).

Given the importance of this type of systems operating on clearly defined processes, absent of waste sources and properly mapped, the integration of approaches associated with the Lean management philosophy can represent a facilitating factor. It is already mentioned in the literature that Lean practices can support the improvement of processes that are fundamental to automation, and organizations must present a certain level of maturity of Lean practices, before starting an I4.0 strategy (Rossini, Costa, Tortorella, et al., 2019).

This article analyses the challenges of an Industry 4.0 implementation strategy and how the Lean philosophy can be useful in reaching the answers to those challenges. To this end, an exploratory literature review was carried out in order to evaluate the impact of Lean on I4.0, and vice-versa, culminating the results in the proposal of a Lean 4.0 shop floor framework, capable of summarizing the bilateral benefits of these practices - Lean and I4.0.

In the first section, an analysis of the literature is conducted pondering key concepts such as Industry 4.0, Digitization, Lean and Information Systems (here the two main systems in an organization, MES and ERP are focused). Then, in the second section, the framework is displayed, as well as the explanation of its core elements. Finally, final considerations are highlighted, as well as some further research.

II.2 Background

II.2.1 Industry 4.0 and the digitalization necessity

Industry 4.0 emerges with a redefinition and reorientation of processes to digitizing the physical world through the introduction of various technologies, such as artificial intelligence technologies, internet of things (IoT), cloud computing, cyber-physical systems, among others (Sony, 2018; Telukdarie & Sishi, 2019; L. Da Xu et al., 2018). The IoT is the crucial technology in the 4.0 environment since it enables the incorporation and communication between the different technological layers of the organization, establishing the integration of processes and data flows in real-time (Govender, Telukdarie, & Sishi, 2019).

Within the scope of I4.0, three types of integration are known: vertical, horizontal, and end-to-end integration (Telukdarie & Sishi, 2019). In vertical integration, the organization is connected in hierarchical terms, thus guaranteeing a continuous data flow between the production systems, usually at the shop floor level, and the management layers through the ERP (Enterprise Resource Planning) system (Govender et al., 2019). Horizontal integration delivers information sharing between the supply chain, involving business partners. Finally, end-to-end integration provides and manages all functions and data flow evolving from product lifecycle management (Govender et al., 2019; Telukdarie & Sishi, 2019).

In the scope of vertical integration, and associated with cyber-physical systems, a new concept emerges, the Digital Twin (DT) (Schroeder et al., 2016). This concept is based on the creation of virtual models using physical entities for this purpose, thus offering the possibility of making decisions in virtual environments, while assessing and analysing the impacts of these decisions on the physical world (Qi & Tao, 2018). Additionally, DT allows to represent real-time production systems and other organizational components (Zhu, Liu, & Xu, 2019).

However, for the DT concept to be efficiently implemented, it is necessary to transpose the physical world to the digital world, attending to the level of integration of resources, services, as well as the necessary skills to operate in this new reality (Gigova, Valeva, & Nikolova-Alexieva, 2019). Despite the vast literature on I4.0, and DT, few studies report the challenges inherent to the introduction of this paradigm in the context of companies. Table 2 summarizes a set of challenges inherent to the adoption of the Industry 4.0 paradigm, based on different sources present in the literature.

Table 2- I4.0 challenges

I4.0 challenges	Description
Digitizing the shop floor is expensive and time-consuming	Need to acquire new hardware, to update the physical and technological infrastructure, to integrate systems and to carry out and promote in-house training for employees (Ghobakhloo & Fathi, 2020). The installation of equipment with sensors, controllers and data transmission modules is time-consuming for the company (as well as resources) (Ghobakhloo & Fathi, 2020; Haddud & Khare, 2020).
The digitization process needs specialized knowledge	Many companies lack skills for digitization (Ghobakhloo & Fathi, 2020; Haddud & Khare, 2020), and therefore need to use external service/consultants (Ghobakhloo & Fathi, 2020).
I4.0 lacks the definition of a digital strategy	In the scope of I4.0, before its effective operationalization, it is necessary to define a strategic plan for digitization (Haddud & Khare, 2020). The company's digital maturity must be assessed, and the future action plan must be defined, clearly integrating the goals to be achieved (Romero et al., 2019).
Digitization requires the intervention of all (of people)	It is essential that employees are open to change and willing to participate in it (Ghobakhloo & Fathi, 2020). It is also essential to foster a culture based on factors of innovation, adaptability, openness, transparency, decision based on data and focused on customer requirements (Romero et al., 2019).
Digitization can decrease problem management skills	The introduction of numerous levels of automation can degrade the skills of employees (Stadnicka & Antonelli, 2019). Also, the skills in moderating problem management are less used and decrease by managers and / or team leaders (management is more remote and even autonomous with the introduction of I4.0 technologies) (Meissner, Müller, Hermann, & Metternich, 2018).
Digitization and automation require definition, mapping and standardization of processes	When I4.0 was introduced, all processes must be known, mapped and standardized, thus allowing their reproducibility for virtual environments (Mayr et al., 2018), while ensuring a known data flow (Rosin et al., 2020).
A priori need for the shop floor to have Lean management	For a successful implementation of I4.0, companies must pay attention to Lean management (Wagner et al., 2017). The Lean implementation combined with I4.0 leads to an improvement in operational performance (Rossini, Costa, Tortorella, et al., 2019).

Taking into account Table 2, it should be noted that, in addition to what is already expected, such as financial investment, companies that wish to embrace this new paradigm associated with the fourth industrial revolution will have to deal with several challenges, namely: (i) acquisition of technological resources (Ghobakhloo & Fathi, 2020); (ii) integration of specialized human resources (Ghobakhloo & Fathi, 2020; Haddud & Khare, 2020); (iii) definition of a digital strategy (Romero et al., 2019); (iv) promoting a culture that fosters everyone's participation, involvement and collaboration from management to the most operational level (Meissner et al., 2018; Romero et al., 2019); (V) guarantee the knowledge (mapping) of all processes, so that they can be reproduced (Rosin et al., 2020); and, finally (vi) take advantage of the lean culture already present in most companies, as this is seen as a facilitator of the principles of I4.0 (L. Teixeira, Ferreira, & Santos, 2019; Wagner et al., 2017).

II.2.2 Lean: An organizational management philosophy

The Lean philosophy aims to minimize sources of productive waste, thus ensuring an increase in operational and organizational productivity, as well as the quality of the products and services produced (Haddud & Khare, 2020). Besides, establishes a set of practices aimed at reducing inventory, decreasing the variability of processes, minimizing delivery times and customer satisfaction, as well as lowering cycle times (with minimum delay in processes) (Mardiana & Alfarisi, 2020). For this, it uses a set of techniques, tools and methods, some of which described in Table 3.

Table 3- Lean tools description

Lean tools	
Value Stream Mapping	Lean tool allows to have a global perspective of the entire production process (materials and data flow). It offers organizations the ability to develop a map of the current state of how the company works and a map of the future state (Kale & Parikh, 2019).
Total Productive Maintenance (TPM)	Total Productive Maintenance Management includes practices that help to anticipate or reduce the frequency of equipment stoppages, ensuring the smooth completion of activities related to production (Yadav et al., 2020).
Hoshin Kanri	Technique that intends to transform the corporate vision of a company into objectives and actions that are cascaded into the organization to achieve multilevel PDCA cycles (Plan-Do-Check-Act) (Romero et al., 2019).
Poka-Yoke	Mechanisms that help employees avoid production errors (Mayr et al., 2018b).
Just-in-Time	Method that guarantees the delivery of the right product, at the right time and place, with the appropriate quantity and quality, at the appropriate cost (Mayr et al., 2018).
Total Quality Management	It includes the adoption of innovative quality practices, such as the commitment of top management and the strategic planning of all production processes (Yadav et al., 2020).
Kanban	It intends to maintain a minimum stock level, with a view to the uninterrupted supply of material (Mayr et al., 2018).
Andon	It works as a real-time tool for communicating problems that may occur in the workplace in order to obtain an immediate solution (Bhuvaneshwari Alias Sunita Kulkarni & Mishrikoti, 2019).

II.2.3 Information Systems (ERP and MES)

Information systems, which include hardware, software, people, processes, and data are essential elements in the context of I4.0. They are considered crucial tools to support business processes, information flows and data analysis. In addition, they are also the basis for the concept of smart factory (Soujanya Mantravadi & Møller, 2019) since they already collect and pass on data between different agents. Within the category of Information Systems, the ones that have shown the most relevance in the context of I4.0, are ERP systems and MES systems.

ERP systems have the function of planning material and human resources in a company with a long-term perspective (M. Hoffmann, Büscher, Meisen, & Jeschke, 2016), focusing, essentially, on management levels (T. H. Kim, Jeong, & Kim, 2019; Telukdarie & Sishi, 2019). The MES is more oriented towards the management of shop floor activities, based on production planning (T. H. Kim et al., 2019). This type of systems guarantee knowledge of the status of operations in real-time, through the acquisition and analysis of data in an almost instantaneous way, allowing a flow of information in real-time between the shop floor and the business (ERP) (Telukdarie & Sishi, 2019). For the above, some authors refer that the MES system acts as the production cockpit (Mantravadi & Møller, 2019). Among the various functions of the MES, its role stands out: (i) in the allocation and control of resources; (ii) in the dispatch of production; (iii) in the management of quality; (iv) in the management of processes and monitoring of production; (v) in the analysis of operational performance; (vi) in the scheduling of operations; (vii) in document management; (viii) in the management of maintenance and transportation, and; (ix) in the accounting and tracking of materials (X. Chen & Voigt, 2020).

Within an organization, MES complements ERP functions (Mladineo et al., 2019; Mladineo, Veza, Jurcevic, & Znaor, 2017). For example, if the planning generated by the ERP is not carried out as planned, the MES can support re-planning, such as assisting decision making affecting the ERP system, creating changes to it (Mladineo et al., 2019).

MES is a type of integrated system that operates closer to the manufacturing floor, working with granular data and suitable to complement and integrate management systems such as ERPs, which work at the highest level of data. In this context, a multi-agent approach is attributed to the MES and, as an agent (physical or virtual entity) it can understand the surrounding environment, act, communicate and cooperate with other agents, whether as data availability suppliers, or as data consumers (Luo, Luo, & Zhao, 2013).

II.3 Lean 4.0 Shop Floor Framework: Confluence of Lean and Industry 4.0 practices

It was mentioned earlier that one of the challenges of the industry 4.0 implementation would be the existence of a shop floor with Lean management practices. This idea is reinforced in several studies, not only because of the need to preserve current manufacturing systems and Lean has been a wave of the 90s (mainly in the Western industry) (L. Teixeira et al., 2019; Wagner et al., 2017), but also because the automation of inefficient processes will only further increase operational inefficiency and, therefore, industrial inefficiency (Mayr et al., 2018). Because the MES system works on shop floor operations, it can benefit from Lean procedures and tools already present in several organizations.

The Lean's core is mainly the specification of value and the discovery, identification, and eradication of waste (Cottyn, Van Landeghem, Stockman, & Derammelaere, 2011). It is a philosophy which is governed by objectives of time, quality, costs, safety, and workers' engagement. I4.0 also considers these objectives in its mission, adding the customization capacity fostered by information and communication technologies, thus empowering new models to operate, flexibility in operations and systems connectivity (Enke et al., 2018; Unver, 2013).

Table 4- Lean's impact on I4.0

Lean's Tools	Lean's impact on I4.0	Author(s)
Just-in-Time	Potentiates the creation of a system that, through the Just-in-Time philosophy, provides the necessary information, at the right time and in the appropriate format, further promoting the reuse of knowledge.	Cattaneo et al. (2017)
Hoshin Kanri	Hoshin Kanri technique makes it possible to scale a company's vision into objectives in a cascading organizational logic (from management to production), facilitating the involvement of all stakeholders following a digital strategy.	Romero et al. (2019)
Poka-Yoke	The introduction of Poka-Yoke's system allows the deposition of greater confidence in robots since, like humans, they can make mistakes.	Stadnicka et al. (2019)
Value Stream Mapping	The Value Stream Mapping tool allows you to understand and establish the value for the consumer and find out where the waste is, to better select and align I4.0 technologies.	Romero et al. (2019)
5 Lean Principles	The vertical hierarchical integration of subsystems must happen with a well-defined strategy that can be designed by the Lean philosophy (namely the 5 Lean Principles).	Sony (2018)
Obeya Room	The purpose of the Obeya Room tool is to conduct daily meetings to discuss process improvements provided by digital technologies, thus boosting a collaborative and innovative culture.	Romero et al. (2019)
Kanban, Kaizen Daily Chart	Tools already used on the shop floor, such as the Kanban, the Kaizen Daily Chart, Batch Construction Chart, etc., can easily be transposed to a digital version, preserving production systems and boosting digital ecosystems.	Mayr et al. (2018b)
5 Whys, Ishikawa Diagram, A3 Risk sheet, FMEA	The design of a digital risk management strategy can be promoted through Lean tools, such as the Five Whys, the Ishikawa Diagram and the A3 Risk Sheet. FMEA (Failure Mode and Effect Analysis) reports can be advantageous in terms of prioritizing the risks encountered.	Romero et al. (2019)
DMAIC	The DMAIC methodology (Define-Measure-Analyze-Improve-Control) can and must be incorporated in the MES system in order to improve the process. Thus, this system must contain pre-established metrics and monitor them, such as controlling imposed improvements and still imposing standard work on the shop floor.	Cottyn et al. (2011)

I4.0's principles do not replace the ones aligned with Lean's philosophy, consequently, these two practices can help each other in the achievement of the aforementioned objectives (Kolberg

& Zühlke, 2015; Mayr et al., 2018). While Lean's environment promotes a culture receptive to new technologies, especially when they enhance the reduction of waste, at the same time, also allows an accurate knowledge about the processes that create value (Bittencourt, Alves, & Leão, 2019). The approach inherent to the I4.0 context integrated in Lean's philosophy can be seen as an accelerator of Lean practices (Ghobakhloo & Fathi, 2020).

Table 4 and Table 5 summarize some contributions regarding the impact of Lean culture on I4.0 (Table 4) and vice-versa (Table 5).

Table 5- I4.0's impact on Lean

I4.0's impact on Lean	**Author (s)**
Tools that exhibit static behaviour, such as Value Stream Mapping, can benefit from ***IoT technologies***, as these allow the availability of data in real-time, giving dynamism to VSM and making it closer and more real to events presented (starts to deal with stochastic data).	Balaji et al. (2020) and Bittencourt et al. (2019)
I4.0 intends to respond to markets' dynamic behaviour, thus being capable to benefit from a levelling of production based on Lean (Mayr et al., 2018b), fostering a ***make-to-order*** business logic (products customized according to consumer specifications).	Enke et al. (2018)
The digitization of some Lean tools, such as ***e-Kanban***, for example, facilitates their adaptation to processes (changes in stocks or cycle times require changes in Kanban cards), also guaranteeing that they are not lost along the flow productive paths.	Ghobakhloo et al. (2020)
Information technologies can support Total Quality Management by offering statistical process management tools through control charts, significantly reducing the cost of quality.	Ghobakhloo et al. (2020) and Sader et al. (2019)
Connectivity and IoT technologies enable more efficient and effective Visual Management, as the data is updated in real-time, with the possibility of identifying anomalies close to the event and, thus, making decisions almost in real-time.	Haddud et al. (2020)
The introduction of I4.0 technologies makes it possible to plan and schedule preventive operations (***TPM-Total Productive Maintenance***) and maintenance requests more effectively and efficiently. Monitoring allows you to create fault patterns on the machines, generating an alert system and automatically calculating OEE (Overall Equipment Effectiveness). The transition from preventive to predictive maintenance is also made easier with the integration of IoT technologies and artificial intelligence.	Ghobakhloo et al. (2020)
The ***simulation*** can anticipate potential difficulties and mitigate process failures (reducing the use of Poka-Yoke systems) and can also detect sources of waste.	Pagliosa et al. (2019) and Rosin et al. (2020)
In the Just-in-Time and Continuous Flow philosophy, ***IoT*** allows tracking and sending progress states to flow managers, the ***simulation*** is able to test different scenarios for the production flow and ***autonomous robots*** to independently adjust production.	Rosin et al. (2020)
Augmented reality enables employees to obtain visual feedback on possible errors (Jidoka), as in conjunction with ***simulation***, it can facilitate employee training.	Rosin et al. (2020)

Considering the challenges previously exposed related to I4.0, Lean will be essential in the preparation of a proactive organizational culture and will be able to solve problems, since it encourages the involvement of employees in continuous improvement. In addition, the design of a digital strategy and the ability to manage risk can be promoted using Lean tools and principles. For the digital strategy, the Five Lean Principles are considered and for the risk management, tools such as the Five Whys, the Ishikawa Diagram and even the FMEA (Failure Mode and Effect Analysis) are highlighted.

The preparation of manufacturing processes is another condition to be considered since they must be standardized. Value Stream Mapping is a Lean tool capable of identifying value for the consumer and, above all, aligning I4.0 technologies with processes.

I4.0, in turn, will allow to assign dynamics to Lean tools (such as VSM and Kanban) and add stochastic data to them. The IoT, together with the tools for real-time data control and Business Intelligence, can improve Total Quality Management, as well as the company's Visual Management, allowing the detection of errors closer to the event in time. Simulation and augmented reality are also two technologies that have revolutionized how certain functions operate, how data is viewed in context, and how skills are guaranteed through employee training.

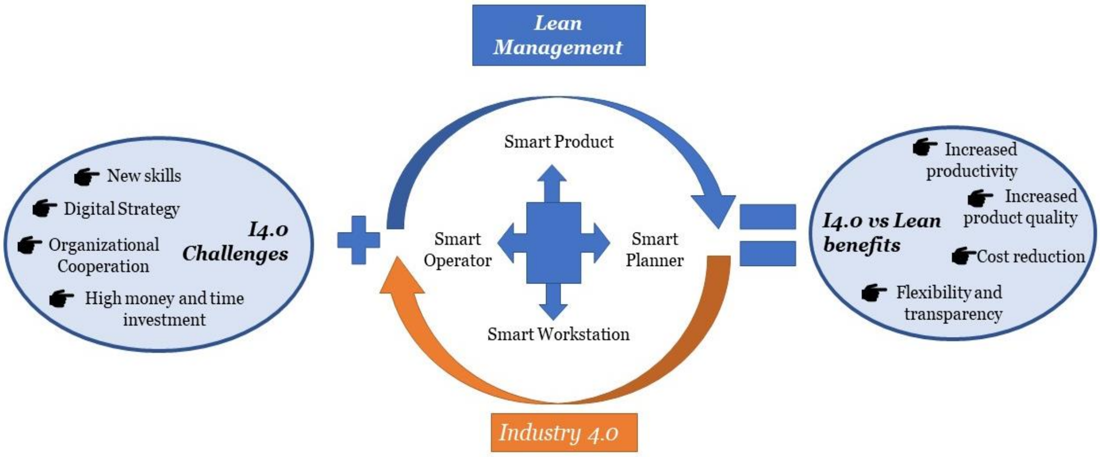

Figure 8- Lean 4.0 Shop Floor Framework

Considering the evidence reported in the literature, a Lean 4.0 Shop Floor Framework is proposed (Figure 8), with the main bilateral effects between Industry 4.0 and Lean, based on the challenges established by I4.0. Thus, the main challenges that emerge from I4.0, can find answers in the integration of Lean philosophy, together with the emerging technologies of the fourth industrial revolution. According to Kolberg et al. (2015), the integration of Lean philosophy with the principles inherent to the I4.0 context gives rise to four new concepts on the shop floor, namely: Smart Operator, Smart Product, Smart Workstation and Smart Planner. Since the MES is the information system connected to the shop floor, its essential elements are based on the components indicated, operator, product, planner and workstation. It is important to realize that these four elements must be integrated with the MES information system and be part of it, thus giving "life" to those elements that were previously static.

The ***Smart Operator*** concept includes the introduction of IoT mechanisms, such as Smart Watches, which will facilitate the notification of employees, using Andon logic, about messages and error locations. Augmented reality can help establish JIT on cycle times, scheduled tasks and even digital work instructions (Ghobakhloo & Fathi, 2020; Kolberg & Zühlke, 2015). Simulation in combination with augmented reality, on the other hand, will facilitate training when new functions or jobs are involved, as well as maintenance actions (Rosin et al., 2020). The establishment of knowledge management systems will make it possible to retain the right knowledge, at the right time and in the right place (JIT), in addition to the potential to foster brainstorming (creating new knowledge) and thus consolidate the skills of the teams (Ghobakhloo & Fathi, 2020).

The ***Smart Product*** concept also includes the integration of IoT components in the final product, in order to allow its tracking and, thus, ensure knowledge of the various stages of the product, from origin to destination, adopting a JIT logic (Rosin et al., 2020). It is also possible to track the various stages of the product throughout production, as well as production needs, relying on the information presented in e-Kanbans (Kolberg & Zühlke, 2015). The real-time monitoring of the products will also allow the generation of performance indicators, in order to control several parameters, from the quality of the products, and may even allow the appearance of FMEA forms, where the number of risk priority is calculated (it is possible to attach documents related to the causes of failure found or actions necessary to expedite existing concerns) (Ghobakhloo & Fathi, 2020).

By ***Smart Workstation*** is meant the use of IoT technologies in order to assign the ability to react to processes, through alerts based on events, and decision-making by the job itself (e.g., stopping the process or even exchanging production products). Communication via RFID (Radio Frequency Identification) of products/materials in progress with equipment is also a reality, which allows to avoid production errors (Jidoka) (Rosin et al., 2020). As with the product, here it is also possible to establish statistical process control systems. In the area of maintenance management, the entire action schedule becomes more agile, the control of equipment inactivity is performed and predictive analysis is possible to be carried out, contributing to a Total Productive Maintenance Management (TPM) (Ghobakhloo & Fathi, 2020; Haddud & Khare, 2020).

Finally, in ***Smart Planner***, the introduction of autonomous robots (example of Automated Guided Vehicles - AGV) is a reality that allows the movement of products and materials between workstations, the information sharing about the destination and delivery times, as well as the readjustment of milk-run routes (logistics system for the collection or delivery of materials with several stops, in order to optimize the route) whenever necessary (Rosin et al., 2020). In this context, visual management benefits from real-time data, offering conditions for better risk management and identification of anomalies in the system (Haddud & Khare, 2020). Simulation techniques will also be essential in the context of testing different production parameters and the design of numerous flows, contributing to better planning of movements and identification of sources of waste (Kolberg & Zühlke, 2015).

Therefore, starting from the challenges inherent to the fourth industrial revolution and relying on the integration of Lean principles and emerging technologies from I4.0, several benefits can be expected such as:

i. **Increased productivity**, since integration enhances agile and intelligent processes (Doh, Deschamps, & Pinheiro De Lima, 2016; Pagliosa et al., 2019);
ii. **Increased quality**, as it is possible to anticipate production errors and manage equipment malfunctions in a more controlled approach (Doh et al., 2016; Pagliosa et al., 2019; Stadnicka & Antonelli, 2019);
iii. **Greater flexibility**, since I4.0 allows flexible and modular production systems, so that highly customized products can be mass produced, with the possibility of demand's adjustment (Ghobakhloo, 2020; Pagliosa et al., 2019);
iv. **Greater transparency** in communication, as there is constant monitoring of production, with real-time data, which promotes more accurate and decentralized decision-making in near real-time (Gigova et al., 2019);
v. **Increased worker safety**, since the heavier and more routine activities, which normally lead to workers' injuries, are likely to be automated (Stadnicka & Antonelli, 2019);
vi. **Cost reduction**, either by eliminating a substantial part of waste or by predictive maintenance enhanced by these environments that lead to a reduction in maintenance costs (Ghobakhloo & Fathi, 2020).

In this way, with the application of emerging I4.0 technologies, integrated with Lean's principles, using for that Information Systems, namely ERP and MES, it is possible to increase operational efficiency and, consequently, organizational efficiency.

II.4 Final considerations and future work

Although some studies in the literature report effects between I4.0 and Lean, there are few that address the main challenges of I4.0 combined with Lean practices, as well as the impacts and benefits expected from the convergence of these two practices. While I4.0 favours connectivity, flexibility and, therefore, responses to volatile and increasingly demanding markets, integrating information systems to support process and continuous data flows, Lean favours continuous improvement in a logic of waste reduction, acting primarily on production and material processes and flows.

For an adequate association of Lean practices and the principles of I4.0, we have the support of Information Systems, highlighting the role of MES as complementary functions to ERP systems. Particularly with the help of MES, organizations easily plan their production and send planning data in real-time to employees and equipment that will operate in that manufacturing order, as well are capable of re-plan without harming to overprocessing or overproduction. The conditions of the equipment are also verified in real-time, which makes MES the key system in the context of I4.0, with an impact on resource allocation, product quality and, consequently, company productivity (S. W. Lee, Nam, & Lee, 2012).

Regarding Lean, a practice already rooted in the Western industry, its ultimate goal is to increase the efficiency of operations and processes that add value, while reducing waste-enhancing activities (Hoellthaler et al., 2018). Transparency is an assumption that encourages digitization, as well as standardization and work organization, being these concepts strongly associated with the Lean philosophy (Bittencourt et al., 2019).

Some studies have already shown that there is strong evidence that companies with a low level of Lean maturity also have a low level of integration of I4.0 technologies (Bittencourt et al., 2019; Rossini, Costa, Tortorella, et al., 2019). There are also authors which defend that Lean principles should first be implemented in a traditional way, and only then an I4.0 approach should be pursued (Adam, Hofbauer, & Mandl, 2019).

It is thus concluded, even if using approaches presented in the literature, that there is a strong relationship between the adoption of I4.0 technologies and the implementation of Lean (Rossini, Costa, Tortorella, et al., 2019). There are also studies that demonstrate the effects of Lean implementation, but, prevail over the benefits evidenced by the implementation of I4.0 in an organizational performance’s perspective (efficiency and productivity) (Rossini, Costa, Staudacher, & Tortorella, 2019). Thus, when implementing I4.0 technologies, it is necessary to integrate Lean practices to introduce automation in well-designed and robust processes (Rosin et al., 2020; Rossini, Costa, Staudacher, et al., 2019).

Not only can I4.0 benefit from Lean, but this philosophy can also benefit from I4.0 connectivity, evolving its tools to more dynamic techniques and using stochastic data. I4.0's greater flexibility also promises to cooperate with a market where demand fluctuates, making it possible to produce goods in single and more complex batches, something that goes beyond Lean level and standardized production (Mayr et al., 2018).

It is then possible to establish a shop floor that brings together the two worlds, giving rise to four major elements, that is; ‘Smart Operator’, ‘Smart Product’, ‘Smart Workstation’ and ‘Smart Planner’, any of which may benefit from the bilateral advantages of both practices, with the mediation of Information Systems, i.e., MES and ERP.

Given the theoretical and exploratory nature of this work, it is suggested for future work practical studies that should be assessed in real context the effects of the convergence of these two practices - I4.0 and Lean - with a view to corroborating (or not) the advantages listed here. The application may consider the different Lean tools and their automation and / or digitization.

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

Reference

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Industry 4.0 as an enabler of Lean Practices: A systematic literature review

Abstract

Industry 4.0 and its application in the business fabric has been the focus of attention by the academia, for its ability to establish principles of flexibility to market changes and shop floor occurrences and also for the fact of promoting mass customization. However, because of a Lean wave in the 1990's, most of the western industry adopted principles, techniques and tools of Lean production whose results were quickly captured, guaranteeing its adoption worldwide. Thus, with a view to turning traditional manufacturing companies into smart companies, it is essential to preserve the existing system and find ways for the two concepts (Lean and I4.0) to come together. This article carries out a systematic review of the literature capable of analysing the contributions of each of the concepts to each other, thus updating the state of the art and realizing which directions should be started to be adopted.

Keywords

lean production; industry 4.0; lean manufacturing; digitalization

III.1 Introduction

Industry 4.0 or Fourth Industrial Revolution is the wave of the moment and has surfaced due to disruptive advancements in manufacturing processes and technology (A. C. Pereira, Dinis-Carvalho, Alves, & Arezes, 2019). These technologies allow production systems to be flexible and modular, enabling the mass customization (Pagliosa et al., 2019).

Lean is the current companies shop floor's philosophy (Rossini, Costa, Tortorella, et al., 2019) that drives for stability and low variability in products type (Pagliosa et al., 2019). This philosophy aims to reduce the waste on the shop floor and improve productivity, not forgetting customers' requirements (A. C. Pereira et al., 2019).

Even though I4.0 has gotten significant attention from academia in the past few years, the actual effects, obstacles and key success factors for its broad embracing across different industrial sectors and contexts still require additional investigation (Tortorella, Rossini, et al., 2019). Empirical studies have shown that the implementation of I4.0 technologies can benefit greatly from Lean practices, since these guarantee standardized and robust processes. (Tortorella & Fettermann, 2018).

The question that stands out is whether I4.0 should be implemented taking Lean into account and if so, what contributions can Lean philosophy make to I4.0 and vice versa.

This article intends to carry out a systematic review of the literature, in order to answer the question of the confluence of Lean and I4.0 concepts for the future of organizations. For this reason, after having selected and duly filtered the universe of articles to be taken into account, an analysis of the most relevant technologies in I4.0 and the practices that were also most relevant in the academia was carried out. This was an essential input for the next phase, which consisted of the establishment of a matrix capable of summarizing the current contributions, practices, and theorists of the two concepts. An important and necessary conclusion was that there are currently many more works that investigate the contribution of I4.0 to Lean. This may be since the authors already take advantage of the generalization that it is only appropriate to implement I4.0 technologies in line with already established Lean practices and with a certain maturity in companies.

The present article is structured as follows: in the second section, there is a theoretical background, where Industry 4.0 and Lean concepts are specified. Then in the third section, the planning of the systematic literature review is presented, emphasizing the need for a systematic review on this topic, as well as the formalities taken into account for the selection of articles (research formula and inclusion and exclusion criteria). The fourth section exhibits the bibliometric and content analysis to universe of selected papers and, finally, the summary and outlook, in the fifth section, intends to review the results obtained. The sixth and last section stipulates the future research according to this paper authors.

III.2 Background

III.2.1 Industry 4.0

Today, major changes are now happening, being supply chain's globalization, efficient consumption of resources, unpredictable markets and customer demands, new technologies and growing digitalization, individualization and shorter product life cycles, some identified by Lugert et al. (2018).

Industry 4.0 (I4.0) brings together a series of initiatives to improve processes, products and services favouring the interconnection between people, objects and systems through the exchange of data in real-time (Dombrowski & Richter, 2018; Kamble et al., 2020; A. G. Pereira, Lima, & Charrua-Santos, 2020; Rosin et al., 2020). This phenomenon contributed to the paradigm shift of production from a centralized to a decentralized system (Sader et al., 2019). If production data relates to consumer behaviour, enterprises can dynamically answer to changing market demand (Ayabakan & Yilmaz, 2019; Cattaneo et al., 2017), increasing capability to adapt quickly to products with shorter cycles (Cattaneo et al., 2017; Pagliosa et al., 2019). Communication, flexibility, real-time and decentralized decision-making represent the most popular keywords associated to I4.0 (Molenda, Jugenheimer, Haefner, Oechsle, & Karat, 2019; Rosin et al., 2020).

This I4.0 paradigm is strongly techno-centric with cyber-physical systems (CPS) (Rossit, Tohmé, & Frutos, 2019), incorporating intelligent machines, storage systems and production mechanisms with power to swap information autonomously, whilst promoting actions to adapt to mutable contexts (Cimini, Boffelli, Lagorio, Kalchschmidt, & Pinto, 2020; Rosin et al., 2020). Although Material Requirements Planning (MRP) or Enterprise Resource Planning (ERP) are almost a standard, to turn companies more agile and flexible, more advanced solutions must be implemented (Rosienkiewicz, Kowalski, Helman, & Zbieć, 2018). Smart factories use CPS to link the physical world with the virtual one, creating a working network (Bittencourt et al., 2019; C. H. Li & Lau, 2019; Lucato, Pacchini, Facchini, & Mummolo, 2019). The internet of things (IoT) included in CPS contributes to monitor and, consequently, improve the production process (Balaji et al., 2020). During IoT implementation it is important to understand how the company is structured and how different sectors should be put together. Thus, three types of integration arise: (i) horizontal - through value networks allowing inter-corporation collaboration; (ii) vertical - integration of hierarchical systems inside a manufacturing system; and (iii) end-to-end, allowing connectivity throughout value chain (Gambhire, Gujar, & Pathak, 2018). Manual ways of production will not be able to deal with the challenges of mass customization and globalization in such a way that the solution passes by extending levels of industrial automation in manual work in the form of human-machine collaboration (Malik & Bilberg, 2019). In what concerns to decision-making the technologies mainly pertinent are Cloud Computing, IoT, Big Data and RFID connections (Rossit et al., 2019).

Although, this new environment, creates to manufacturing industry challenges of automation and digitalization of production processes (Rosin et al., 2020) that represents an important technology-based opportunity to shift how companies generate value for their customers (Cimini, Boffelli, et al., 2020). For many manufacturers, the existing infrastructure may not be capable of supporting the transformation into Industry 4.0, since this makeover might impact human resources development and customer relationship management (Rossini, Costa, Staudacher, et al., 2019). Dutta et al. (2020) established that large enterprises tend to be better equipped and prepared than small enterprises to receive the introduction of disruptive technologies. This happens because companies from emerging economies mostly need to import technological solution which adds a substantial financial barrier if compared to companies from developed economies (Tortorella, Rossini, et al., 2019).

It is important to understand, however, that applying high automation technologies to enhance production system flexibility may cause troubles, examples of them are high-level of investment cost, low returns and, consequently, investment transformation failure (J. Ma, Wang, & Zhao, 2017).

Generally talking, a I4.0 project must be carried out as a gradual process, and the current manufacturing systems must be preserved and considered in a socio-technical view (Bittencourt et al., 2019; Wagner et al., 2017). Western industrial production was typified by the wave of lean production and lean management in the recent decades, creating now the notion that the I4.0 context may have to be integrated into existing lean production systems in order to succeed (Wagner et al., 2017).

Furthermore, lean philosophy has been identified as a beneficial tool to change and improve cultural value of a company, improving at the same time the work that is done. In this line of though, lean could support the development of industry 4.0 in a company (Erro-Garcés, 2019).

III.2.2 Lean Manufacturing

Lean manufacturing can be deemed as one of the most meaningful contributions in the history of operations management (Z. Huang, Kim, Sadri, Dowey, & Dargusch, 2019; Ramadan, Salah, Othman, & Ayubali, 2020). This philosophy has turn into a widespread approach because of its high efficiency gain in enterprise production and logistics (Pekarčíková et al., 2019; Rossini, Costa, Staudacher, et al., 2019; Tortorella, Pradhan, et al., 2020).

Lean aims to have a streamlined process flow where a systematic and visual approach is used to reduce waste (Rossini, Costa, Tortorella, et al., 2019) and increase flow via extensive employee involvement and continuous improvement, always identifying value from the customer's perspective (Haddud & Khare, 2020; Kamble et al., 2020; Tortorella, Pradhan, et al., 2020). Therefore, the basis of this philosophy places the human being as an import issue in all its decisions (J. Ma et al., 2017; Rossini, Costa, Staudacher, et al., 2019; Varela, Araújo, Ávila, Castro, & Putnik, 2019), although, nowadays, companies tend to forget this facet, focusing just on waste reduction (A. C. Pereira et al., 2019; Varela et al., 2019).

Lean emphasizes that everyone can recognize problems and anomalies, triggering the problem-solving process, which is considered to be an essential capability, providing both development of organizational processes and individuals who execute it (Tortorella & Fettermann, 2018). It incorporates several tools, such as Key Performance Indicators (such as Overall Equipment Effectiveness), Single-minute exchange of dies (SMED), Kaizen, 5S, Value Stream Mapping, Jidoka, Kanban and others which collect various types of data. In the line of this thought data analytics is considered to affect enormously the success rate of a lean implementation. However, this data is just used to monitor and not to improve existing operations. That way, Abd Rahman et al. (2020) referred that the utilization of data analytics in process improvement is one of the most challenging aspects in lean manufacturing. If managers do not have all the environmental information they require in terms of decision-making parameters and/or effects, subsequently do not perceive the positive impact of good practices on their company's performance (Santos, Muñoz-Villamizar, Ormazábal, & Viles, 2019). Practices associated with just-in-time (JIT) production systems are more extensively implemented and appreciated by manufacturers in emerging companies compared to productive/preventive maintenance tasks which use more advanced statistical process control (Tortorella, Giglio, et al., 2019).

Globalization has been intensifying competition among manufacturers and Lean has been a valuable approach in improving productivity and it is already recognized that I4.0 technologies have the potential to further increase that (Yeen Gavin Lai et al., 2019). Nonetheless, Ma et al. (2017) emphasizes the idea that lean production eradicates much of the creativity required for innovations, making enterprises miss advanced technology-push chances. Although, Pagliosa et al. (2019) alerts to the possible conflict between I4.0 and Lean, since the second is considered to be a low-tech approach (Pagliosa et al., 2019; Ramadan et al., 2020) that protrudes for simplicity which may possibly conflict with technology-driven approach of I4.0 (Pagliosa et al., 2019). On the other side, Kolberg et al. (2017) and Kolberg et al. (2015) identify potential in the integration of Information and Communication technologies (ICTs) and Lean, reactivating the idea of Lean Automation that has been around for some time (since 1990's). Even though, and in the I4.0 context, authors suggest that existing approaches are proprietary solutions, not supporting modularisation and changeability and need to be tailored to individual needs.

III.3 Methodology

III.3.1 Motivation for a systematic review study and research question

In the last three decades an extensive adoption of lean practices was occurred, primarily in the occidental industry (Rossini, Costa, Tortorella, et al., 2019). Yin et al. (2018) stated that Lean is considered to be a production concept which is nowadays still explored by researchers and imitated by many companies. Since several shop floors were completely converted to Lean, numerous authors started to pay attention to the integration of the two aspects, Lean and I4.0, with the arrival of the I4.0 context. Lean has its focus on financial and operational performance via a systematic and continuous search for waste decrease and improvements, so in line of this thought a few researches support that the implementation of Lean and I4.0 could mitigate existing management complications and direct manufacturers to even higher performance standards (Tortorella, Rossini, et al., 2019). Industry 4.0 is capable of improvement but in a mostly technical approach which does not replace the value-based mind set of lean (Meissner et al., 2018). For this reason, the integration of both concepts is better received by the academia, hoping that the opportunities that I4.0 can bring will take Lean to another level of excellence. Thus, this paper intends, in a systematic way, to address the confluence of the two concepts and understand the impact on each other, in order to update the state of the art in this area and to understand what remains to be done. This work may help companies to understand what bases they should already have for the introduction of the I4.0 environment, so that it is not a target of disappointment and high investment with no return. Given this contextualisation, this study aims to answer the general research question "how Lean and I4.0 can help each other towards achieving a more decentralized, efficient, and cohesive shop floor?". This question was divided into other 9 specific questions, some of them with respect to a bibliometric analysis and the remaining directed to a more content analysis, as it can be seen above.

Bibliometric analysis
RQ1- What is the distribution of papers over time?
RQ2- Which Journals or Proceedings publish the most in this area?
RQ3- What is the ranking of journals belonging to the selected article universe?
RQ4- Which articles are most cited and which author has the most publications in this area?
RQ5- What is the distribution of papers with reference to the geographical context?

Content Analysis
RQ6- What are the most relevant I4.0 technologies?
RQ7- What are the most relevant Lean tools?
RQ8- What is Lean's contribution to I4.0?
RQ9- What is I4.0's contribution to Lean?

III.3.2 Research Formalities- Article's selection

III.3.2.1 Research Formula

The database used for the research was Scopus that is now the major database for multidisciplinary scientific literature. Overhead, it is a database which allows connections among different disciplines, attaining high levels of accuracy when corresponding references to summaries (Anegón et al., 2007). To collect all relevant articles, the following research formula was developed (Table 6). With this research formula, in May 2020, 159 articles were collected for a base.

Table 6- Research Formula

Scope	String
Industry 4.0	(“Industry 4.0” OR “fourth industrial revolution” OR digitization* OR “Digital Twin”)
Lean	(lean OR Kaizen OR “Value Stream mapping” OR “Just-in-time” OR “Total productive maintenance” OR “Kanban” OR “Total Quality Management”)
impact between the two concepts	(Effect* OR influence* OR impact* OR response* OR reaction*)

III.3.2.2 Exclusion and Inclusion Criteria- PRISMA method

In order to filter some articles, primary exclusion criteria had to be carried out, first the language (only articles in English were accepted), then the source type (conference proceedings, journals and Book series were accepted), consequently the type of document was also the target of choice (conference paper, article, conference review and review) and then, and finally, those articles that did not present an author and / or it was not possible to access the full paper. The remaining 90 articles of these exclusion methods, later, had to be read and analysed, so that the exclusion criteria (3 and 4- Table 7) and inclusion criteria (1 and 2- Table 7) were applied. By applying criteria 3 and 4, 42 articles were excluded, remaining 48 to integrate the research procedure. The table below (Table 7) makes reference to the exclusion and inclusion criteria and Figure 9 exhibits the PRISMA method scheme, capable of illustrating all of the steps carried out until reach the final 48 articles.

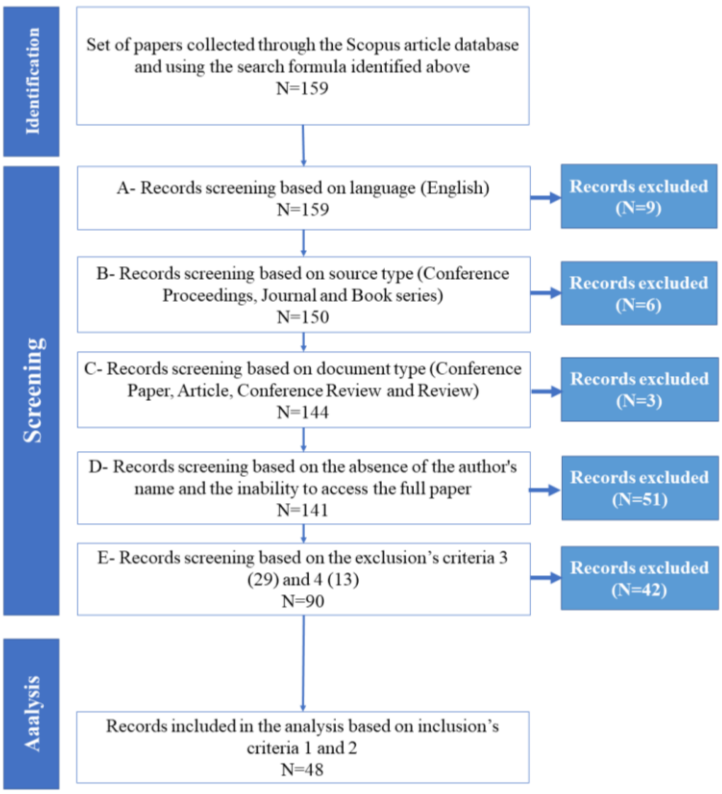

Figure 9- PRISMA scheme of articles' selection

Table 7- Inclusion and exclusion criteria

Criteria type	Criteria number	Criteria specification
Inclusion	1	The paper investigates I4.0 and Lean, showing contributions of both concepts to each other, carrying out systematic reviews, case studies, practical applications or surveys design and distribution.
	2	The paper investigates in an exploratory way about I4.0 and Lean, evidencing contributions of both concepts to each other, creating frameworks that initiate ideas for more practical studies.
Exclusion	3	The paper refers to I4.0 and Lean concepts in a broad way just for contextualize, with no interconnection of the terms.
	4	The paper uses the notions of Lean and I4.0, however it applies them in another area than manufacturing sector.

III.4 Literature review analysis

This section presents the results divided into two parts. In the first part, a bibliometric analysis is carried out to answer the questions, Q1, Q2, Q3, Q4 and Q5. Q6, Q7, Q8 and Q9 are answered in the second part that is composed by a content analysis.

III.4.1 Bibliometric analysis

RQ1: How articles are distributed over time?

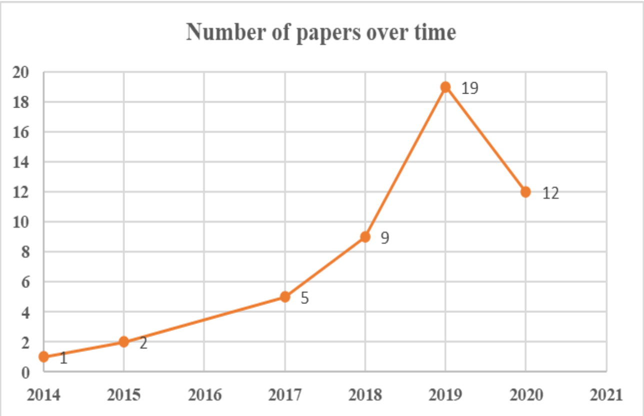

Figure 10- Distribution of papers over time

Until 2019 it is possible to observe an almost exponential growth in the number of articles published in the Lean and I4.0's subjects, and it is in that year that the largest number is registered (19). Since the date of completion of the paper, the year 2020 has not yet ended, growth is also expected this year, in the sense of following an exponential curve. It is possible to conclude that we are facing with a recent topic with the first paper to appear in 2014.

RQ2: Which Journals and/or proceedings have published the most in this area?

Figure 11- Frequency of type of documents - and Journals and/or Proceedings that have published the most in this area

By analysing Figure 11, it can now be argued that the journals are already quite interested in this area, being able to see it as a subject on which to invest in future investigations. Two journals were very active on this topic, IFAC-OnlinePapers and International Journal of Production Research. It should be added that the value of conference articles is also significant, so it can be extrapolated that this is a relatively new subject, as already observed by the distribution of papers over time presented in Figure 10.

RQ3: What is the ranking and quality of the Journals that published in this area? and RQ4: What is the most cited article?

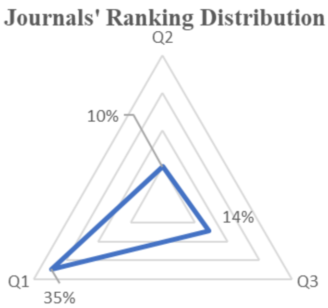

Figure 12- Journals' Ranking distribution

Table 8- Articles' Top 5 with the most citations

Article	Journal/Proceedings	Citations	Year
Kolberg et al.	IFAC-PapersOnline	164	2015
Yin et al.	International Journal of Production Research	83	2018
Tortorella et al.	International Journal of Production Research	79	2018
Wagner et al.	Procedia CIRP	74	2017
Kolberg et al.	International Journal of Production Research	60	2017

Figure 12 presents the universe of journals inherent in the group of articles analysed, journals of quartile 1 (Q1) stand out, whose quality is considered the highest, followed by quartiles 3 (Q3) and 2 (Q2). Pondering the previous question that referred to those who published the most in this area, the International Journal of Production Research which is a Q1 stands out. Regarding the highest number of citations (Table 8), it is highlighted the article published in 2015 in the IFAC-OnlinePapers Journal. Two papers of 2018 published in International Journal of Production Research appear again, in second and third place. Finally, with 5 articles published, Tortorella is the author with the most publications in this area.

RQ5: How are the papers distributed in the geographical context?

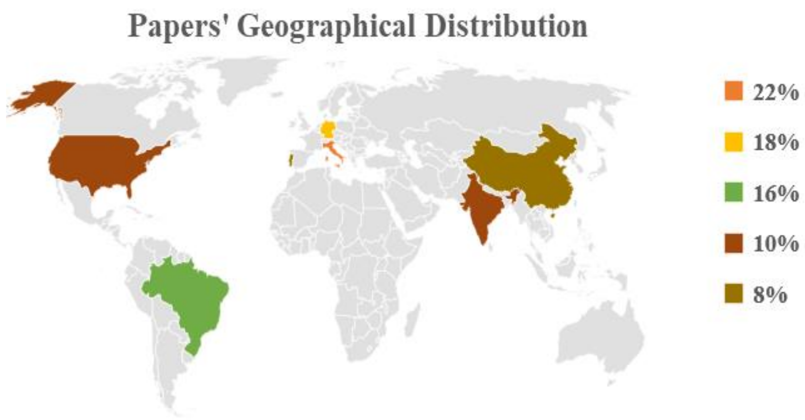

Figure 13- Papers' geographical distribution

By analysing the figure presented above (Figure 13), Italy is the country with the highest incidence of publications (22%), followed by Germany (18%) and Brazil (16%). It should be noted that the author with the most publications, Guilherme Tortorella, has a Brazilian origin.

III.4.2 Content analysis

RQ6: Which I4.0 technologies are considered most relevant?

The number of articles where it was possible see each reference to I4.0 technologies was considered, so that the most relevant I4.0 technologies could be established. It should be noted that only I4.0 technologies with a frequency equal to or greater than 10% were considered, which corresponds to a minimum of 5 number of articles where the technology was referred. The following table (Table 9) is intended to summarize these same technologies. The top 3 most referred technologies were Internet of Things (with 47%), Big Data Analytics (with 43%) and Cloud Computing (with 35%).

Table 9- Most relevant I4.0 technologies

I4.0 technologies	Frequency
Internet of Things	47%
Big Data Analytics	43%
Cloud Computing	35%
Cyber-Physical Systems	31%
Virtual reality (VR) and Augmented reality (AR)	25%
Robotics	22%
3D Printing	22%
Data Analytics	16%

RQ7: Which Lean techniques practices are considered most relevant?

As in RQ6, it was analysed the number of articles that referred in their content to each of the technologies belonging to the I4.0 paradigm, here, the same was carried out, however the scope of the scrutiny was based on Lean tools. The ones that demonstrated just one article where the tool was referred were not considered (corresponding this to about 2 %). The following table (Table 10) intends to summarize these tools. Here, the top 3 most referred practices were Just-in-Time (with 18%), Value Stream Mapping (with 18%) and Heijunka (with 16%). The existence of more references in these tools may constitute the conclusion that they are seen in the academia as being more viable and easier to integrate the I4.0 paradigm. The 5 S, for example, which appear at the end of the table, can nevertheless be considered a very mechanical tool, where the application of technology does not bring added benefits.

Table 10- Most relevant Lean practices

Lean practices	Frequency
Just-in-Time	18%
Value Stream Mapping	18%
Heijunka	16%
Jidoka	14%
Kaizen/Continuous Improvement	14%
Andon	12%
Kanban	12%
Key Performance Indicators	10%
Total Productive Maintenance	10%
Single minute exchange of die	8%
Poka Yoke	6%
Visual Management	4%
5S	4%

RQ9: What is the contribution of Industry 4.0 to Lean?

Looking at the table that presents the most relevant Lean practices (Table 10), in the top 3 are Just-in-Time, Value Stream Mapping and Heijunka. If these are the practices most referred to by the universe of articles analysed, then it can be inferred that these are the ones that possibly appear to have the most possibilities for I4.0 technologies to impact.

The next paragraphs aim to clarify, in each of the Lean practices, how I4.0 technologies can benefit them.

In Wagner et. al (2017), ***Just-in-time*** is integrated in an IT-system which pretends to support a lean Just-in-Time materials flow process (Cyber-Physical Just-in-Time Delivery). In this project, Kanban cards were switched by a vertical integrated solution, creating a gapless information flow between manufacturing order, material supply, material stock and material consumption, not forgetting the computerized purchase order to the supplier. Sensors detect every material movement (IoT tracks products in real-time) (Rosin et al., 2020) , displaying the information into a basic big data architecture, that in connection with the material consumption of the manufacturing machines, can send an automatic order to the supplier, each time the minimum inventory level is hit. An analytics service on statistical data was aggregated here in order to have a prognostic of material requirement, comparing the available information with a digital model of the complete process (Wagner et al., 2017). Robotics, more specifically collaborative or even autonomous robots, are able to adjust the productive flow and take action promptly, ensuring that production runs smoothly (Rosin et al., 2020). With 3D Printing, 3D printers can be mounted near customer's location, reducing distance and delivery cost, which enhances JIT principle, decreasing lead times and augmenting logistics performance (A. C. Pereira et al., 2019). CPS-based devices will be able to provide information about cycle times to operators using for that Augmented Reality, which will support JIT tasks performing (A. C. Pereira et al., 2019). Therefore, JIT can benefit with I4.0 in a way that provides the visualization of the entire supply chain, the improved demand forecast and accuracy, the responsiveness to changes and the superior inventory management and control (Haddud & Khare, 2020).

Value Stream Mapping (VSM) is the lean tool with more practical applications, and because of that has more evidence of the capabilities gathered through the connection with I4.0 technologies. Phuong et. al (2018) developed the Sustainable Value Stream Mapping (SVSM) which involves three dimensions above the traditional one, they are economy, societal factors and environment. I4.0 technologies were integrated in this tool, such as RFID (Radio Frequency Identification), providing a real-time tracking, allowing, at the same time, employees to be more quickly reactive to potential incidences. Also, Big Data collected by the real-time tracking of SVSM can be used for forecasting reasons, possibly preventing waste in resources consumption and any damage to workers. Molenda et. al (2019) inspired in Value Stream Mapping 4.0 to suggest a new methodology for the visualization, analysis and assessment of information processes in manufacturing companies – The VAAIP mapping. For the visualization, quantitative measurements and a qualitative analysis were carried out. Ramadan et. al (2020) presented a Real-time scheduling and dispatching module (RT-DSM) that traces the flow of products and detects the incompatibilities and inconsistencies between the physical and virtual world that are caused by lean waste. This module runs on Dynamic Value Stream Mapping (DVSM) to prevent a frozen production schedule, producing appropriate reactions and directives to be executed both by machines or a human to relieve the impact of incidents and try to match up the Virtual Value Stream Mapping with the Actual Value Stream Mapping. Huang et. al (2019) also designs a DVSM version that is included in a cyber-physical multi agent system which real time and virtual attributes make visible the conditions of material, workforce and machine. The DVSM is considered by authors capable of providing valuable information for the decision-making process. Therefore, DVSM or VSM 4.0 provides real-time data which allows appropriate action in the right time, overcoming the static behaviour of VSM and above that, the current value stream can be constantly displayed and bottlenecks as well as improvements continuously ascertained, what facilitates the implementation and concretization of Kaizen activities (Balaji et al., 2020; Lugert et al., 2018). Balaji et al. (2020) also refers the enhancement of team's morale as an advantage since they are able to see the results of their kaizen activity very quickly and suggests the standardization of measurement methods across the organization.

For the ***Heijunka*** principle, Ante et. al (2018) reveal some projects in the I4.0 context. One of them it is related with the construction of a Digital Heijunka Board. It pretends that the system automatically creates the production Kanban cards and place them in the Build to Order slot of the Digital Heijunka board, which have been developed following the standard levelling rules for assembly. Logistics department sends the assembly program automatically to the system board and levelling performance is calculated automatically. In Kolberg et. al (2017) another project is revealed by WITTENSTEIN AG which digitised their Heijunka board. Graphical user interfaces connected to the production line and MES are displayed which contributes to diminish information flows and efforts for updating the board. Pekarčíková et. al (2019) exposes some relations between Heijunka and I4.0 technologies, such as Augmented Reality, Virtual Reality, Cloud Computing, Big Data Analytics and IoT. The last three can be assumed by the examples listed above, although the first two still need practical application. Even though, it is appropriate to extrapolate the use of AR and VR to display the Heijunka board, eliminating the one that is physical. Pereira et. al (2019) sums to all the seven I4.0 technologies, Artificial Intelligence, arguing that this technology is indicated to provide analytical support in the decision-making process and apply intelligence environment approaches that allows complex analysis and learning.

A CPS-based ***Jidoka*** system was already planned and implemented by Ma et. al (2017). It is considered a distributed system self-possessed of analogue and digital parts, actuators, controllers, ICT, software,and Jidoka rules. Pereira et. al (2019) also cited an integrated and standardized approach to implement and design a CPS-based smart Jidoka system which was a system mainly based on CPS technology, including others technologies such as Cloud Computing and IoT, capable of allowing data collection of resources and flexible configuration of the system itself. Rosin et. al (2020) also cited the use of autonomous robots capable of detect and correct production errors, which makes part of the Jidoka principle. Thus, the defect detecting process is carried out with more accuracy, the identification of any errors is supported in real-time, preventing them from moving to the next process, and is easier to manage the identification of the causes of any errors occurred (Haddud & Khare, 2020). Together and closely linked to the principle of Jidoka, there is the ***Poka Yoke*** Lean tool which is improved and more effective using the technologies mentioned for Jidoka. Haddud et. al (2020) analyses this tool together with Jidoka, and the benefits encountered were the same as the mentioned above. Although, some authors show some reluctance with the relation between Simulation and Poka Yoke, since the first one can foresee potential difficulties and mitigate failures in the production process, however it does not avoid errors (which is Poka Yoke's goal) (Pagliosa et al., 2019). A particular complementarity between these two methods can be achieved, even though practical application is needed (Pagliosa et al., 2019).

Kaizen strategies relay profoundly on well-timed detection of errors and abnormalities all over the processes and supply chain operations (Haddud & Khare, 2020). Because of this, some tools mentioned above, such as Jidoka, VSM, Heijunka, Kanban and Andon, properly integrated with I4.0 technologies can be a source to provide insights to adopt kaizen strategies or even can be the kaizen strategies itself. In that way, a totally integrated production system will actually increase the value chain's performance and the responsiveness of the whole system (Sader et al., 2019), make it easy to catch, process and distribute information to the right people, permit suppliers and customers participation and make timely improvements, since identification of errors is easier and promptly (Haddud & Khare, 2020).

In the ***Andon*** principle, IoT provides products to connect with equipment and send a warning once the incorrect product is being produced, offering the capability of the equipment to react to errors, discontinuing the work or changing products (Rosin et al., 2020). In Pereira et. al (2019) and Kolberg et. al (2015) it is mentioned that the use of CPS-based smart devices (smart watches, SMS or even email, for example) by operators provides the reception of error messages in real time, alerting the operator in case of failure, prompting repair actions and reducing delay times due to failure incidences. With this approach, recognizing failures will not depend on location of employees. In a more standardized environment, CPS will be capable of automatically trigger fault-repair actions on other CPS (Kolberg & Zühlke, 2015). It can happen that alert notifications become frequent, alerting for a possible failure for the system. In that way, it will be important if PLC's will be programmed to generate an alarm whenever any sensor value captured is outside of the tolerance or even when the rate of recurrence of number of alerts goes beyond a certain limit (Gambhire et al., 2018). For this to happen, the combination with artificial intelligence would be important, in a way that it could be confirmed, based on historical data, if the problem would be on the product or machine.

Several studies have been already investigated the digitisation of conventional ***Kanban*** cards, thus emerging the e-Kanban system. With this system, missing or empty bins can be exposed, and replenishment can be triggered automatically (Kolberg et al., 2017). In Bittencourt et. al (2019) a case study is cited, carried by the Wurth Company which introduced an order replenishment system based on Kanban baskets. The new program can send orders automatically to suppliers, decreasing, in that way, stock, and consequently space clearance on the shop floors occurs. Above that, orders are concise with demand. Another study in the Wittenstein Company uses Automated Guided Vehicles (AGVs- included in the Robotics group) which provide and establish the milk-run system-based interval via real-time demand (Bittencourt et al., 2019), possibly changing the e-Kanban system. Also, Cloud Computing can be of superior interest when it is necessary an exchange platform to facilitate JIT supply between the producer and the supplier (Rosin et al., 2020). With the implementation of a system like the ones mentioned, lost Kanban will not cause problems anymore, modifications in Kanbans due to shifts in batch sizes, work plans or cycle times will be more easily (Kolberg et al., 2017; Kolberg & Zühlke, 2015).

Key Performance Indicators (KPI) are metrics often used by Lean. Pereira et al. (2019) makes reference to a case in automotive electronics production where the main problem was in the missing traceability for shop floor KPI reporting process. To apply a solution, data analytics and a cloud solution were essential for process the live data collected from all lines in the production network.

The ***Total Productive Maintenance*** (TPM) is another lean tool that has been recently attracting attention for the integration with I4.0 technologies. Big data analytics, cloud-based systems and IoT enable real-time information and data that can support productive and preventive maintenance (Haddud & Khare, 2020). Sensors produce data which is then contrasted to the information from the machine and the specific workpiece being processed, allowing to continuously keep in check and predict incidence of failures as there are multiple signs and tendencies that the component demonstrates "symptoms" of forthcoming failure or degradation in performance (Gambhire et al., 2018; Wagner et al., 2017). The timely information sharing, and real-time data provides better inventory management and shorter downtimes (Gambhire et al., 2018; Haddud & Khare, 2020). Smarter maintenance is capable of guarantee better processing equipment performance and fewer defects, which makes to increase the product's quality (Yeen Gavin Lai et al., 2019). With promptly notion about equipment state and properly triggered repair actions, a smart planner can be easily updated reconfiguring production lines and updating kanbans in real-time, based on changes (A. C. Pereira et al., 2019). Pagliosa et al. (2019) refers the connection between TPM and AR what can be explained by the support in performing maintenance remotely through knowledge sharing and technical guidance. Marcello et al. (2020) carried out a construction of an ensemble-learning model that combines prediction results from multiple algorithms, that pretend, using big data analytics, estimate failure rates of equipment subject to distinct operating conditions (reached an accuracy value of 96.15%). On the other side, Passath et al. (2019) created a standard criticality analysis as a foundation of an agile, smart and value-oriented asset management system to dynamically adjust the maintenance strategy. It was concluded that the more complex and disparate assets are, the more essential it was to have a guideline to dynamically adapt the maintenance approach due to the environmental variations as well as production circumstances.

Ayabakan et al. (2019), has already mentioned, analysed a digitalization of a kanban system, but above that, an automatic change over system was focus of attention too (based on Single-Minute Exchange-of-Die- ***SMED***- Lean principle). The system uses RFID (Radio Frequency Identification) to recognize each die and know their storage address. It was concluded that with this system an increasing of the line's productivity was felt, as well its capacity, reducing, at the same time, the number of production man. Pagliosa et al. (2019) supports the idea that IoT can have a crucial impact in the execution of adjustments and setup of workstations, but states too that the integration of robotics with SMED can cause conflicting efforts for operational improvement. This can happen because elevated levels of Robotization and Automation can conduct to less flexible production lines, limiting the customization of products and weakening changeover time. However, on the other hand, the authors assume the capacity of carry complex activities with the utilization of Advanced Robotization. Therefore, more study and practical applications are needed in this aspect, to converge results.

In ***Visual Management*** 4.0 the automated acquisition of data (using IoT) saves time to managers and employees since boards can be automatically updated with information (with preprocessed data) (Meissner et al., 2018). Smart visualization abilities emerge from this combination, and entire processes and activities can be visualized across the supply chain, allowing a better risk management, predicting future incidents (Haddud & Khare, 2020).This is possible using for not just IoT, but also the cloud which makes information available to all the right people, Big Data Analytics can be used to extract and process the data collected, convert it in information and the Augmented Reality provides and presents the visual information to managers and/or employees (Rosin et al., 2020).

Gambhire et al. (2018), Pagliosa et al. (2019), Pekarčíková et al. (2019) and Wagner et al. (2017) considered that the ***5Ss*** lean tool can usufruct of the I4.0 technologies' integration, believing that Virtual Reality and Augmented Reality are the ones capable of having a huger impact. This can be explained by the fact that this lean tool is still some kind of mechanical, which just can be solved by I4.0 tools capable of representing it in a virtual world, in order to facilitate the shop floor disposition.

After analysing each of the lean principles and their correlation with I4.0 technologies, it can be concluded that lean and digital technologies support organizations in becoming faster, more efficient and economically sustainable (Dombrowski & Richter, 2018; Nicoletti, 2014).

Since waste reduction is the Lean's main goal, an overall analysis about the impact between the seven wastes and the I4.0 introduction should be done. Overproduction can be reduced in the I4.0 context since a better order management is provided and information is communicated through the shop floor directly and constantly (Yeen Gavin Lai et al., 2019). The waiting time is able to be decreased too as smarter decisions are made on site and feedback from related stakeholders can be got by vertical or horizontal levels (Yeen Gavin Lai et al., 2019). Here, the horizontal and vertical integrations will be a huge impact in identifying waste, as well as Big Data which can be used to detect, in real time, unusual situations in the production system and identify the root causes of these conditions (Rosin et al., 2020). IoT is already assumed as an important tool to reduce transportation, since it takes advantage of real-time product tracking to see unnecessary transportation (Rosin et al., 2020), and robotics and infrastructures brought by I4.0 supports the transport by itself and even the calculation of best routes (Yeen Gavin Lai et al., 2019). Simulation allied with augmented reality or virtual reality is a possible resolution to over-processing, because allows the replication of scenarios for testing ideas, providing managers space to choose the most promising ones. Also, the defects and unnecessary processes can be minimized with this tool, as a copy of production system can be constructed, and several scenarios be provided to solve production problems (Rosin et al., 2020). Additionally, the digitalization of value streams provides real time feedback, allowing the control of processes efficiency (Yeen Gavin Lai et al., 2019). A better control of production and raw materials is given by the connectivity between customer, supply chain and individual processing equipment, which offers an inventory's decreasing (Yeen Gavin Lai et al., 2019).

Besides, since Lean puts people at the centre of almost every strategy, the I4.0 impact in the way collaborators do their work is essential to be understood. Augmented reality, for example, is considered by Rosin et al. (2020) and Dutta et al. (2020) a useful tool to learn new processes, perform material audits and further down, to execute on-site maintenance tasks, allowing the share of knowledge with other employees. Simulation is another tool considered to be able to validate human operations and training new employees (in conjunction with AR and VR) (Dutta et al., 2020; Kamble et al., 2020; Pagliosa et al., 2019; Rosin et al., 2020). I4.0 pretends to change the workers' role from Machine Operators to Augmented Operator which the main position is supervising the work (while it is being performed by the machine) (Sader et al., 2019).

Although, before introducing I4.0 technologies, companies should appropriately weigh the maturity of their organization (Lucato et al., 2019), having special attention to structure, jobs and competences. Experimentation is essential to recognizing the interventions at both technological and organisational levels and companies must never misjudge the time required (Cimini, Boffelli, et al., 2020).

Table 11, shown below, appears as a summary of the impact of I4.0 technologies on Lean practices. In this way, and with a view to a consistent follow-up, the horizontal axis refers to Lean tools identified as being the most relevant and most referred in the articles. The vertical axis refers to I4.0 technologies, which were also presented as being the most significant. Every Lean tool was evaluated by studying the combination with I4.0 technologies, which resulted in the introduction of an "x" in case of existing impact between the two (I4.0 technology and Lean tool).

Table 11- 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												
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							

RQ9: What is the contribution of Lean to Industry 4.0?

In the previous chapter, I4.0's contribution to Lean was analysed. Therefore, it is time to analyse the reverse.

Architectures for establishing dynamical and self-controlled Industry 4.0 productions centred on CPSs exist, but they are predominantly high-level methodologies focus barely on technology point of view. It has been said in academia that smart factories must consider the technology point of view as well as the organisational and human point of view (Kolberg et al., 2017).

According to Tortorella et al. (2019), Rauch et al. (2017), Tortorella et al. (2018), Erro-Garcés et al. (2019), Rossini et al. (2019), Bittencourt et al. (2019) and Rossini et al. (2019), Lean Practices implementation shows a great potential to a higher adoption of I4.0 technologies. This is assumed because of the solid behavioural and processes foundation that lean can provide. However, Tortorella et al. (2019) considered that in order to implement I4.0 technologies it is necessary that the organization present a minimum level of Lean practices maturity, since if this level is not adequate and I4.0 technologies are implemented into ill-structured processes, results will be below expectations, producing management frustration and financial waste. Tortorella et al. (2018) discuss the association regardless the companies' size and the conclusion is that size is not an impediment for implement I4.0 technologies, although both are likely to be widely implementing Lean Practices. Nonetheless, Rossini et al. (2019) establish the independence of Lean practices adoption from the presence of I4.0 technologies. Lean practices adoption effects still prevail over the impact of I4.0, and this happens since companies' perception and implementation maturity with respect to Lean are considerably larger than I4.0.

There are already some more concrete contributions from Lean to I4.0. It is the case of Rosienkiewicz et al. (2018) which contribution settles in the conception of a lean production control system that uses the Glenday Sieve lean tool ("states that a small percentage of procedures, processes, units or activities account for a large portion of sales, and includes a color-coding system for labelling processes by output volume" (Rosienkiewicz et al., 2018)) and I4.0 technologies, such as artificial neural networks (ANN). The lean tool was used to establish which type of products were able to be predicted by ANN networks.

Bittencourt et al. (2019) recommend having a framework for the implementation of I4.0 technologies in a production system and that it must adopt tools such as process standardization and production flow, intrinsic to Lean, which will ensure transparency of the process and gain of productivity. Qu et al. (2018) creates a framework to overpass gaps between requirements for traditional manufacturing system and smart manufacturing system. Some of the design requirements settle in lean principles such as standardization, in which it pretends to establish a data dictionary, uniform document format and sheet design and standardize the database.

Constantinescu et al. (2015) suggest another approach which the authors called Just-in-Time Information Retrieval (JITIR) founded on using as an input the users' environment and activity, and delivering as an output to the user information reclaimed, proposing documents, which potentially match users' concern. Furthermore, JITIRs agents are capable to perform automatically and therefore to decrease considerably the cost of search, behaving as a time-saver search. Other authors carried out the analysis of the importance of using JIT principle to display information, since they agree about the power of having information displayable, reusable and provided to the right person, in the right format, at the right moment (Cattaneo et al., 2017; L. Teixeira et al., 2019). Lean information management (LIM) is a management practice enhanced by Teixeira et al. (2019) as a benefit for systems such as Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES), because of its capacity in eliminate all waste in terms of avoidable data and processes.

Bittencourt el al. (2019) also conclude that in one side lean thinking focuses on waste reduction, while on the other side, I4.0 concentrates on the use of new technologies driven by IoT. Even though with different tactics, the concepts can and ought to be complementary, since the implementation of Lean will inspire a company to stimulate thinkers who will be necessary in implementing the changes needed by I4.0.

III.5 Summary and outlook

Considering the bibliometric analysis carried out, it can be concluded that the integration between I4.0 and Lean is a recent topic and with a growing trend. Most of the papers are articles, belonging to journals of high quality (Q1), which allows to claim that the subject in question is in force in the academia with a tendency for more investigations in this area.

Regarding content analysis, 29% of the papers were practical applications, being the remaining of theoretical and empirical character, however distant from the practical scope, of, for example, the creation of prototypes. It is also worth highlighting the disproportion of work regarding Lean's contribution to I4.0 (Figure 14), which allows us to conclude that the focus of attention is on how I4.0 can improve Lean. Several authors have already taken the entrance of I4.0 into manufacturing as being beneficial, capable of creating a flexible and interconnected shop floor. However, integration with Lean is said to be essential for successful implementation.

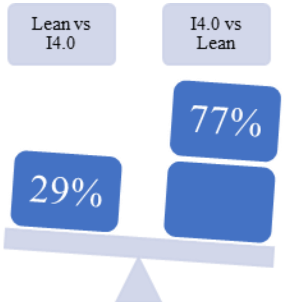

Figure 14- Proportion of influence of the Lean concept on I4.0 (left) and I4.0 on Lean (right)

There are several examples of Lean tools capable of integrating I4.0 technologies. Some, though, need to be subject to practical application. However, the ones that have already seen their integration in the virtual world and its consequent application in the real world following should be highlighted: Kanban, Jidoka, VSM, SMED, TPM and KPIs.

It should be noted that one of the problems highlighted in the theoretical background in relation to Lean was its excessive difficulty in using and managing data analytics in the improvement process, with difficulty, consequently, in understanding the positive impact or not of the practices introduced in the organization's performance. 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.

Therefore, Lean practices have an enormous space to grow and be more impactful since I4.0 allows a better insight of customers’ demands and accelerates information sharing processes, empowering employees, which is the core key in Lean Production (Tortorella, Giglio, et al., 2019).

In the perspective of Lean's contribution to I4.0, however, there is little practical and theoretical application, the actual contribution is still somewhat blurred. In any case, it is highlighted the knowledge management systems, which with Lean techniques (specifically the JIT) will promote the effective and efficient distribution of existing and stored knowledge, as well as its creation.

The architectural structures of information systems can also take advantage of principles such as standardization.

Either way, there is already a considerable amount of work carried out by the academia that suggests the need for the Lean environment to be on an I4.0 implementation basis (Rosin et al., 2020; Rossini, Costa, Staudacher, et al., 2019; Rossini, Costa, Tortorella, et al., 2019). In this way, companies can rely on the implementation of their technologies into standardized and tough processes.

Lean establish practices, behaviours, and habits, stimulating the problem-solving process among their collaborators. Besides, it groups several simple tools, capable of having a successful outcome. 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.

III.6 Future research

The authors of this paper were unable to understand, in the universe of selected articles, which lean tools are most applied on the companies' shop floor. In this sense, it is necessary to understand which tools have the most application, in order to later establish a guideline for the integration of I4.0 technologies, as a way of not occupying research in outdated tools or with low use incidence.

Another issue is in the testing of business applications for the practical integration of the two concepts (I4.0 and Lean).

Lean's contribution to I4.0 is also another necessity, as a low focus in this regard has been noted.

An implementation guidance framework for these two concepts is still lacking. Therefore, the primary stipulation that lean tools are necessary and capable of upgrading with I4.0 is of utmost importance.

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

Reference

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Notes: This article is presented here in a more complete format than the one accepted by the conference, due to the word limit factor (in the literature background, another chapter is included, this being the one that refers to the integration of all concepts - IV. 2.5). In addition, in the body of the article, only two diagrams are presented, the rest of which are shown in the annexes with the respective explanation (see **Appendix 1**, at the end of the dissertation). It should be noted that the fact that there are more diagrams to be displayed, this has no implications for the conclusions drawn, which remain valid.

Organizational Knowledge in the I4.0 using BPMN: a case study

Abstract

In the context of industry 4.0, management of knowledge represents a real challenge, since the tacit knowledge acquired by the expert operators is not transferred quickly and easily to newly arrived operators. This sharing of knowledge could help in the faster adaptation of humans to workstations and could bring the more agile accommodation of artificial intelligence techniques to allow the self-learning. The Business Process Management (BPM) is a technique which enables the representation and analysis of processes, has been already mention in the literature as a useful tool that can facilitate the Knowledge Management. A process repository can be accomplished with BPM, thus promoting agile and fast knowledge transfer in a context where new skills emerge and must be quickly taken up. This paper intends to show the development of the working instructions maps, with workers' tacit knowledge, using the BPMN 2.0, in a chemical industry. This representation allowed the creation of a knowledge's repository which will help the company (in a I4.0 environment) to deal with the most existing workforce rotation, thus preserving most of the knowledge within the company itself.

Keywords

Knowledge Management; Industry 4.0; Business Process Management; BPMN 2.0; Organizational Knowledge

IV.1 Introduction

Nowadays, Industry 4.0 (I4.0) pretends to allow “smart decisions” for managing disruptive events via decentralized production control (Kavakli, Buenabad-Chávez, Tountopoulos, Loucopoulos, & Sakellariou, 2018).

The management of knowledge is one of the achieve challenges of the industry, mainly in the context of industry 4.0. Expert operators acquire valuable knowledge about the manufacturing processes and the transference of this knowledge to new operators is a difficulty process in companies. This happens since this transference is sometimes not efficient or even does not take place, endangering the future of organizations (Roldán, Crespo, Martín-Barrio, Peña-Tapia, & Barrientos, 2019).

Business Process Management emerges as a management discipline with the purpose of build a process-centric thinking (J. Teixeira, Santos, & Machado, 2018). Business process models can be useful to assess the limitations of current processes, while representing an As-Is model (that is a snapshot of the present process), and after a careful analysis, while representing a To-Be model (representation of the business flows that is intended to achieve). The Business process management as well as business process models can have an important role in knowledge management, since they can convert the informal knowledge of processes to formal knowledge (Kalpič & Bernus, 2006; Kovačić et al., 2006).

One of the tools that has been considered to be crucial for modelling business processes is the Business Process Model and Notation (BPMN) (Haseeb & Ahmad, 2020; Nesic, Ljubic, Radojicc, & Vasovic, 2016).

Industry 4.0 has is core in implementing technologies which enable the creation of Cyber Physical Systems (CPS) (Telukdarie & Sishi, 2019). This new context requires more flexibility and agility to meet customer needs. To achieve these both requirements companies will need faster decision-making processes and production systems self-adjusting and self-optimized (Savastano et al., 2019). This way, information and knowledge will have to move through the company more quickly. However, as already mentioned in Haldin-Herrgard (2000), in organizations, knowledge resources have significantly been labelled as an iceberg, where the explicit knowledge is the observable top of the iceberg, and below the surface (where there is a significant part of this phenomenon), it is assumed that remains the tacit knowledge.

Therefore, it is essential to capture the tacit knowledge and place it in the smallest possible portion in relation to the explicit, in order to the company does not lose organisational knowledge when its employees leave. As cited in Jerman (2020), “You do not only gain competence through formal education but also through life-long learning”, and many organizations realize the promotion of competencies as the key to developing competitive advantage, having the same time an upgrading in company's performance, promoting knowledge at all organization's levels.

Currently, the loss of skills due to the turnover of the workforce is something to be avoided by companies, since the creation of value in industry 4.0 can be profitably achieved through the adoption of technologies that end up placing human beings at the centre of the innovation process (Caldarola, Modoni, & Sacco, 2018).

The goal of this paper is to take advantage of business process models to represent the knowledge associated with the tasks of operators on the shop floor of an organization belonging to the chemical industry, thus transforming the tacit knowledge of these employees in explicit knowledge (creating a knowledge repository). Furthermore, through the analysis of these models we will be able to identify gaps and weaknesses in the enterprise 'processes. The Business Process Model and Notation (BPMN 2.0) is applied in this paper to promote the integration between organizational knowledge and business process management.

The present article is structured as follows: in the second section there is a literature review, where concepts such as knowledge management, business process management, BPMN and industry 4.0 are specified. Then, in the third section the case study is shown, where the context of the problem, methodology, results, and discussion of them are presented. Finally, the conclusion intends to summarize the relationship between the concepts explained by the academy's analysis and the results taken in practice, in order to raise the need to apply the BPMN language to the manufacturing floor and how much it can favour the organizational knowledge.

IV.2 Literature review

IV.2.1 Knowledge management

The combination of data and information to which is added expert opinion, skills and experience is called knowledge (Bosilj-Vukšić, 2006). It may be explicit or tacit, the latter being associated with the minds of knowledge holders, and therefore difficult to communicate, share and put into a document or database (Bosilj-Vukšić, 2006; Nonaka & Lewin, 1994). On the other side the explicit one is typically structured and retrievable, and should often being in repositories, embedded in documents, organizational routines, processes, practices and norms (Bosilj-Vukšić, 2006; Kalpič & Bernus, 2006; Kovačić et al., 2006; Nonaka & Lewin, 1994).

As cited in Ebrahimi, Ibrahim, Razak, Hussin, & Sedera (2013), an organization's competitiveness depends on its specialized knowledge, its diversity and the way it is integrated effectively in the company. Rules and directives, routines and self-managing teams are the mechanisms for integrating knowledge, and the last one (self-managing teams) is the most adequate for integration of knowledge for non-routine and complex organizational tasks that include uncertainty and novelty. Knowledge is a vital resource for obtaining competitive advantage, converted into quality improvement and more efficient business processes (Manesh, Pellegrini, Marzi, & Dabic, 2019).

Knowledge management (KM) is as a strategy of getting the right knowledge to the right people at the right time, facilitating sharing of information between people, putting it at the same time into action providing the organizational performance improvement (Kovačić et al., 2006). Its lifecycle has four core tasks, knowledge creation, knowledge storage/codification, knowledge transfer/distribution and knowledge application (García-Holgado, García-Peñalvo, Hernández-García, & Llorens-Largo, 2015; Papavassiliou & Mentzas, 2003). Knowledge must be transferred or shared to have a wide organizational impact, representing the knowledge embedded in the organization's processes one of the main components of knowledge management (having for that a process oriented perspective) (García-Holgado et al., 2015; Kalpic & Bernus, 2002; Sarnikar & Deokar, 2010).

Nowadays, KM is one of the biggest challenges for organizations. For small and medium-sized enterprises (SMEs), this practical is more important because they usually cannot afford the investment needed to achieve a credible business value from knowledge management. This group of enterprises end with erosion of knowledge due to the leaving of key employees (García-Holgado et al., 2015).

IV.2.2 Business Process Management

"Business Process Management (BPM) is valued as a means to gain and sustain competitive advantage." (as cited in Niehaves et al., 2014). This is true because this methodology allows companies a faster organizational adaptation to the continuously changing requirements of the market and its customers, since it enables development and continuous improvement of corporate strategies (Neubauer, 2009).

BPM is also a subject that is strongly tailored to the modeling of organizational processes and the subsequent implementation of process models in executable software (Geiger, Harrer, Lenhard, & Wirtz, 2018). From a lifecycle point of view, this subject includes activities such as "the identification, definition, modelling, implementation, execution, monitoring, control and improvement of processes" (Lehnert, Linhart, & Roeglinger, 2017). It promotes cross-functional processes synchronization and facilitates companies to focus on what is believed value from the customer's perspective (Kaziano & Dresch, 2020).

The core of one organization are the processes and for managing them it is vital to know how they are performed inside the organization and how they are linked to each other. Because of that the modelling and documentation of processes are a matter of concern regarding their maturity within the organization (Ongena & Ravesteyn, 2016).

In what concerns to the processes' classification, they can be divided into core, support and management processes. First ones are groups of activities, and decision points that include players and objects which in a communal way drive to valuable outcomes. Support processes secure core processes, enabling its continuous operation and management processes, plan, monitor and control business activities (Lehnert et al., 2017).

The arrival of Industry 4.0 and the consequences in the complex industrial ecosystems are motivating new architectures and new business processes in order to help the organization with the adaptation of existing enterprise architecture, Information and Communication Technologies (ICTs) infrastructures, processes and relationships (L. D. Xu, Xu, & Li, 2018). In this line of thought, the Business process reengineering (BPR) arises with the necessity to redesign the entire business from its fundamentals to take advantage ICTs (Martinez, 2019).

IV.2.3 Business Process Model and BPMN

A model is a set of all relevant facts about an entity apprehended in some structured and documented form (Kalpič & Bernus, 2006).

"Use cases descriptions and documentation of complex procedures are often very difficult to understand and error prone" (Chinosi & Trombetta, 2012). A clear picture representing either a workflow or a business process is in most cases self-explaining and many users intend to enrich descriptions of processes with diagrams. Moreover, a graphical description of a process lets users to discern inconsistencies. For that, a formal graphical notation is necessary in order to express a valid representation of a process, having the same meaning as the textual description of the process (Chinosi & Trombetta, 2012).

The BPMN is already the de-facto and widely accepted standard language among others for most business experts to model processes (Arevalo, Escalona, Ramos, & Domínguez-Muñoz, 2016; Geiger et al., 2018; Haseeb & Ahmad, 2020). It offers the advantages of a graphical language, simplicity, standardization and provision for execution processes (Arevalo et al., 2016; Ben, Mohamed, & Faïez, 2019). Besides, it is capable of unify the way business analysts and technical developers see process models (Stroppi, Chiotti, & Villarreal, 2016).

IV.2.4 Industry 4.0 and Organizational Knowledge

The emergence of new technologies such as cloud computing, Internet of Things, Cyber Physical Systems (CPS) and Big Data is encompassed by the concept of Industry 4.0 (Nascimento et al., 2019; L. Da Xu et al., 2018). These new tendencies have their role in improving the transmission of information throughout the entire system (A. Moeuf et al., 2018). Therefore, the Industry 4.0 'execution system' is based on the interrelations between CPS building blocks. This kind of blocks can be seen as embedded systems with decentralized control and advanced connectivity. They track, monitor and optimize the production processes and the full integration of manufacturing and business processes in an organization can be achieved with a concise unification of Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP) (Rojko, 2017).

The literature already assumed that ERP system is insufficient to support the information flow in an organization. Since ERP mainly focus on managerial level issues, not treating real-time shop floor situation (C. Huang, 2002; T. H. Kim, Jeong, & Kim, 2019), the industry 4.0 promise of decentralized decision making cannot be achieved. The MES is the solution to this problem. It is a system which promotes the optimization of overall manufacturing operation management from work order to finished products (T. H. Kim et al., 2019).

In the growing of Industry 4.0 environment it is perceived that there is a lack of knowledge sharing, control on data management practices, as well as lack of understanding of how companies should integrate 4.0 technologies, in order to improve the workflow in businesses (Hurst, Shone, & Tully, 2019).

This transition in the industrial sector establishes new challenges and requirements to the knowledge management in enterprises. Smart factories can enjoy, from knowledge management systems, the possibility of implementing and organizing newly value creation networks more efficiently and successfully. Beyond that, these systems support the unification of these networks within internal manufacturing processes and resources (Tinz, Tinz, & Zander, 2019).

In the literature several knowledge management models suggest that every framework of this concept should incorporate knowledge management enablers and processes. The first ones have been considered as mechanisms or systems in which organizations use in developing, stimulating, creating, sharing and protecting their knowledge (Abubakar, Elrehail, Alatailat, & Elçi, 2019).

In any organization, individuals draw and behave according to a corpus of generalizations that are summarized in own experiences, specific knowledge, procedures and routines, and this is called the organizational knowledge (Tsoukas & Vladimirou, 2001). Some companies promote the development of organizational learning (OL) capabilities and this influences knowledge, beliefs and behaviors within the organization which allow business growth and innovation. In the literature appear that OL can occur based upon trial and error situations or consists of work procedures and routines established from stored knowledge in organization's memory employed in successive situations like those that initially offered the experience (Economics, Kogan, Ouardighi, & Herbon, 2017; Jennex, Olfman, & Addo, 2002; Tortorella, Cawley Vergara, Garza-Reyes, & Sawhney, 2020). If I4.0 allows a faster and richer understanding about products, processes and services the OL development may be expected to have their learning and information sharing catalyzed by 4.0 technologies (Tortorella, Cawley Vergara, et al., 2020).

The complexity in manufacturing industry is increasing regards to the higher product variety in assembly systems and a competitive advantage can be gained by adopting the complexity that can improve the performance of those assembly systems (D. Li, Fast-Berglund, & Paulin, 2019).

The adoption of Cyber-Physical Systems (CPS) dominates the I4.0 context and aims at increasing the flexibility and adaptability of production system, although the human factor must be considered (Mourtzis, Zogopoulos, & Xanthi, 2019).

The operator of the future, already mentioned on the literature as Operator 4.0, will have to come up with news skills related to KM. In order to aid humans at workplaces, the dissemination of information and knowledge becomes important and this dissemination it has to be with and among operators and managers (D. Li et al., 2019). Although it is essential assure that information reaches its target in a way that is perceivable by the end user, helping him to perform its operations and make decisions (Mourtzis et al., 2019).

ICTs will accelerate the collection, storage and retrieval of knowledge, however they still strive to express the so called tacit knowledge (S. Hoffmann et al., 2019). In fact, ICT is a key element in knowledge management, since it is capable of integrate fragmented knowledge, eliminating at the same time barriers to communication within the organization. Therefore, ICT-support can improve work and businesses efficiency, which will allow the increase of overall organization's performance (Abubakar et al., 2019)

In nutshell, it is essential to establish new points of connection between the human operators and the digital systems in manufacturing, in the sense of providing them with technical information or updating production databases with information concerning the status of production. It is believed that the operator's productivity will be stimulated by the increased flexibility of the workplace and the ability to more easily learn (Mourtzis et al., 2019).

IV.2.5 Linkage between the concepts (Industry 4.0; KM; BPM; BPMN; Organizational Knowledge)

As cited in Kalpič & Bernus (2006) the more a given item of knowledge or experience has been codified, the more economically it can be transferred. This happens because messages are better structured and less ambiguous if they can be transmitted in codified form.

Some researchers have been already emphasizing that there is a need to extend the concepts of Business Process Management to support knowledge flow in organizations. In the context of an organization's operative business processes and even from a knowledge management perspective, process orientation is critical to providing task relevant knowledge (Sarnikar & Deokar, 2010). In line of this thought, Business Process Management it can be seen not only important for process engineering but also as a methodology that allows the transformation of informal knowledge into formal knowledge (Bosilj-Vukšić, 2006; Kalpič & Bernus, 2006).

In the context of industry 4.0 the management of business processes will have significant requirements across the entire value-added chain (Halaška & Šperka, 2019). And tacit knowledge is hard to share since it is connected to skills and experiences, thus becoming the most transparent and subjective form of knowledge (Haldin-Herrgard, 2000). As mentioned, organizations' knowledge had been described as an iceberg, where the top is the explicit knowledge and beneath the surface, hidden and hard to express, the tacit one. To depend on personal tacit knowledge is unsafe, so the ability to convert it to explicit knowledge and to share it offers to the organizations a greater value (Haldin-Herrgard, 2000).

The embodiment of Information and Communication Technologies in the form of social robots can have drastic effects on communication and knowledge transfer, so the literature has been proposed Artificial Intelligence (AI) systems rather than the traditional software view on human intelligence (Fast-Berglund, Thorvald, & Billing, 2018). It is in these kind of AI systems that process mining can have a huge impact, since it is a family of techniques to extract knowledge of business processes from event logs. It encompasses, among others, techniques for automated discovery of process models (Conforti, Dumas, García-Bañuelos, & La Rosa, 2016). This technique is related to the general domain of knowledge discovery in databases (KDD) ever since it has an analogous approach to the analysis of large repositories of data and learning from them. With process mining researchers developed quantitative techniques and approaches to allow studying the execution of traces of business activities from the process-oriented perspective (Halaška & Šperka, 2019).

Besides the group of technologies that by itself will enhance the concept of organizational knowledge, in Industry 4.0, the successful systems integration has an enormous impact and, for that to happen, a detailed understanding of business processes is essential, since their amalgamation will contribute to a more interoperation and inter coordination in enterprises (Javidroozi et al., 2020).

Another profitability that industry 4.0 can bring is through the adoption of human-centred technologies (Caldarola et al., 2018) which can provide new approaches for the integration and transference of knowledge within and across companies (Zangiacomi et al., 2020). The Operator 4.0 will require several types of assistance in different phases, such as a learning phase (with new tasks), an operational one (regular state) or even a disturbing phase (where problems occur) (Sandbergs, Stief, Dantan, Etienne, & Siadat, 2019). For all the phases, data, information, and knowledge will have to flow within the company and will have to be of easy access (Sandbergs et al., 2019). As cited in Nantes et al. (2019), "the integration of data and knowledge enables automatic reasoning, the integration of artificial intelligence, and the creation of decision support systems to help workers at different decision levels".

The human element should be in the centre of the shift to the new I4.0 paradigm and companies are tested to develop a group of competencies (a whole new curricula), in an effort to handle with the increasing technological and organizational complexity of operations (Caldarola et al., 2018; Zangiacomi et al., 2020). Skills gain will not only be achieved through education called “normal” but also through lifelong learning (Jerman & Aleksi, 2020). In this way and since the knowledge flow will be preponderant in the I4.0 paradigm, it is essential that companies are able to retain all the skills of their employees (tacit knowledge), in order to make the workforce rotation easier, so that the process on-site learning be also more facilitated and capable.

In Kovačić et al. (2006), organizational knowledge is seen as an important element of the entire business knowledge that could be systemized, documented and retrieved in business process repository, which can be developed by business process modelling tools.

The integration of knowledge has one of its dependencies in common knowledge, being this the common understanding about a subject, which is shared by organizational members. (Ebrahimi et al., 2013). Business Process Modelling has capabilities that allow the enhancement of the common knowledge level in the organization. This happens because business processes are cross-functional, and people involved learn about the overall processes of the organization and how their task fit with others in the organization. Furthermore, business process models materialize, under the hat of Business Process Management, the transformation of informal knowledge of organization’s different processes to formal knowledge (Kalpič & Bernus, 2006; Kovačić et al., 2006). And that facilitates its externalization in the form of knowledge artifacts, sharing and subsequent internalization (García-Holgado et al., 2015).

The BPMN language allows the construction of diagrams where processes are described with a high abstraction level and consequently, they are suitable to describe a wide range of organizations (García-Holgado et al., 2015).

Business Process Modelling has a role in knowledge management (KM). If business processes are modelled and captured in business process repository they can be assumed as a part of codified intellectual capital of the organization. Business process repository should have knowledge processes as a part and above that, the business process repository himself could be used for knowledge creation, sharing and distribution (Kovačić et al., 2006).

Business rules constitute the business process repository and they could enable employees to reuse and adopt the knowledge and best practices from previous business process restructuring efforts (Bosilj-Vukšić, 2006).

The development and improvement of BPM and KM software tools should allow the transformation of the integral business processes model into the knowledge repository. And in line of this thought the creation and implementation of a knowledge management system should allow employees to search, retrieve, distribute and transfer organization knowledge throughout the company (Bosilj-Vukšić, 2006). In this line of thought, before the I4.0 phenomenon, the tacit knowledge in the organization has his curve represented by a) in Figure 15, since there is a lack of conversion of tacit knowledge to formalized knowledge. However, during the I4.0 phenomenon it is expected that tacit knowledge suffers a conversion to explicit one, having consequence in the curve slope, represented by b) in Figure 15.

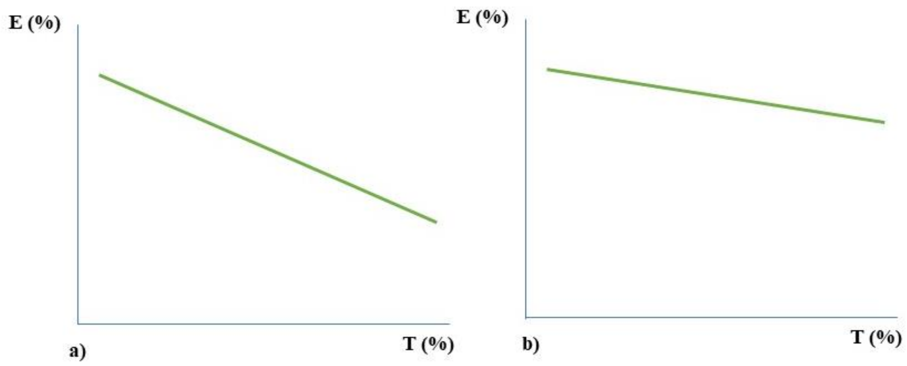

Figure 15- a): Explicit (E) and Tacit (T) Knowledge proportion before I4.0
b): Explicit (E) and Tacit (T) Knowledge proportion during I4.0

IV.3 Case Study

IV.3.1 Problem contextualization, goals and methodology

This case study has its main goal in showing how organizational knowledge can be obtained and facilitated using for that the representation of the working instructions through the BPMN 2.0. The company where the case was developed produces flush toilets. The production area is the core task, with about 80% of the employees working there (a total of about 400 employees) in two distinguished areas: injection and assembly areas. The injection area works almost only with injection moulding machines and the main actors that intervene in this section are the *Injection Operator*, *Injection Technician*, *Logistics*, *Injection Team Leader*, *Quality*, *Planning* and *Maintenance.* The assembly area is mostly stocked by injection area, being that there are isolated manufacturing cells and others that are in stream with injection machines.

For all manufacturing cells there are standard processes, notably for filling OEE sheets, which aim to check cell and operator efficiency, the declaration process of productions in the company's ERP (IS transversal to all the departments) and how to proceed when downtime results from malfunctions, shortages or even non-conformities. The Kanban (a card that assures the supply of parts to the production line as needed, increasing efficiency) is used in this side of the enterprise and lean tools here implemented, such as sequencing, batching and levelling boards. These instruments work similarly to any cell. Here the main actors in the processes are the *Assembly Operator, Mizusumashi Operator, Supplier, Assembly Team Leader, Area Manager, Planning* and *Logistics Team Leader*.

This paper presents a shop floor tasks' mapping repository (of the main figures evidenced above), using the concepts of BPM and BPMN 2.0. This repository aims to create the foundation for knowledge management in an unstable environment that characterizes the I4.0 paradigm, since it will make available know-how to manage the rotation of the workforce of employees, preserving knowledge inside doors, without losing it with the departure of key workers.

Having in account the Business Process Management life cycle described by (Dumas, La Rosa, Mendling, & Reijers, 2013), the strategy that was followed is settled in the three first stages, Process Identification (PI), Process Discovery (PD) and Process Analysis (PA). In the first phase –PI – the most relevant processes are identified. The second phase, in the PD, detailed about processes are recognized and documented through the AS-IS Models (using BPMN 2.0). In the third one, the main problems are identified and analysed and subsequently the TO-BE models are mapped.

IV.3.2 Results and Discussion

As mentioned, the aim of this work is to map the working instructions normally present in workers' tacit knowledge and therefore knowledge which is difficult to transmit, causing organisational problems, in particular loss of knowledge when workers rotate or leave from the organisation. In short, it is intended to convert tacit knowledge using by workers in the execution of different tasks in a company's shop floor into explicit knowledge, by usage of BPM concepts.

Given the limited space, in this work only the maps related to the work of the *Injection Technician* (Fig. 16) and the *Assembly Operator* (Fig. 17) will be explained and graphically be represented.

As can be observed in Figure 16, in the injection area the process initiates with the execution of the Daily Mold Change Plan (DMCP or MCP). The *Injection Technician* has in his power the injection moulding machine monitoring through Andon lights, the box supply for parts coming out of injection machines and the mold change preparation and assistance. Furthermore, the operator controls the parts quality, dimensionally and functionally. The *Injection Technician* solves malfunctions that can happen in injection machines and carries out mold changes. The *Injection Team leader* is a point of contact with other entities like the maintenance technician, the planning and the quality departments. He solves some problems that the Operator cannot solve and furthermore he opens work orders in the company' Enterprise Resource Planning to Maintenance.

As shown in Figure 17, in the assembly area the operator must, in addition to assembling the different components, fill in the OEE sheet, inform the team leader whenever something goes wrong (eg. device breakdown), record production and at the end of the shift ensure the execution of the 5 S's. On the other side, the *Assembly Team Leader* is the person who update the Daily Kaizen Board Indicators as well as the allocation of operators by workstations. This person must also monitor the working rate of each cell allocated to them and audit them according to safety rules. It also controls the supply by *Mizusumashi* by placing the so-called query's in the levelling frames. And in this area, it is this person who opens work orders in the event of malfunctions in machines or mounting devices to maintenance. The *Mizusumashi Operator* is guided by the query's placed by the team leaders on the levelling board. It has its own supermarket where it supplies itself and then supplies the line edges of the cells that belong to it. Between the *Mizusumashi Operator* and the Assembly Operator there is always communication whenever there is supply in the cell so that the Mizusumashi knows what needs to be supplied and in what quantity. It is also this operator who executes the batch construction framework that controls what should be and when it should be removed from logistics by the logistics *Supplier Operator*. It is only at the end of the shift that the *Mizusumashi Operator* tends to write off consumables on the ERP by executing it by scanning the query's barcodes. Lastly, The *Supplier Operator* has three main tasks, supply the Mizu's supermarkets, collect finished product pallets and empty boxes pallets.

During the analysis of the tasks performed in the two main areas of the company, some problems were identified:

(i) performing redundant tasks;
(ii) lack of communication between systems;
(iii) manual records (high paper traffic);
(iv) outdated information in the computer system;
(v) low level of real-time machine state interpretation.

The still very manual execution of some processes is one of the most prevalent aspects that is leading to excessive paper traffic on the shop floor as well as the execution of very redundant tasks. This very manual input of data results in the easiest errors to occur, so there is no cohesive efficiency analysis structure. The excess of paper causes an increase of time in the notification between actors, since there is no real time access to what is updated and / or performed in the process. The same happens with the stock that it is in the system which is not equal to what it is in the reality, considering the notification time to the system that materials have been moved to other location or even consumed.

The lack of communication between systems also proves to be a matter of extreme concern, since there is no platform that functions as a common trunk and encompasses the data of all solutions created / acquired. Shop floor machine data is also not being fully captured as access is subject to costly communication protocols. Thus, the interpretation of the state of the machines is limited and is mostly performed by andon lights that refer to machine stopped, in alarm or in production.

Even more obvious is the disintegration between business processes and existing information systems. All the shop floor relies heavily on the human hand to enter data and to carry out the necessary tasks. The information systems that exist does not consider these tasks, so data can be manipulate by operators and the process is not so reliable as should be.

The understanding of business processes is claimed in academia as the survival of the organization and currently, the business process modelling is a fundamental part of many companies, since document and redesign complicated organizational processes (Ternai, Török, & Varga, 2014). Regarding the KM, the essential goal of this practice is to transform implicit or tacit knowledge into an explicit one (representing in a formal way). Besides, after this representation, the distribution throughout the organization is a target, contributing to enterprise knowledge availability and re-usability, building internalized pragmatic expertise (Kalpic & Bernus, 2002). In fact, the representation of tacit knowledge through process maps using BPMN in this work, as well as the subsequent analysis to identify potential sources of waste, has not only made it explicit and more easily transmissible, but has also boosted the creation of a repository of useful knowledge when moving or leaving employees. The amalgamation of KM into business processes has become a potential feasible and theoretical task in KM (Ternai et al., 2014) and BPM is capable to offer procedures for "knowledge capturing, externalization, formalization, structuring and re-use" (Kalpic & Bernus, 2002).

Cyber-physical systems have been predicted as facilitators of knowledge services in smart systems (Manesh et al., 2019), since they are constituted by digital technologies which are able to create and share knowledge (Ansari, 2019). These technologies offer connectivity among activities and stakeholders at all levels, creating an enterprise integration

When a company implement a KM practices, a main subject having into account is how this KM assist the accomplishment of organization's goals. In that way, the alignment between the KM strategy and the business strategy is essential (Samadhi, Siswanto, & Suryadi, 2019).

Although, a whole work must be done in capturing what is already in people's minds, and a collaborator strategy needs to be aligned. In smart factory complex system the human element is an often forgotten piece (Jerman & Aleksi, 2020), although the I4.0 paradigm brings the obligation to educate collaborators with new curricula in order to cope with the growing necessities of the factories of the future (Caldarola et al., 2018).

The Operator 4.0 must have access to information and knowledge, in an effort to make decisions, lean faster new tasks or just to monitor the current operational state (Sandbergs et al., 2019). A knowledge cycle must be created in enterprises, where all begins in capturing tacit knowledge that could be stimulated by the sharing of formalized and documented knowledge (explicit).

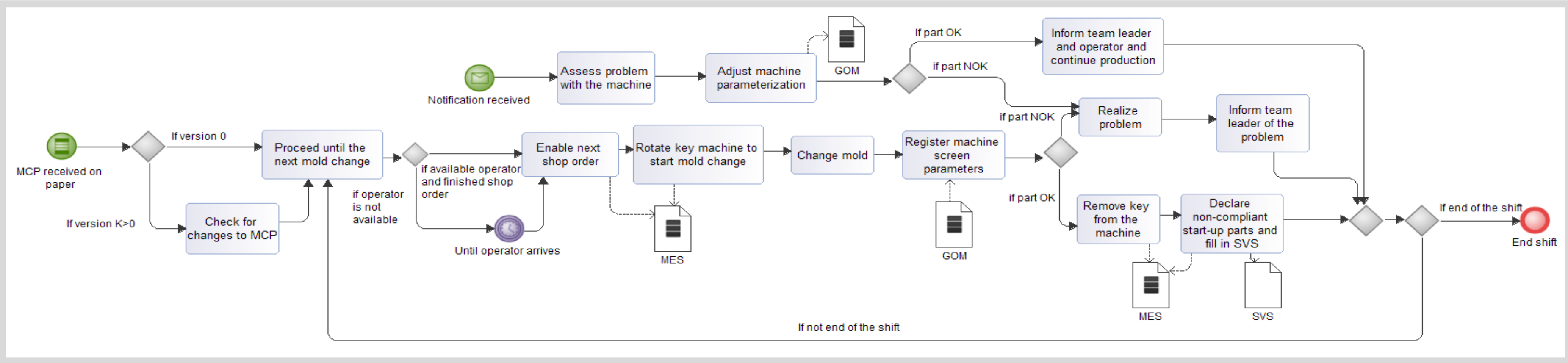

Figure 16- Map of Injection Technician working instructions based on BPMN 2.0

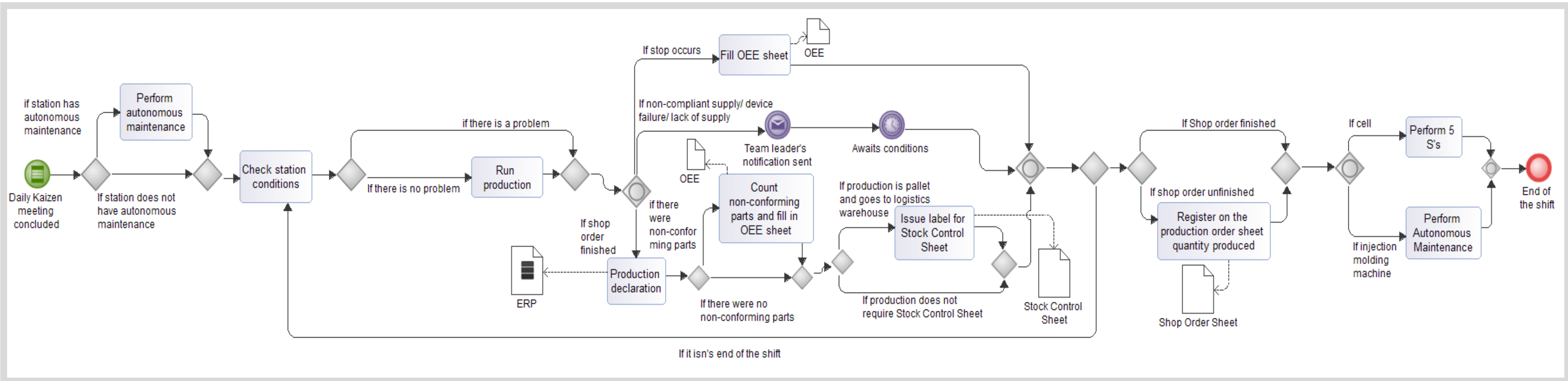

Figure 17- Map of Assembly Operator working instructions based on BPMN 2.0.

IV.4 Conclusion and Future Work

The Business Process Modelling is a crucial tool to represent and to analyse processes in an organization's environment. The resulting maps allow the visualization of connections between processes and systems which helps to identify gaps and think which processes should be automatized.

In this paper the BPMN 2.0 was used to represent human tasks in an organization in order to achieve an organizational knowledge repository. It was concluded that almost the entire shop floor is excessively dependent on the human hand and that the processes are nonetheless very manual. Considering the information systems that the company has, it stands out as a suggestion of future work, the modelling of these same systems and their updating in order to contemplate the processes highlighted in this paper. Only after a good process stabilization in the factory MES is there, as a second suggestion of future work, a feasibility analysis of the introduction of AI techniques that consider Process Mining.

Moreover, even though the existing business process modelling tools support the modelling and execution of business processes, they lack some assistance in knowledge dimension. Because of that, some authors have already proposed extensions to the language (BPMN 2.0) (Ternai et al., 2014)

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 et al., 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).

To conclude, Business Process Modelling can be applied 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 and/or establishing 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, since 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.

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

Reference

Salvadorinho, J. & Teixeira, L. (-). Shop floor data in Industry 4.0: study and design of a Manufacturing Execution System. 20ª *Conferência da Associação Portuguesa de Sistemas de Informação (CAPSI),* Porto, Portugal *(undergoing review)*

Notes: This article is presented here in a more complete format than the one accepted by the conference, due to the word limit factor. Since the present article was based on a case study of a company with two large areas in production, the analysis of the second large area (Injection Area) is attached in **Appendix 2**.

Shop floor data in Industry 4.0: study and design of a Manufacturing Execution System

Abstract

Industry 4.0 brings numerous challenges. However, it is being seen by companies as essential in their ability to adapt to the market and to the demands of consumers. Thus, intending to achieve more flexible and more decentralized production, the acquisition of technologies emerging from this fourth industrial revolution is crucial. This is where information systems will make a difference, as they will enable the cohesion of processes within the company, such as a more streamlined flow of information.

This article has as main objective to study and design an Information System with characteristics of a Manufacturing Execution System (MES), following an approach capable to respond to a whole set of key processes on the shop floor, such as addressing the problem of so-called information islands (silos) stored in fragmented information sources. This study was conducted in a company belonging to the chemical industry located in the centre of Portugal.

Keywords

Industry 4.0; Smart Factory; Manufacturing Execution System; Unified Modelling Language (UML), System Design

V.1 Introduction

The labelling of a new Industrial Revolution establishes substantial changes within the industry sector at the technical, economic, and social levels. The “Industry 4.0” terminology showed up in Germany at the Hanover Fair event in 2011, demonstrating the start of the Fourth Industrial Revolution (Bibby & Dehe, 2018).

The Manufacturing industry is moving from mass production to mass individualization (Ding, Lei, Zhang, Wang, & Wang, 2020; Park, Lee, Kim, & Noh, 2020), flexibility, autonomy, and faster market reply (Ding et al., 2020). Digitalization is one course to face these enlarged market challenges (Joppen, Lipsmeier, Tewes, Kühn, & Dumitrescu, 2019). Although, it is important to emphasize that digital transformation is not just about using new technologies but highlights the necessity of developing a strategy that places employees at the core to accomplish a successful implementation (Temel & Ayaz, 2019).

As mentioned in Yao el. al (2019) the “Manufacturing is the backbone of our modern society”, so the advances in Information and Communication Technologies (ICTs) and the introduction of the Internet of Things (IoT), brought, a new whole scenario in the industry, called Smart Factory, where manufacturing practices use networked data and ICTs to rule operations (Ding et al., 2020; Mittal, Khan, Romero, & Wuest, 2019).

In I4.0, likewise their physical representation, production elements have moreover a virtual identity (Rojko, 2017), which has the name of digital twin. Cyber-physical systems (CPSs) – which plays a crucial position in connection and sensor network (T. Kim, 2019) – and the Digital Twin (DT) technologies are capable of build, both on the physical shop floor and the corresponding cybershop floor, interconnectivity and interoperability (Cupek, Drewniak, Ziebinski, & Fojcik, 2019). Therefore, I4.0 opens doors to capabilities like tracking, communicating, and monitoring smart units, such as jobs, machines, tools, workers and other resources along the value chain (Ramadan et al., 2020).

Since interoperability and traceability are pillars in the I4.0’s context, it is essential to understand how to achieve this state of smart manufacturing, being the information systems critical tools to this accomplishment (Soujanya Mantravadi & Møller, 2019; Rojko, 2017).

Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES) are the two most important information systems which can provide, as long as they are properly integrated, a good overview of the shop floor, as well as a good readjustment to the long-term planning enabled by ERP.

ERP is acknowledged as the evolution of Manufacturing Resource Planning (MRP II) and it can be seen as a tool that conducts the information in production systems and other departments in a company (Ferro, Ordóñez, & Anholon, 2017). It is largely used to control the production's planning and logistics functions (Subramanian, Patil, & Kokate, 2019).

MES is considered to be a decision support system (Arica & Powell, 2018) that simulates and administers intradepartmental material flows (Makarov, Frolov, Parshina, & Ushakova, 2019). It is responsible for simplifying the buffer management, as well as Work in Progress monitoring on the production control level (Reddy & Telukdarie, 2018).

Since MES 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.

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).

The main objective of this paper is to create a software specification and the corresponding conceptual model (using the Unified Modelling Language - UML) capable of filling the key processes of a factory floor, eliminating isolated information cores. This approach was carried out using a case study in a company belonging to the chemical industry and the specification in question aims to address concerns such as interoperability, knowledge management, and data visualization. These three characteristics are imperative in the context of Industry 4.0.

The present article is structured as follows: in the second section, there is a literature review, where concepts such as Industry 4.0, Smart Factory, Information Systems, and Manufacturing Execution System (MES) are specified. Then in the third section, the case study is shown, where the context of the problem, goals, methodology used, results and discussion of them are presented. Finally, the conclusion intends to summarize the connection between the notions explained by the academy's analysis and the results taken in practice, to assume the approach demonstrated in this paper as being valid and capable of replication for other business contexts.

V.2 Background

V.2.1 Industry 4.0 and Smart Factory

Industry 4.0's concept brings an approach that engenders a conversion from machine major manufacturing to digital manufacturing (Oztemel & Gursev, 2020). In this context, machines are allowed to process data and interconnect with other machines or humans, through a network, called Internet of Things (Jerman, Bertoncelj, Dominici, Pejić Bach, & Trnavčević, 2020; T. Kim, 2019). This paradigm has been transforming all the supply chain, because of the use of real-time sensing and transfer of data (Jerman et al., 2020). The Industry 4.0's context brings advantages which are already known by academia, such as a more production flexibility (Büchi, Cugno, & Castagnoli, 2020; Rojko, 2017) and a friendlier work environment (Rojko, 2017), an improvement of productivity (bigger output capacity) (Büchi et al., 2020; Soujanya Mantravadi & Møller, 2019), a faster real-time response both for the decentralized production control (Büchi et al., 2020) as well for customer responsiveness (Rojko, 2017) and developed product quality (Büchi et al., 2020), enabling at the same time customized mass production without increasing overall costs (Rojko, 2017).

The I4.0 pretends to develop smart factories, where the physical and the digital worlds come together and business processes become collaborative (Cimini, Pirola, Pinto, & Cavalieri, 2020). A smart factory represents an imminent state of an entirely connected manufacturing system, where data will be generated, transferred, received and processed in order to perform all required tasks, with almost without human force (Osterrieder, Budde, & Friedli, 2020; Rub & Bahemia, 2019). The human force just needs to intervene in problem-solving phases (Oztemel & Gursev, 2020). All these interconnected and heterogeneous objects generate a huge amount of structured, semi-structured, and unstructured data, called big data (Alcácer & Cruz-Machado, 2019). Smart manufacturing is capable of using information continuously, contributing to improve and preserve performance (Mittal et al., 2019).

Smart factory integrates groups of cyber physical systems (CPS), which combine computing and physical processes (Oztemel & Gursev, 2020; Yao et al., 2019). CPS consolidate imaging and control events that allow responding to any feedback spawned (Oztemel & Gursev, 2020). CPS can be employed through the digital twin (DT)'s concept (T. Kim, 2019), which consists, basically, in a digital profile of a physical object which contains the historical and current behaviour of this element (T. Kim, 2019; Schmetz et al., 2020). Sensors and actuators (from the physical world), integration, data and analytics (from the cyber world) are the digital twin enablers 'components (T. Kim, 2019). The DT has its goal in synchronizing the information and tasks of the manufacturing place, allowing the monitoring, production planning, and process control. This accompaniment provides, at the same time, the production process performance improvement (Park et al., 2020).

There are two types of systems integration in I4.0, the horizontal and the vertical one. In the first, there is a foundation for a near and high degree of cooperation between several companies (inter-company integration). In the second, the integration among the different levels of the enterprises' hierarchy (intracompany integration) (Alcácer & Cruz-Machado, 2019).

Although some of the advantages of implementing the I4.0 paradigm have already been unravelled by the academy, there is still some concern about its implementation. Barriers such as the high initial investment (Raj et al., 2020), risk of investing in technology that can quickly become obsolete (Alexandre Moeuf et al., 2020), lack of digital skills (Alexandre Moeuf et al., 2020; Raj et al., 2020) and lack of a strategy that aligns all the resources necessary for the achievement of this paradigm (Alexandre Moeuf et al., 2020; Raj et al., 2020), hinder the entry of I4.0 in manufacturing companies. It is also known that the low levels of standardization of processes, regulations and forms of certification, as well as the low level of understanding of software architecture (Raj et al., 2020), become imperative obstacles and which must be strongly analysed to determining the success of an industry 4.0 project.

The lack of real-time data and information islands are two of the main deficiencies that manufacturing information systems have (Yao et al., 2019). Traditional manufacturing systems are poor in real-time data acquisition and processing and sometimes they do not capture data that would be valuable to the process. The other problem is related to all devices that need to be integrated vertically and horizontally in enterprises' shop-floors (Yao et al., 2019).

V.2.2 Information Systems: Automation Pyramid

As already mentioned before, the vertical integration represents the link among IT systems in different company's levels, ranging from the field level, via the control and process control to the operational and company management level (Joppen et al., 2019). To achieve success in the complete integration, IT systems must map and endorse entire business processes (Sauer, 2014).
In the I4.0's context, broad software support based on decentralized and customized styles of Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) is essential for a smooth integration of manufacturing and business processes (Rojko, 2017).

In most companies, almost all the data is recorded by hand and this contributes to a time lag problem. Because of that, it is difficult to keep track of the work-in-progress (WIP) in real-time, as well as to estimate material consumption for production (T. H. Kim et al., 2019).

From a top-down automation perspective, Enterprise Resource Planning (ERP) systems are the top of the pyramid, where they are responsible for long-term planning (M. Hoffmann et al., 2016b). ERP can be seen as a global system for organizing the distribution of human and material resources (Rix, Kujat, Meisen, & Jeschke, 2016). Right after ERP, Manufacturing Execution Systems (MES) occupies the second place, and they are in charge of mid-term production planning and execution (M. Hoffmann et al., 2016). MES systems depend on the combination between machines and plants in production and assembly. Because of the machinery's heterogeneity, the connection between machines is always different and involves manual outlay for configuration and integration on the part of the MES providers, system integrators, and project operators (Sauer, 2014). Below the MES, it is possible to find the Supervisory Control and Data Acquisition (SCADA) which can be assumed as a control system of the conditions and states during operation, to prevent significant problems or serious failures (M. Hoffmann et al., 2016). The SCADA is constituted by sensors and actuators which are programmable by logic controls (PLC) (Rix et al., 2016).

This paper focuses its study on the MES layer, and for this reason, this type of information system will be detailed in the next chapter.

V.2.3 Manufacturing Execution System (MES)

Manufacturing Execution Systems are created to operate in aggregation with "workstations, manufacturing lines, conveyor belts and automated processes throughout a manufacturing facility" (Lynch et al., 2019). This type of system is used to track, inspect, and notify in real-time all that happens on the shop floor, ranging from raw materials to final products (Coito et al., 2019). Production reporting, planning, shipping, product tracing, maintenance procedures, performance analysis, workforce tracking, resource allocation, are all functions of the MES, which permits covering all that is shop floor management, as well as all communication between different systems (Rojko, 2017).

A good MES should provide a group of characteristics to be capable of delivering good service, they are:

Interoperability – the MES needs to be gifted with the capability of being integrated with other systems (Coito et al., 2019; Mittal et al., 2019). Nowadays, it is a reality that software solutions accessible on the market are centralized and not dispersed to the shop floor elements (Rojko, 2017). This can create challenges when incorporating new equipment, since the interfacing of the two software packages (MES and the new equipment) can be a difficult process. The resolution settles in the development of Interoperability solutions that are capable of enabling communication between the two (Lynch et al., 2019).

Flexibility – The production environment, including the shop floor configuration, should be able to adapt in a way that answers customers 'order flow, as well as product specifications and quality requirements (Govender et al., 2019; Rojko, 2017). This can include the integration of new modules (creating the modularity's capacity) (Coito et al., 2019; Mittal et al., 2019).

Virtualization – it is centred in the establishment of digital twins (Coito et al., 2019), letting and facilitating to manufacturing operations be planned, performed, and monitored easily (S. Mantravadi, Moller, & Christensen, 2018).

Real-time – data should be collected and then analysed, providing, almost immediately, insights (Arica & Powell, 2018; Coito et al., 2019; Naedele et al., 2015). The efficiency in data collection is about to obtain the desired data of the manufacturing's traced entities and transmit it efficiently and precisely through the MES system (Arica & Powell, 2018).

Visualization/User Interface – a system that offers a user-friendly interface (Arica & Powell, 2018; Coito et al., 2019)

Analytics – the MES should provide visibility to the data which is collected by IoT's (internet of things) mechanisms as well as cyber-physical devices. This data must be used for strategies that should be defined to improve enterprise's operational efficiency (Govender et al., 2019). All the data needs to be stored to provide an analysis of historical data. This would be necessary, for example, to maintenance management (Naedele et al., 2015). In this way, it can be concluded that MES provides Business Intelligence from production procedures and can be used to measure, as well monitor Key Performance Indicators (KPIs), such as Overall Equipment Effectiveness (OEE) (Coito et al., 2019; Makarov et al., 2019) and Manufacturing Cycle Effectiveness (MCE) (Makarov et al., 2019).

Traceability/Monitoring – the system provides the ability to track and monitor the resources' entire life cycle in real-time (Govender et al., 2019).

Level of access – Data access policies must persist in MES and, to diminish risks, the needed data must be moved to the data warehouse to preserve their integrity (Coito et al., 2019).

Decentralization – MES should have incorporated decision support systems, which make decisions on their own (using the existing data) (Arica & Powell, 2018). In this line of thought, MES can be seen as an intermediate translator layer, which turns raw data stream into valuable information, essential to the decision making (Makarov et al., 2019).

Prognostics – It is supposed that MES enables the planning of future processes as well as allows prompt warning of process or quality nonconformities (Naedele et al., 2015).

Knowledge Management – the MES must allow the information flow through the organization (Coito et al., 2019), as well document control, where relevant information is distributed at the right time to the people working on tasks and the documents resulting from production are collected (Naedele et al., 2015).

To achieve a completely integrated and successful MES, important attention needs to be given to the modelling phase, this means: software architecture together with a specification of features. The complexity's growth of information systems and the concern about the optimization of software applications design encouraged scientists to establish some modelling methods (Sekkat, Kouiss, Saadi, Deshayes, & Deshayes, 2013). The object-oriented methods are the most appropriate tactics of development (Sekkat et al., 2013). The Unified Modelling Language (UML) is an OMG (Object Management Group) standard and is constituted by a group of diagrams. It is used for taking a specification of a software system (highlighting all requirements), detailing the structure, disintegrating into objects, and construing relationships between them. With UML software development teams can communicate among themselves (Cao, Jing, & Wang, 2008).

V.3 Practical Case: Study and Design of a MES

V.3.1 Context goals and methods

The case study in this article was carried out based on a company belonging to the chemical industry, whose business focus is flush toilets. Its production area has two zones, the injection and the assembly areas, the former becoming mostly the supplier of the second. The assembly area is the one that, until now, requires more human labour and where there is a greater flow of paper. In this way, the automation of the various stations and their proper sensing will allow the constitution of an MES information system capable of monitoring performance and carrying out processes that are currently executed manually, but which with the introduction of MES can be supported by the software.

The paper's main goal is to model, using the UML notation, an architecture MES system capable of supporting the processes of the assembly area of the company under study. For the modelling to be idealized in the most effective way possible, informal interviews and observation techniques were carried out on the factory shop floor. Also, before the final construction of the model was elaborated, the several fragmented data repositories (programs scattered across the manufacturing floor not connected to each other) were analysed and so that in the end a completely integrated solution could emerge.

V.3.2 Results and discussion

For the modelling, two types of diagrams were used, the class diagram and the use case diagram, which are part of the UML notation.

The use case diagram aims to highlight the features of the system and which actors in the process are allowed to access them. The class diagram is intended to represent the structure that the MES database should acquire, with all relevant data to be saved.

Considering the use case diagram (Figure 18) first, the assembly operator should be able to enter shop orders (“Enter shop order”), and immediately must add his employee number / number of all team members to the cell (“Insert operator allocated to the station”) where the manufacturing order will be produced. Thus, there will be tracking of who performed the assembly, something that will be necessary for a later performance analysis. Before all the production be launched, and in cases it is a workstation cell, the operator must validate all the components that are in the cell’s line edge (“Validate components at the work cell’s line edge”), using for that a code bar system.

When a station stops, the system issues a warning so that the justification of it can be done (“Stop justify warning”). Therefore, when possible, he must justify, accessing for that purpose a list of those stops that are missing justify (“View stops without justification”). Some of these justifications can be accessed by the machines’ PLC and put it automatically in the system.

After the shop order is completed, the assembly operator must confirm the production, with the record of the same, printed immediately afterward (“Print production log”). Note that the rectification functionality is present, for possible errors in the data (“Rectify production value”). The assembly team leader has the possibility to “Register work order requests”, which are sent as a warning to the maintenance so that it can proceed with the repair of faults. Also, he/she must be able to register kanbans (“Register kanban”), where, depending on the shop order he is working on, he can consult the components that make it up, before proceeding (“View components that make up the shop order”). Each time a kanban is registered, the dashboard of the Mizusumashi (cell supply train) is updated and whenever there is a batch construction of a missing item, the supplier's dashboard is also updated (with a batch construction notice right away). Both the assembly team leader and the area manager can consult performance reports for the stations, as well as consult non-conformity failures.

The Mizusumashi can, through its dashboard, visualize warnings of the cells (replacement or lack of components), active kanbans (to supply cells), which may suffer (through Mizu) changes in their status (active, inactive, supplied, for example). The supplier is also able to view orders that can be made to them (they are also kanbans but whose "type" attribute (in class diagram) varies, such as priority). The option to change status is also presented here so that the orders are being fulfilled.

The class diagram (Figure 19) brought together processes such as the use of kanban (signal card that controls production or transport flows in an industry), audits, quality control, work order requests for maintenance and even execution and planning of work, maintenance actions, whether routine or urgent. Added to this, the question of automatic records (Record table and Stops_Record), in order to save stops and even calculate cycle times, were safeguarded by the data structure.

Starting with the Kanban system, knowing that a shop order (ShopOrder table) has several components, each component (Component table) needed will correspond to a kanban (Kanban table) that, with the accumulation, will make batch construction (Batch Construction table), this already having a maximum number of pre-defined accumulation articles.

In the follow-up, it is important to emphasize that both audits (Audit table), as well as stop recording (Stop_Record table) and quality control (Quality_Record table), are connected to tables that function as information repositories (Audit_Bank, Stops_Bank and Quality_Bank). In this way, for example, to justify the reason for the stop, the user easily accesses a list of various reasons, leaving him only to select the most opportune one. The same is true with audits and quality control.

Each device has access to a maintenance plan (Maintenance Plan table), which consists of several actions (Maintenance Action table), carried out by operators. These same actions can be requested by work orders requests (Work Order Request table) that arise from possible failures that are associated with the Shop Orders.

It is essential to mention that in this structure, knowledge management was taken into account too, since a task repository (Tasks_Bank table) was associated. In this way, when carrying out any task, it will be possible to search for employees with the most favourable skills (since there is a connection between Collaborator and Tasks_Bank), as well as the steps of the same can be investigated (since there is a precedence situation as attribute in Tasks_Bank table). In addition to the class diagram presented with more granular data, it was necessary, for data about the performance of the stations to be saved, to create a view (Report –Figure 17) above the level of the data structure represented in Figure 19. In this view, data from Overall Equipment Effectiveness is saved, so that shift performance is easily accessed. Also included here, is data about the stops, which are divided into total stops, programmed and micro stops.

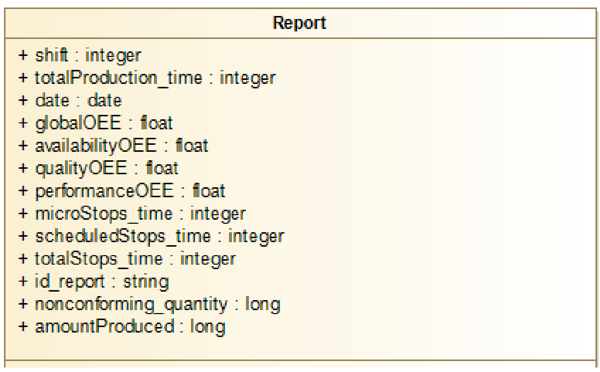

Figure 17- Report class diagram (View)

The MES's architecture presented in this paper offers an integration of the processes on the shop floor, decreasing in an abrupt amount the paper flow, which was previously used for example to signal station stops, for later calculation of OEE. With this approach, it is possible to establish a more continuous flow of information in the company, which originated almost in real-time.

The MES architecture and specification outlined here highlight some of the features previously considered to be crucial in such a monitoring system. They are the ability to support the saving of data in real-time (Real-time characteristic) (Arica & Powell, 2018; Coito et al., 2019), as well as its subsequent visualization (Visualization characteristic) (Arica & Powell, 2018) using analytics (Analytics characteristic), where performance indicators are calculated (OEE) (Govender et al., 2019). In this way, decentralized decision making (Decentralization characteristic) is possible to be sustained (Makarov et al., 2019). In addition, knowledge management is provided (Knowledge Management characteristic), with the possible distribution of relevant information at the right time and in the right place (through information repositories) (Naedele et al., 2015).

With this architecture, it is also possible to establish a vision of the digital twin of the shop floor, in which data from the equipment (mostly sensors and actuators) is collected and subsequently treated with a view to its monitoring and historical view (Park et al., 2020; Schmetz et al., 2020). In this way, it is possible to have a pre-structure capable of leveraging the first moment of the Smart Factory, which can be improved by artificial intelligence algorithms capable of predict future machines' behaviours.

The two major deficiencies of the production systems listed above, such as the capture of data in real-time and the existence of islands of information (Yao et al., 2019), are addressed in this approach, since all the processes in this section of production were previously mapped and integrated into the architecture. At the same time, the equipment with integrated sensors capable of generating data that was previously stored only on the machine's PLC was used. This is a basic software architecture for a factory floor, being able to be flexible to the introduction of other modules.

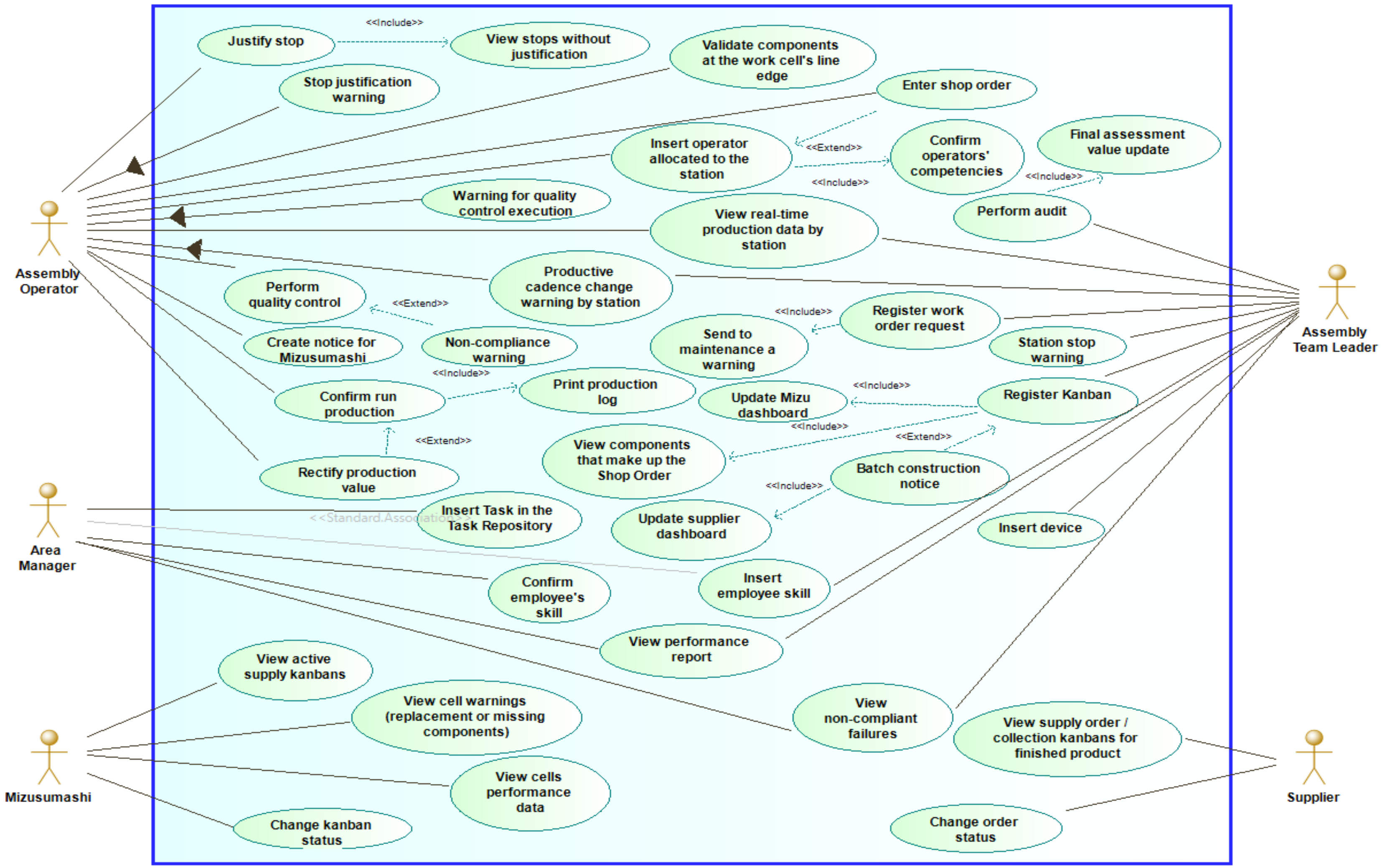

Figure 18- MES Use Case Diagram

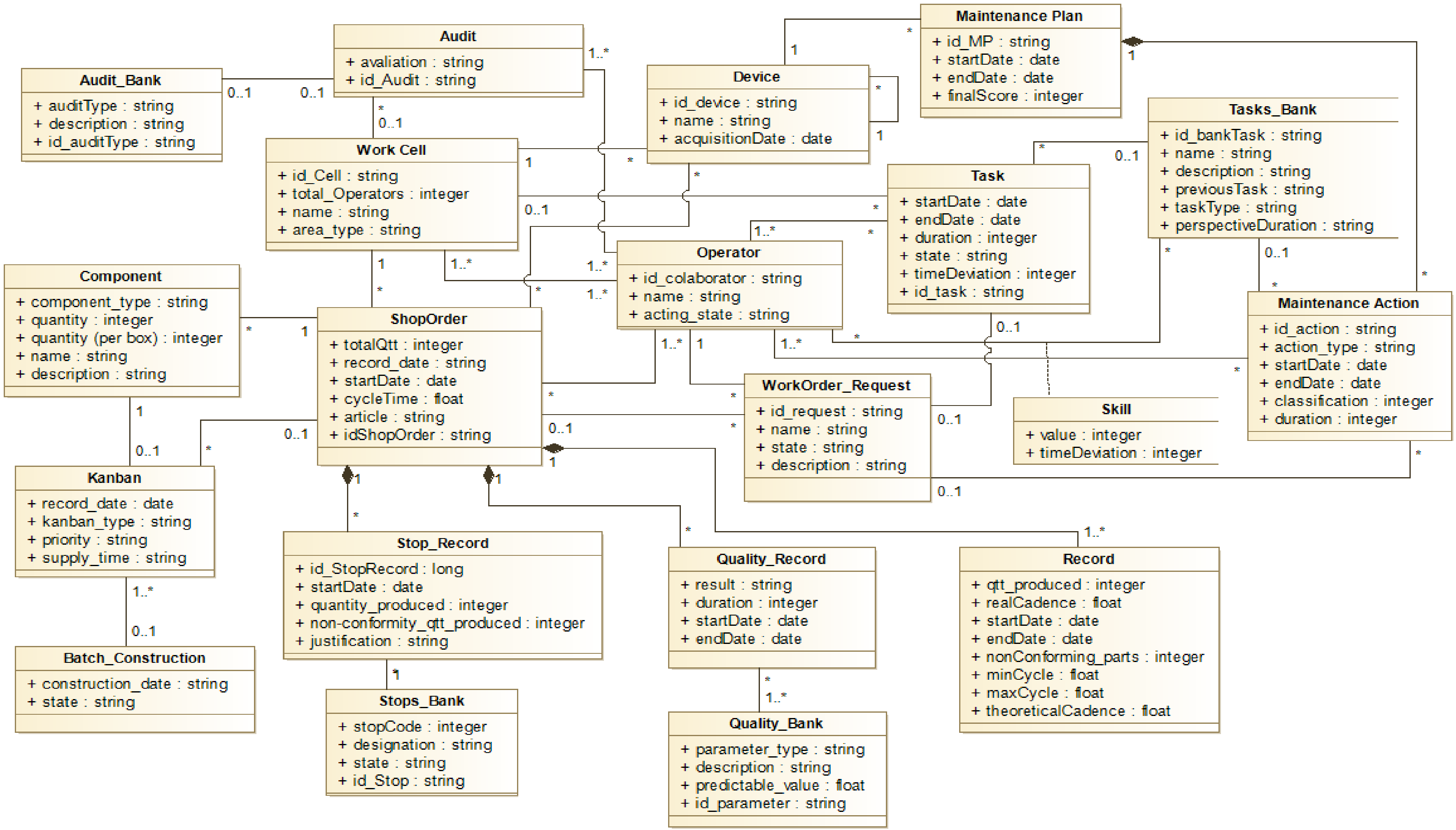

Figure 19- MES Class Diagram

V.4 Conclusion

The constant changes in the market have been asking companies to adapt their way of working and the consequent fever of the moment to apply I4.0 technologies. Information systems will be crucial in this regard as they will enhance the flow of information in the company promoting decentralized decision-making processes.

The modelling phase of an information system (using UML) appears to be one of the most essential tasks since the system requirements are designed so that all relevant processes are supported. Thus, and for the modelling to be properly idealized, previously a study focused on the company's processes was carried out, as was its mapping (using another language, the Business Process Model Notation).

A Manufacturing Execution System with the mentioned approach intendeds to solve the problem associated with the existence of fragmented and scattered sources of information on the factory floor. Thus, the creation of a data structure (through the UML class diagram) was essential in order to bridge this phenomenon and to acquire a broader view of what data sources a company owns and what use it can consequently make of them .

In addition, the same approach aims to solve the difficulty of establishing a software architecture capable of leveraging the concepts of Smart Factory and Digital Twin. It is suitable for the basic processes of a factory floor and facilitates the introduction of topics such as knowledge management and data visualization. The flow of information with an architecture of this type flows more easily through the company and decision making is easier and faster.

For future work, it is suggested to implement the above specification of MES and complete this approach with modules that answer to artificial intelligence methods capable of predicting possible anomalies in equipment, as well as the application of this architecture in another type of business structure, with a view to its generalized validation.

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Chapter VI- Storytelling with Data in the Context of Industry 4.0: A Power BI-based case study on the shop floor

Reference

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Storytelling with Data in the Context of Industry 4.0: A Power BI-based case study on the shop floor

Abstract

Industry 4.0 (I4.0) is characterized by cyber physical systems (CPS) and connectivity, paving the way to an end-to-end value chain, using Internet of Things (IoT) platforms supported on a decentralized intelligence in manufacturing processes. In such environments, large amounts of data are produced and there is an urgent need for organizations to take advantage of this data, otherwise its value may be lost. Data needs to be treated to produce consistent and valuable information to support decision-making. In the context of a manufacturing industry, both data analysis and visualization methods can drastically improve understanding of what is being done on the shop floor, enabling easier decision-making, ultimately reducing resources and costs. Visualization and storytelling are powerful ways to take advantage of human visual and cognitive capacities to simplify the business universe. This paper addresses the concept of "Storytelling with Data" and presents an example carried out in the shop floor of a chemical industry company meant to produce a real-time story about the data gathered from one of the manufacturing cells. The result was a streaming dashboard implemented using Microsoft Power BI.

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Keywords

Visualization, Storytelling, Industry 4.0, Power BI

Notes: This article is presented here in a more complete format than the one accepted by the conference, due to the word limit factor (in the literature background, another chapter is included, this being the one that refers to the integration of Business Intelligence and Knowledge Management concepts - VI. 2.2).

VI.1 Introduction

The Third Industrial Revolution (3rd IR) brought computers and automation to the manufacturing system. The Fourth Industrial Revolution (4th IR) adds to these two mechanisms the concepts of cyber physical systems (CPS) and connectivity (Hill, Devitt, Anjum, & Ali, 2017). Industry 4.0 (I4.0) is characterized by CPS, preparing the way to an end-to-end value chain, using Internet of Things (IoT) platforms supported on a decentralized intelligence in manufacturing processes. Connectivity is a key-factor in I4.0 environment, ensuring an automatic data collection, but in return responsible for the large amount of data present in most industrial environments that intend to embrace the challenge of I4.0 (Arromba, Teixeira, & Xambre, 2019; Miragliotta, Sianesi, Convertini, & Distante, 2018). In addition to these challenges, there is an urgent need for organizations to take advantage of this large volume of data; otherwise, the value of information will be lost. This data needs to be treated to produce consistent and valuable information to support decision making in organizations. Data science, a scientific approach that uses several mathematical and statistical techniques supported in computer tools for processing large amounts of data is becoming an invaluable area in I4.0 environments, since it can transform data into information and this is useful knowledge for the business. In addition, big data integrated with agile information systems can promote the solutions to convert those data in valuable information (Arromba et al., 2019) improving at the same time the organization's capacity in response to internal, organizational and environmental changes in real-time (Chaudhary, Hyde, & Rodger, 2017).

According to Narayanan and Kp (Narayanan & Kp, 2019) "For a business to exist competently, the two things to keep up are: the management of time and better understanding of current status of the organization". Behind these issues is the importance of data visualization. In the context of a manufacturing industry, both data analysis methods and data visualization methods can drastically improve understanding of what is being done on the shop floor, thus enabling easier decision-making, ultimately reducing resources and perhaps costs. In fact, the human brain is an expert in memorizing data as images, so data visualization is just a clever idea to uncomplicated the business universe (Narayanan & Kp, 2019).

On the other hand, business intelligence (BI) is defined as "automatic data retrieving and processing systems that can help make intelligent decisions based on various data sources" (Choi et al., 2017). Most of the BI solutions offer data analysis and data visualization which with the correct data capture technology should be able to treat data in real-time (Pribisalić, Jugo, & Martinčić-Ipšić, 2019). Some of the advantages of using BI tools are denoted by Stecyk (Stecyk, 2018) as the ability of linking to any data source, building up analyses in real time and having an intuitive and straightforward interface that helps in data visualization. However, to obtain this, some areas of knowledge need to be consistent and strong such as the ability to get data from a variety of sources, the aptitude to properly structure and relate the database and techniques about building key indicators (economic or performance) as well as dynamic reporting (visualization techniques)

(Stecyk, 2018). In addition, it is common sense that "the communication of information is an important capability of visualization" (S. Chen et al., 2015) and recently, literature has laid eyes on the new concept, more specifically the "Storytelling with Data" concept. This concept refers to a set of processes and mechanisms that help organizations to prepare multifaceted information, based on complex sets of data, with the purpose of communicating a story [9], including the arrangement of three elements: data, visualizations and narratives (Pribisalić et al., 2019). To address these issues, companies can use BI tools, but before it is important to choose the correct amount of information to deliver a message and adding to that the techniques that should be applied to produce story-like statements (S. Chen et al., 2015).

One of the open source BI tools referred to in the literature that allows achieving these objectives is the Microsoft Power BI, representing a tool gifted to create "shareable and customized visualizations to communicate data-based stories" (S. Chen et al., 2015), while providing visibility of the information flows (Arromba et al., 2019).

In nutshell, despite the potential advantages in implementing the phenomenon of I4.0, organizations must be prepared to deal with the huge amount of data that IoT will bring. In addition, for that to happen it is essential that information flows be cleared and organized between all the departments in organizations. After that work done it is possible to implement BI tools in order to visualize what is going on in the shop floor. Considering these concerns, this paper intends to clarify the "Storytelling with Data" concept based on a literature review, and at the same time, pretends to describe methods and results carried out in a manufacturing company's shop floor, in order to implement the above concept. The study will be conducted in a chemical industry enterprise and the last goal set is to have a real-time story about the data that is gathered from one of the manufacturing cells. To tell this story we will have a streaming dashboard implemented by a BI tool, the Microsoft Power BI.

VI.2 Background

VI.2.1 Industry 4.0, Cyber Physical Systems and Digital Twin

Industry 4.0 principles are governed by the interconnection and transparency of information for decentralized decision making (Soujanya Mantravadi & Møller, 2019), requiring for that the combination of sensors, artificial intelligence, and data analytics (L. Da Xu et al., 2018). This concept relies on the idea of combining optimized industrial processes with cutting-edge technology and digital skills and is the promotor of 'Smart Factory' or 'Factory of the future', concepts that are becoming the ambition of any enterprise. (Savastano et al., 2019). Giving the concept behind smart factory and taking into account that it is still a utopia for many, it is important to understand the prerequisites to enable the smart in 'Digital Factory' (Soujanya Mantravadi & Møller, 2019). According to (Salierno, Cabri, & Leonardi, 2019), digital factory "refers to a new type of manufacturing production organization that simulates, evaluates and optimizes the production process and systems". While the Digital Factory provides tools for planning in Virtual Reality, the Smart one operates and optimizes the factory in real-time.

Information systems will be pivotal to achieve the vision of "real-time enterprise", remembering that they are "made of computers, software, people, processes and data" (Soujanya Mantravadi & Møller, 2019). These components plan, organize, operate and control business processes (Qu et al., 2018), so they are pivotal in the integration of information flow.

Cyber physical systems are at the core foundation of Industry 4.0 and they intertwine physical and software components, each operating on different spatial and temporal scales. At the same time these components interact with each other in a multitude of ways that change with context (L. Da Xu et al., 2018).

The shop floor is the basic element of manufacturing, so the convergence between the physical and the virtual space becomes imperative (Tao & Zhang, 2017).

As mentioned by Qi (2018) "The digital twin paves the way to cyber-physical integration". This concept aims to create virtual models for physical objects in order to understand the state of these physical entities through sensing data (allowing predict, estimate and analyse dynamic changes). Thus, it can be also assumed as a real-time representation of manufacturing systems or components (Zhu et al., 2019).

This concept incorporates dynamic and static information, where data is transferred from the physical to the cyber part (Schroeder et al., 2016). The data in digital twins are composed by physical world data as well as virtual models (Qi & Tao, 2018). Digital twins combine and integrate data from multiple sources in order to achieve a more accurate and comprehensive information (Tao & Zhang, 2017).

The digital twin is a prerequisite for the development of a Cyber-physical Production System although some difficulties must be overcome, such as data security concerns, standardization of data acquisitions, high costs for new IT-environments that inhibit the application of vertical industry 4.0 and the creation of a central information system which can be combined with decentralized data acquisition (taking into account that in-house implementation of industry 4.0 is frequently insufficient) (Uhlemann, Lehmann, & Steinhilper, 2017).

VI.2.2 Business Intelligence and Knowledge Management: the importance in Industry 4.0

The Business Intelligence (BI) is a concept defined as "a set of concepts and methodologies designed to improve business decision-making by using fact-based systems" (as cited in Stecyk, 2018). However, it is assumed in the literature that BI systems used by business analysts or else by the decision makers with analytical knowledge, allow the effective and rational gathering and examining data, significant for the main business goals of the company (Stecyk, 2018).

In the I4.0 context, data is everywhere in companies and the ample management of this data is expensive. BI is under the hat of industry 4.0 as a tool to collect a big amount of information from different sources and then make valuable analysis from this information and processing (Lopez, Segura, & Santó, 2019).

Knowledge Management is a tactical tool which allows the building of Intellectual Capital (IC) information within an organization. It consists in a technique of searching, acquiring, managing and transferring information and knowledge in organization (Surbakti & Ta'A, 2017).

The combination of data and information to which is added expert opinion, skills and experience is called knowledge (Bosilj-Vukšić, 2006). It can be explicit or tacit, being the second one the knowledge that is its origin and it is applied in the minds of the owners of knowledge. This type is difficult to communicate, share and put into a document or database. On the other side the explicit one is typically structured and retrievable, and should often being in repositories, embedded in documents, organizational routines, processes, practices and norms (Bosilj-Vukšić, 2006; Kalpič & Bernus, 2006; Kovačić et al., 2006).

As cited in Ebrahimi, Ibrahim, Razak, Hussin, & Sedera (2013), an organization's competitiveness depends on its specialized knowledge, its diversity and the way it is integrated effectively in the company.

Big data is viewed by academics as the new "oil" that extracted and refined can be intelligently used to sustain and maintain the organization's competitive advantage (Kamoun-Chouk et al., 2017).

The science of data is the new tendency where expertise is needed to convert a raw resource into something of value since what is obtained from the field is never in a valuable form. In the 21 century that professional "data scientists" appear as an enormous necessity since knowing how to make sense of big data is the new competency at the moment (Kamoun-Chouk et al., 2017).

Knowledge based organizations consider business intelligence as a pillar in the organizational structure (Surbakti & Ta'a, 2016). In an organization that uses both knowledge management system and business intelligence, the first one focuses in explicating tacit knowledge, while the second one concentrates on analytics based on explicit knowledge (Kamoun-Chouk et al., 2017; Surbakti & Ta'A, 2017).

If organizations can capture the tacit knowledge of their operators and make proper use of it, better information will have to be analysed. The combination of business intelligence (BI) and knowledge management (KM) can lead to creation of extremely valued intellectual capital (Surbakti & Ta'A, 2017). Above that, the lack of knowledge sharing among employees and management produces disappointment provoking to misunderstandings and inefficiencies. BI and KM together can actually put emphasis on employee's empowerment, increasing retention and weakening the high rate of employee turnover (Surbakti & Ta'a, 2016).

VI.2.2 Business Analytics, Visualization and Storytelling

Business analytics and business intelligence are assumed, in the Industry 4.0' context, as areas that can actually help to increase productivity, quality and flexibility. The importance of making quick and right decisions is even more fundamental for efficient and effective problem solving and process upgrading (Schrefl et al., 2015). Today these two-knowledge fields have been valorizing the real-time production data, having influence in decision making (Bordeleau et al., 2019).

Business analytics is a field which goal is to measure the company's performance, evaluating its position in the market and at the same time find where there is a need for improvement and what strategies should be carried out (Raghav, Pothula, Vengattaraman, & Ponnurangam, 2016). For that, statistical, mathematical and econometric analyses of business data need to be done in order to support operational and strategic decisions (Raffoni, Visani, Bartolini, & Silvi, 2018).

Visual analysis tools are assumed as technology products that combine information from complex and dynamic data in such a way that support evaluation, planning and decision making (Poleto, De Carvalho, & Costa, 2017)

The understanding and the communication of information is supported by visualization that allows the abstraction of raw data and complex structure (Morgan, Grossmann, Schrefl, & Stumptner, 2019). Therefore, data visualization is concerned with methods to obtain appropriate visual representations and interactions which accept users to understand complex data and confirm assumptions or even examine streaming data (Thalmann et al., 2018) Visualization is seen as a significant tool in many areas for clarifying and even perceive large and complex data (Zhou et al., 2019) and affords the user to obtain more knowledge about the raw data which is gathered from a diversity of sources (Raghav et al., 2016).

Although visualization plays an essential role in providing insights on real-time data, this may not be the exact solution for analysing a large volume of data, as an adequate data extraction process must be carried out (Raghav et al., 2016). In the industry 4.0's context, where the big data concept carries a huge weight, the main goal of big visualization is to acknowledge patterns and correlations (Ali et al., 2016). Newly, visual storytelling is receiving attention from the academic community, where authoring tools have been developed in order to create stories and provide visual support [9]. The entire process of modifying data into visually shared stories includes exploring the data, passing it into a narrative and then communicating it to an audience (B. Lee, Riche, Isenberg, & Carpendale, 2015). Stories offer an effective way of stowing information and knowledge and make it easy for people to perceive them (Kosara & MacKinlay, 2013). There are already many communities that emphasize the importance of storytelling in data visualization (Tong et al., 2018) and this concept has also captivated significant interest in visual analytics. Texts and hyperlinks connecting to bookmarked visualizations can constitute a story which can embrace also graphical annotations (S. Chen et al., 2015; B. Lee et al., 2015). It is assumed that visual storytelling can be critical in contributing to a more intuitive and fast analysis of broad data resources (Segel & Heer, 2010). Even in the scientific approach, the storytelling concept urges as scientific storytelling, which means telling stories using scientific data. Visualization is used in academia to validate experiments, explore datasets or even to transmit findings, so if properly done, such visualizations can be highly effective in conveying narratives (K.-L. Ma, Liao, Frazier, Hauser, & Kostis, 2012).

The Microsoft Power BI software is a business intelligence tool where visualization seems interactive and rich, allowing the creation of dashboards in matter of minutes. Although there is the option of running a R script, the software doesn´t require programming skills. The program is able to connect to various data sources in order to extract and transform them, creating information. (Ali et al., 2016).

Currently and as evidenced by Gartner's Magic Quadrant, the Power BI software has assumed the first position in the ranking, since February 2019, ahead of Tableau, which until then was recognized as the most used tool within the subject of business intelligence[1].

In the next sections an example developed using Power BI is presented that used a Drill-Down Story allowing the user to select among particular details, putting more attention on the reader-driven approach (Segel & Heer, 2010).

VI.3 Construction of a Dashboard Reflecting a Manufacturing Cell

VI.3.1 Context Goals and Methods

The case study presented in this article was carried out at a company whose production focuses on flush toilets. Belonging to the chemical industry, its production is divided into two sectors, injection (made up of several injection molding machines) and assembly (made up of several cells that cover different parts of the flush toilet). In the assembly area, there are numerous manufacturing cells where automation can effectively make a difference. The currently most automated one, having data capture through IoT mechanisms, is the tap cell. The data acquired in this cell do not have any meaning to the decision-maker; yet they may produce potentially relevant information.

The goal of this case study is the construction of a dashboard where it is possible to view the manufacturing cell data in a way capable to help understanding the actual production state and

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1 https://powerbi.microsoft.com/en-us/blog/microsoft-a-leader-in-gartners-magic-quadrant-for-analytics-and-bi-platforms-for-12-consecutive-years (visited, Jan, 2020)

thus support decision-making. It uses data analysis and visualization techniques, as well as storytelling.

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.

It is important to denote that the process of creating the dashboard application involved three representative company divisions (actors), namely, the data analyst, the IT technician and the head of continuous improvement. These three types of users contributed to understand the dashboard requirements, as well as what advantage would be derived from the use of this streaming data to assist in decision making.

VI.3.2 Result with some Software Dashboard Interfaces

Concerning the dashboard application, it was created following a user-centered approach. Figure 20 presents the first dashboard menu, where the user can choose among viewing station stops, cadences, actual production and efficiency levels of the station.

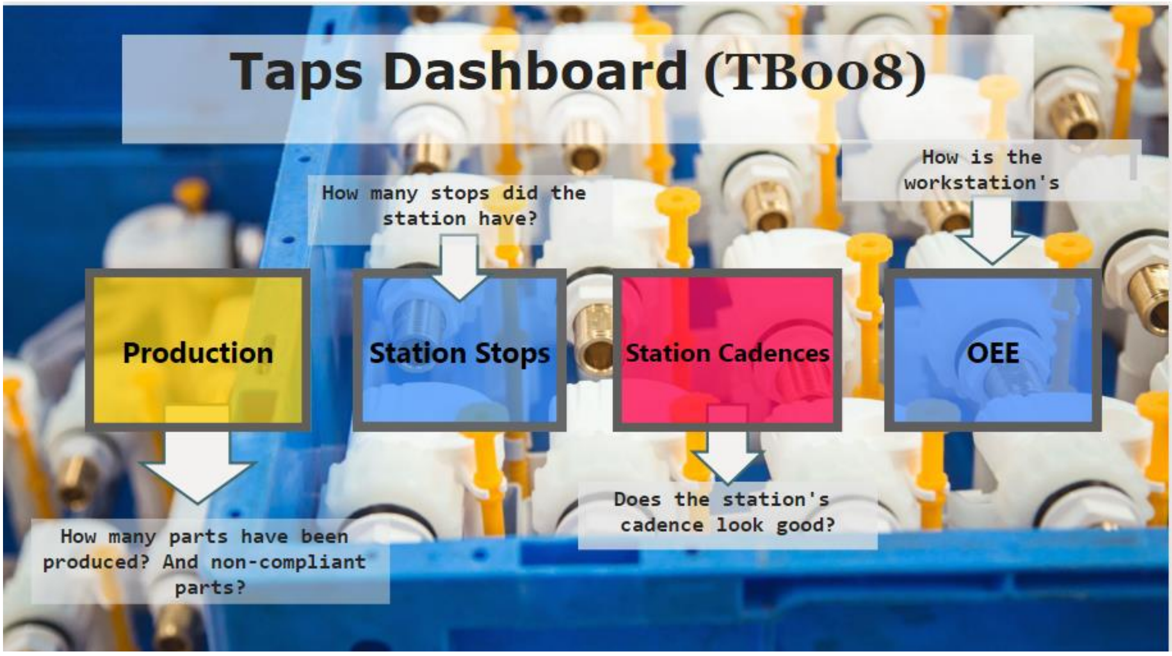

Figure 20- Dashboard Menu

In the “Production” (Figure 21) bookmark the user can find the total amount of parts produced by the station and the total number of non-compliant parts. Once more, there are two filters, one is the date and the other is the product family.

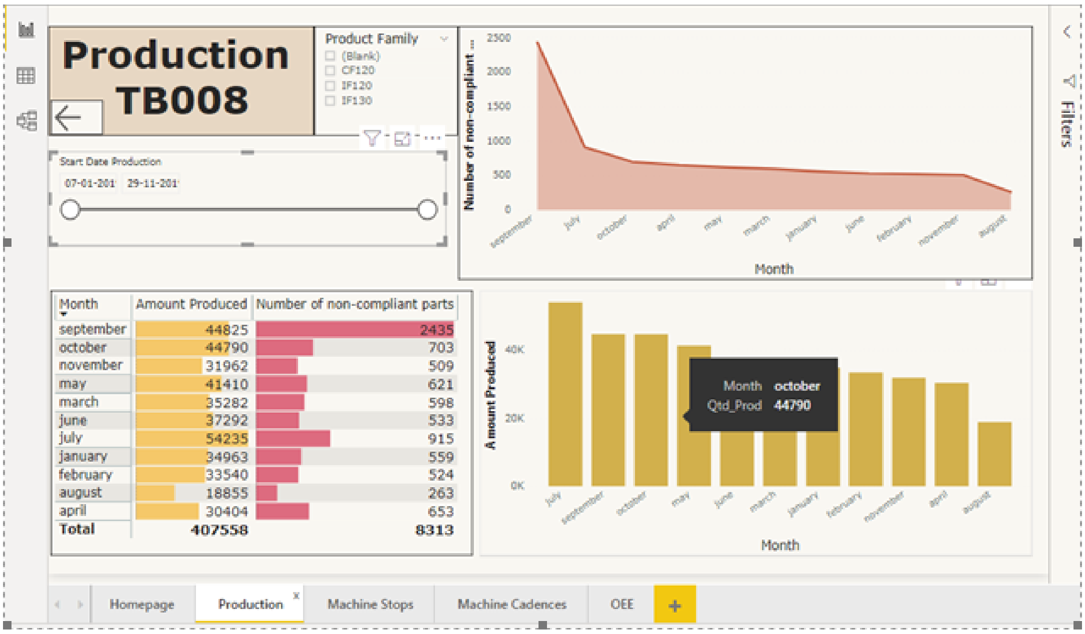

Figure 21- Production Bookmark

In the “Station Stops” (Figure 22) bookmark is possible to visualize the total number of stops at the station, the total number of scheduled stops, micro stops and the total time available for production. The analysis can be filtered according to the date and product family chosen by the user.

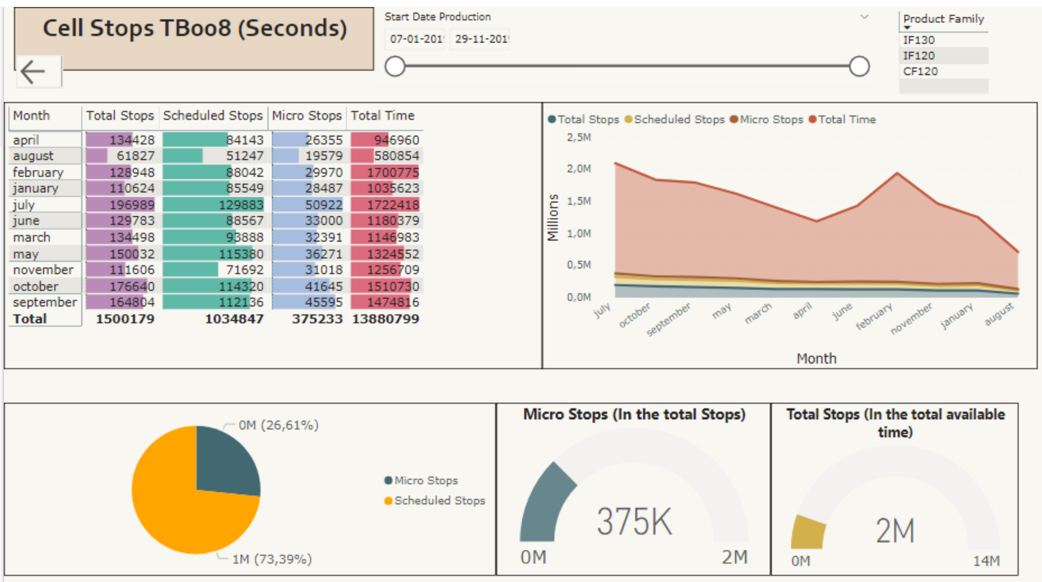

Figure 22- Station Stops Bookmark

The “Station Cadences” (Figure 23) is another bookmark where the real cadence and the theoretical one can be compared.

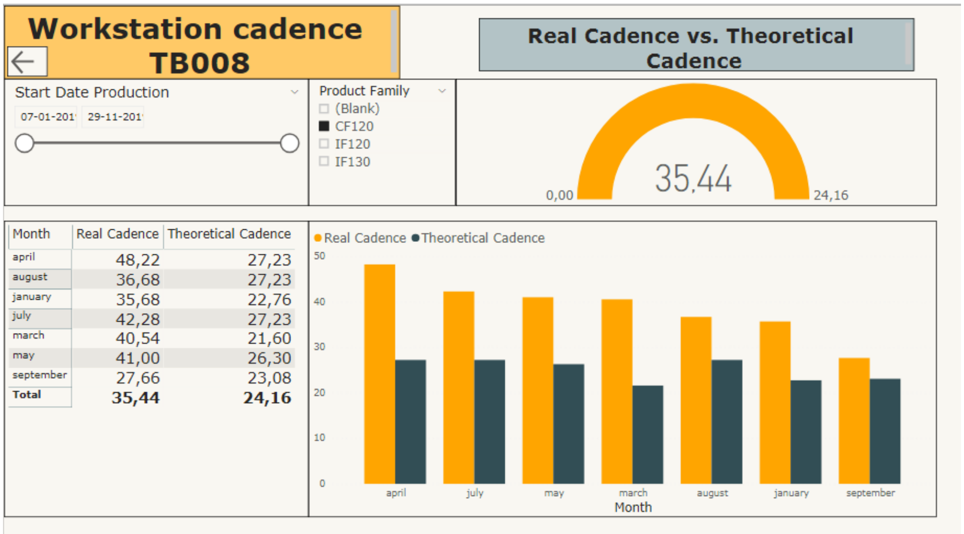

Figure 23- Workstation Cadence Bookmark

The final bookmark “OEE” (Figure 24) 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). Filtering it is also possible using date and product family (Figure 24).

Figure 24- Overall Equipment Effectiveness Bookmark

VI.4 Final Remarks and Future Work

The created dashboard allowed showing an informative overview to the user in order to facilitate the interpretation of the data resulting from the cell's production. Power BI proved to be a tool capable of representing data visually "telling a story" about how the cell is operating that can be easily understood by the user providing insights into the cell's activity.

More and more, particularly in the context of industry 4.0, the use of data becomes essential in order to bring value to the organization and easy decision making. The introduction of IoT mechanisms on the shop floor brings the need to take advantage of the data collected, using data visualization, data analytics and, more recently, storytelling tools. The ability to convey information in a more perceptible way has become a concern, considering the numerous resources and data sources scattered throughout the manufacturing space. Expertise in data processing and visualization is currently one of the foci of hiring companies and software such as Power BI facilitates these activities since they appear to be intuitive and accessible for people without advanced programming skills.

As future work, there is a need to test the dashboard with other types of users in order to evaluate it as a proof of concept, as well as to extend the dashboard to other manufacturing cells, so that operators in the shop floor can have better understanding of the data and of the complete manufacturing process. The application of the dashboard on the shop floor will allow acting in real time in the face of errors or discrepancies that may occur along the processes.

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Chapter VII- Discussion, final considerations, and future work

VII.1 Discussion

VII.2 Final considerations

VII.3 Limitations of the study and future work

VII.1 Discussion

The present dissertation had the major purpose of looking for foundations that help to answer the research question " **Q: What mechanisms should organizations adopt in order to establish (first in the shop floor) the context of Industry 4.0?**". The research procedure started with the literature review which permitted the creation of a theoretical basis to understand the problem domain, allowed to acknowledge the best techniques to better conduct the study, constituting the rigor cycle which was demonstrated in the methodology. Besides, the specific research questions originating from the disintegration of the general research question were created based on knowledge of the literature review.

The first scientific work appeared with the exploratory intention of understanding the state of the manufacturing industry, having concluded that most of the companies' shop floors are based on lean techniques and/or principles. 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 thus, 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. It was possible to verify that the contribution of I4.0 to lean was at an advantage, because of the number of works developed. For this reason, the second work appeared, built on a more methodical approach.

The second scientific work, based on a systematic review of the literature, confirmed once again the disproportion of works in relation to the integration between Lean and I4.0. Therefore, there is a greater number that relates the contribution of I4.0 to Lean. A matrix whose axes represent the technologies and/or practices of each of the concepts was established to highlight 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. A lean gap was also emphasized, since in the literature it is assumed that there is an enormous difficulty in integrating data analysis in Lean tools and using it in the perspective of monitoring the improvement actions implemented. With the introduction of I4.0 and the establishment of lean 4.0 tools this is no longer a problem. 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.

However, the application of technologies should not be frivolous and that is why the third work arises, where the importance of 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. For this reason, Business Process Management, already recurrent in the analysis of processes, was applied, using BPMN, 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.

Thus, the fourth work arises, and it was based on 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. The design of the MES system also included knowledge management, thus creating, now, a basis for the installation of a knowledge management system 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.

With a view to representing these same KPI's, finally, the last work appears, which uses 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 used 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 intends, in a "storyteller" way, to bring to the context of data visualization the display of indicators in a more precise and oriented way.

VII.2 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 analysing 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 25 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.

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.

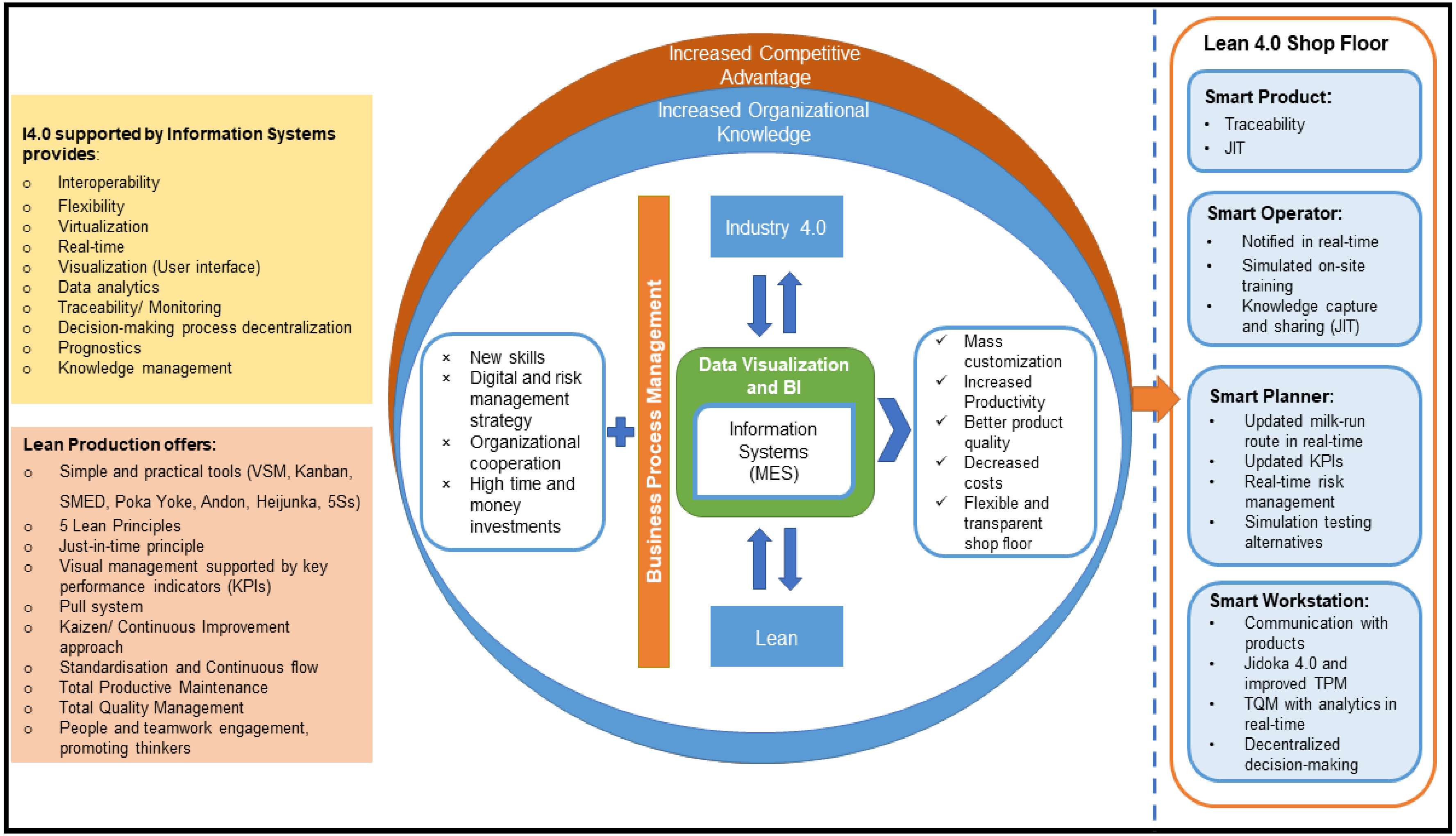

Figure 25- Artefact: Framework for a Lean 4.0 Shop Floor

VII.3 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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Supporting references of Chapter I and Chapter VII

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Appendix I- Chapter IV

In addition to the two diagrams presented in the Chapter IV, others were also developed for the different members of the company's shop floor. Thus, it follows the respective specification for each of the displayed diagrams.

Beginning with the **Injection Area**, the process starts with the execution of the Daily Mold Change Plan (DMCP) by the planning department (version 0). This plan is received by the Operator, Team Leader, Injection Technician and Fifth Element. It should be noted that the diagram referring to the injection technician member has already been presented above in the content of the article.

Figure 26 exhibits the working instructions of the fifth (5^{th}) element. The 5^{th} element has the task of creating the Shop Orders (SOs) in both MES and ERP. Then a sequence of documents must be printed, which are SOs, DMCP's and Start-Up Validation Sheets (which injection technician must complete). In addition to these documents, IF's (Inspection Forms in progress) that are used during the dimensional, visual and functional self-control performed by the operator on the parts injected by the machines allocated to him must be added. After all the papers being grouped by sectors, the 5th element distributes everything on the shop floor. If there are more DMCP versions during the shift created by planning department, the 5th element should assess what changes have been made and, if necessary, replicate the procedures mentioned above, so that the shop floor it is aware of the update.

Figure 27 displays the diagram referred to the injection operator. This element mostly interacts with the injection team leader and with the injection technician. Right at the start of the shift, the operator has access to the DMCP at the daily kaizen meeting and after analysing it, he must perform the autonomous maintenance indicated for the start of the shift. During the shift, the most widespread tasks are monitoring the machines (using the Andon lights), supplying the blue boxes with the parts injected by the machine and preparing and helping with change mold dies (to switch the shop order to be produced).

Injection machines are put to work in automatic mode and, in addition, they are not programmed to stop after a specific number of injected parts. Therefore, during monitoring, the injection operator must go to the several machine variable programming screens and pay attention to the value of parts already injected. If this value is lower than that verified in the shop order, no interference is necessary, and the general monitoring and supply of the blue boxes continues. Although, if the value is equal to the shop order or higher, the next step is to turn off the machine on the screen and then declare the production's value on MES. If the production's value is higher than that of the shop order, the operator has to incur in an intermediate step which is to change the number of pieces of the shop order in the ERP software and only then declare the finished production in the MES system (the ERP does not accept the production if this step does not occurs). Then, it is necessary to prepare the mold die change so that the injection technician can execute it without fail. It should be noted that the operator has the task of assisting in this process and as such does not return to monitoring the machines without completing the all mold die change procedure.

There is also the exception of having to declare production at MES whenever they manage to supply a pallet of blue boxes to logistics department so that stock is not kept in transit on the shop floor.

At the end of the shift, the operator must perform the autonomous maintenance indicated for the defined time of the day, as well as the 5 S's of his station, so that the shift change can be carried out quickly.

Figure 28 shows the injection team leader route at the shop floor**.** The team leader is usually notified by two entities, injection operator or injection technician. Whenever it is the operator to notify (mostly because of machines' problems), the team leader must go to the machine that is causing problems and try to solve it, if this is not possible, but he can check the cause of the damage, he is free to open an action request right away to the maintenance department. If he is unable to resolve or perceive the underlying cause of the problem, the injection technician is notified and proceeds to the due analysis concluding the reason for the failure. If necessary, inform the team leader to proceed with the execution of the action request for maintenance department.

From here there is a divergence, because if the cause is in the mold die, then the notification of the action request is directed to the Molds Workshop, on the other side, if the cause is of the machine or peripheral equipment, then the notification is forwarded to the Maintenance Workshop.

At the Molds Workshop, the problem is evaluated and if it is necessary to remove the mold die from the machine, the planning department is informed so that it is decided whether the next mold change is carried out or if there is a need for a new DMCP. If the problem is solved with the mold die inside the machine, after being resolved, the production continues.

At the Maintenance Workshop, it is evaluated whether it is possible to solve the problem soon or if the machine will have to be unavailable. In the second case, the planning department must be immediately informed so that a new DMCP can be idealized with minimal production losses.

It should also be noted that when there are problems in the machines or in parameterization of the variables that cause non-compliance, it is necessary that between the team leader and the operator these are declared in the MES system, and when there is doubt about this declaration (because, for example there are many parts and there is not enough time to choose them) the quality department is notified and it assesses whether the last production should be forwarded to the Wait Decision Area, where later it will suffer the due choice.

The **Assembly Area** consists mainly of the Assembly Team Leader, the Assembly Operator, the Supplier and the Mizusumashi, who supplies the different cells where are the operators.

Figure 29 illustrates the Assembly Team Leader working instructions. When starting the shift, the team leader must update the indicators on the kaizen board, as well as perform the layout of people by the workstations (still on the kaizen board). If the team leader of the previous shift is not in the kaizen board position, it is necessary to wait for him for the shift change to proceed with the identification of the main problems that have occurred.

Then, the team leader meets with the operators at the Kaizen Daily Meeting and, afterwards, each one goes to the respective workstations. It is up to the team leader to monitor and evaluate the production status of the cells allocated to him.

With the shop orders in progress, the monitoring and updating of the cell tracking chart board must be carried out (production forecast data, actual production and number of non-compliant). It is also the role of the team leader to audit the cells (integrated health and safety management system evaluation, assessment of the cell line edge supply and respective assembly instructions and, if cells are in flow with injection machines, one more audit has to be done concerning the change mold die). If audits turn out to be negative, the area manager is informed. The control of how much is produced in each cell must be continuously marked on the planning paper sheets, so that, in case the shift ends, the current production is available. The levelling board must also be updated with the query's and variable tags (documents that Mizu collects and that act as a “shopping list” that the mizusumashi must supply- they have the bar codes of the components so that it is easier shipping), as well as the shop orders’ prints that are subsequently taken by Mizusumashi to the respective cell. The OEE paper sheets are converted to excel by the team leader. When a cell is in flux with an injection machine, the DMCP for injection technicians ends up being carried out by the assembly team leader who, through consulting his planning paper sheet, creates the work orders for mold die and inserts change. At the beginning of the shift, the injection technicians receive the DMCP paper constituted by work orders and only have to accompany them (the same as in the injection area).

In case of a device or injection machine failure, a work order is created for maintenance department. Even after the creation of the work order, the team leader calls for maintenance department, in order to streamline the notification process of the injection technician area. In the event of absenteeism, it is necessary to notify the area manager, to proceed with the evaluation of people available to replace. In most cases, it is essential to inform the planning department to consider whether to stop a cell or adjust production planning. When the problem reveals the lack of supply of a cell by the logistics, then the team leader is free to call the logistics team leader to inform about the occurrence. After that, he must wait for the supply by Mizusumashi.

At the end of the shift, it is extremely important to ensure the execution of the 5 S's in all cells and pass the shift to the next team leader.

Figure 30 refers to the Mizusumashi diagram. The Mizusumashi is the cell supplying train and, when the shift starts, it must check the notes made by the previous shift in the query's hanging on the different Mizu carriages (carriages are identified for each cell, with one carriage supplying one and only one cell). If it is necessary to supply the train, then the Mizu operator must look for materials at the Mizu supermarket. If it is impossible to supply due to component failure, the operator normally writes the missing reference on a white paper and places it on the sequencing board for the supplier.

The Mizu route is then executed and at each stop in a cell, the operator must perform tasks, such as filling the line, removing empty boxes and documentation from the levelling board if it exists, stacking boxes of finished product on the pallet (if applicable) and, if full, collect the finished product card from the operator and place it in the respective sequencing board for collection.

When there are empty boxes to be collected in the cell line edge, Mizu operator must remove the kanban that is brought with them and subsequently introduced into the batch construction board. If the batch is made, the set of batch kanbans must be, by the Mizu operator, wrapped in a rubber band and deposited in the sequencing board.

Due to the workload, it is only at the end of the shift that the Mizu operator usually declares consumables in the ERP, using for that the query's bar codes.

Figure 31 displays the Supplier working instructions diagram. The supplier's role is to supply the Mizusumashi' supermarkets, collect pallets of finished products and empty boxes.

The sequencing board features several types of cards: kanbans of fixed position products, kanbans of variable products, cards for finished products' collection and empty boxes' collection and query's.

As for products with a fixed and / or variable position, the supplier must collect materials from the logistics warehouse shelves and then supply Mizusumashi' supermarkets. Both when supplying Mizusumashi' supermarkets and when collecting the finished product from the operator, it is necessary to carry out the code transfer of the components.

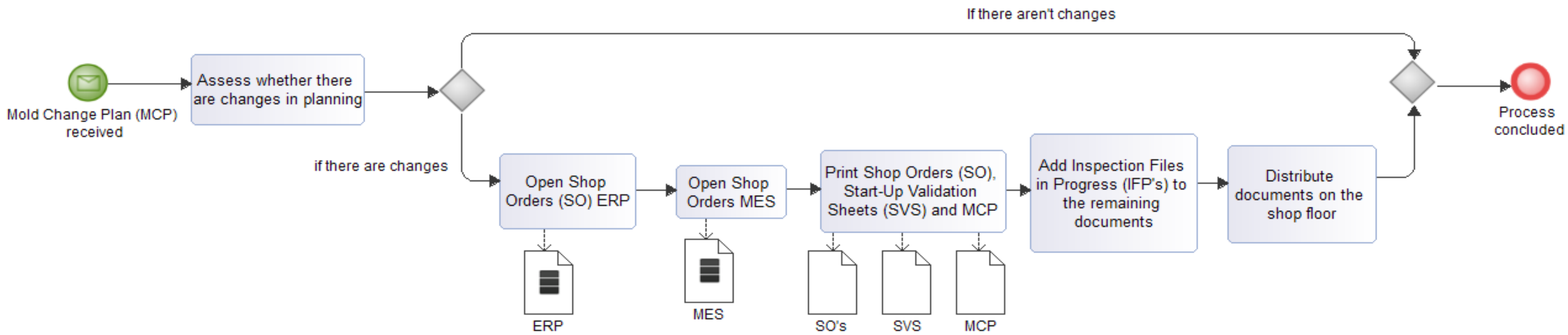

Figure 26- Map of Fifth Element working instructions based on BPMN 2.0

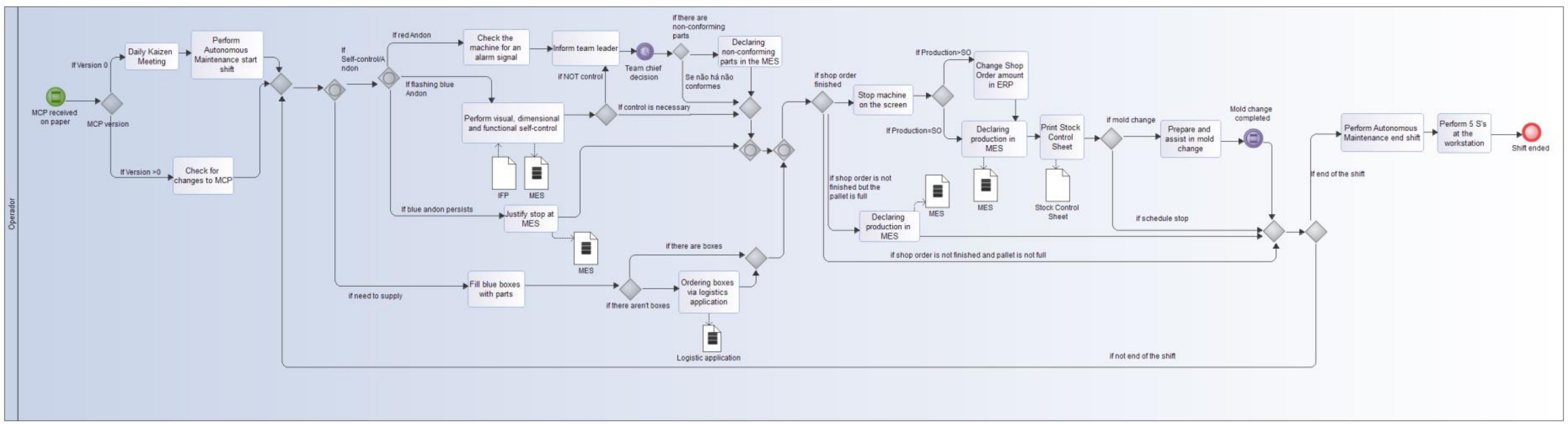

Figure 27- Map of Injection Operator working instructions based on BPMN 2.0

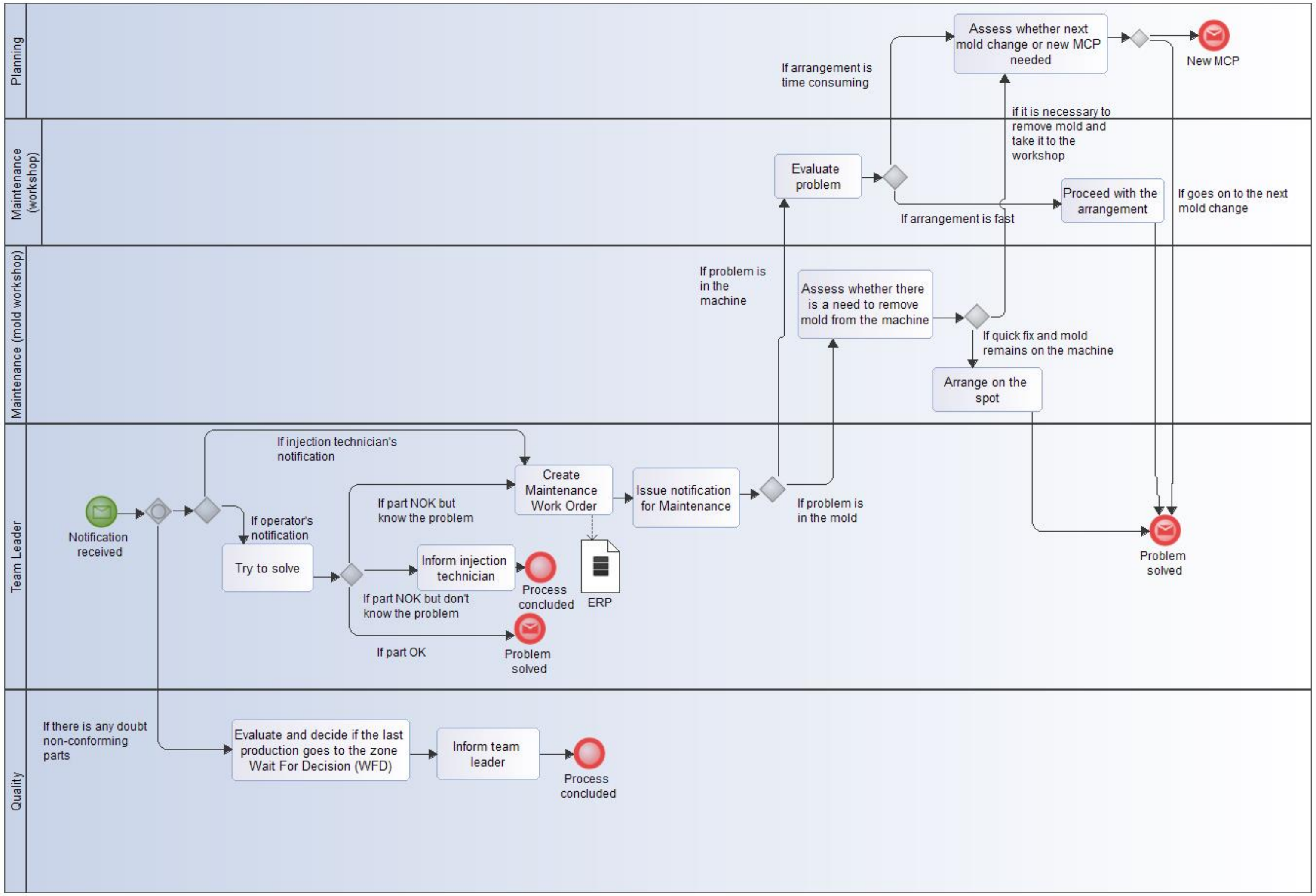

Figure 28- Map of Injection Team Leader working instructions based on BPMN 2.0

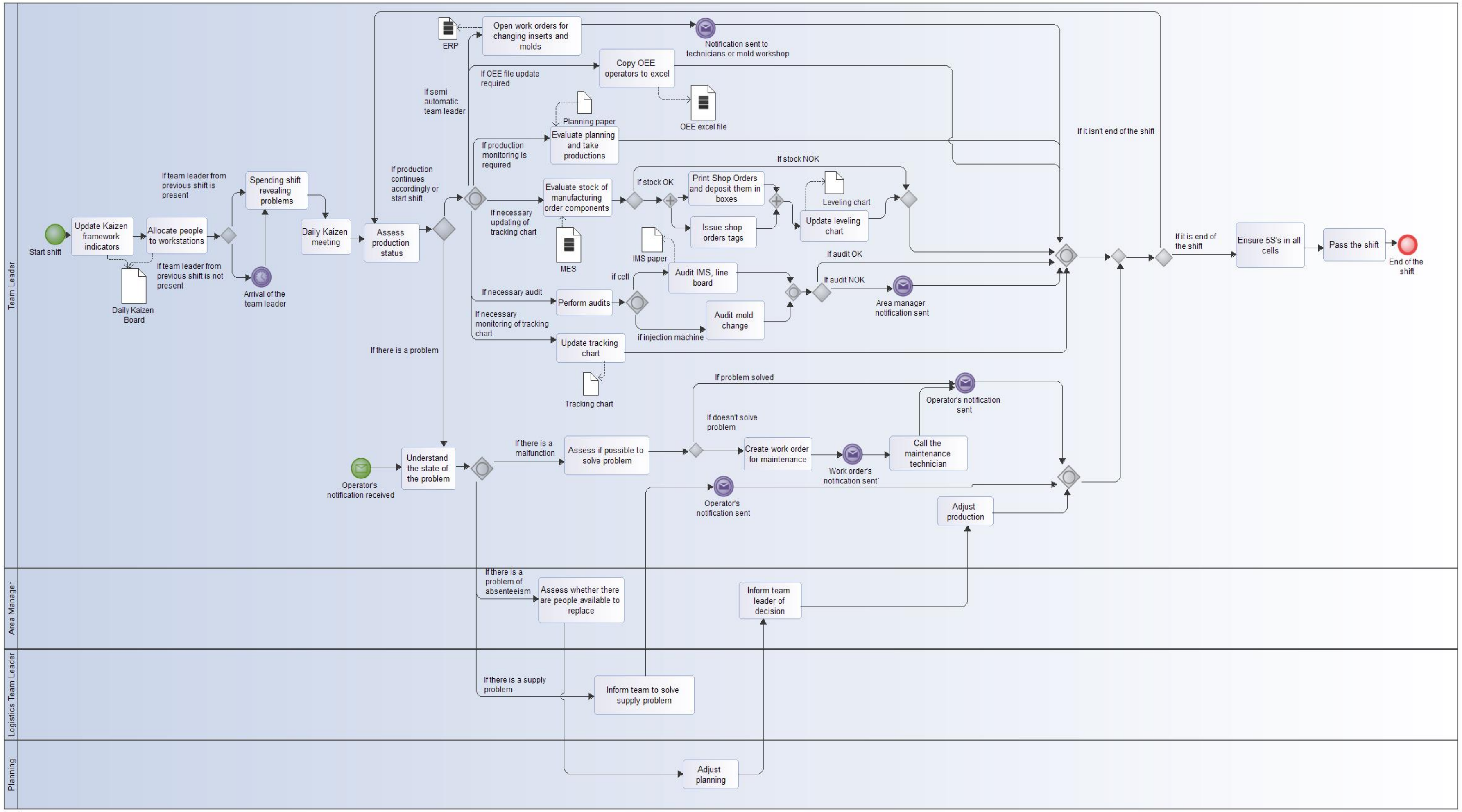

Figure 29- Assembly Team Leader working instructions based on BPMN 2.0

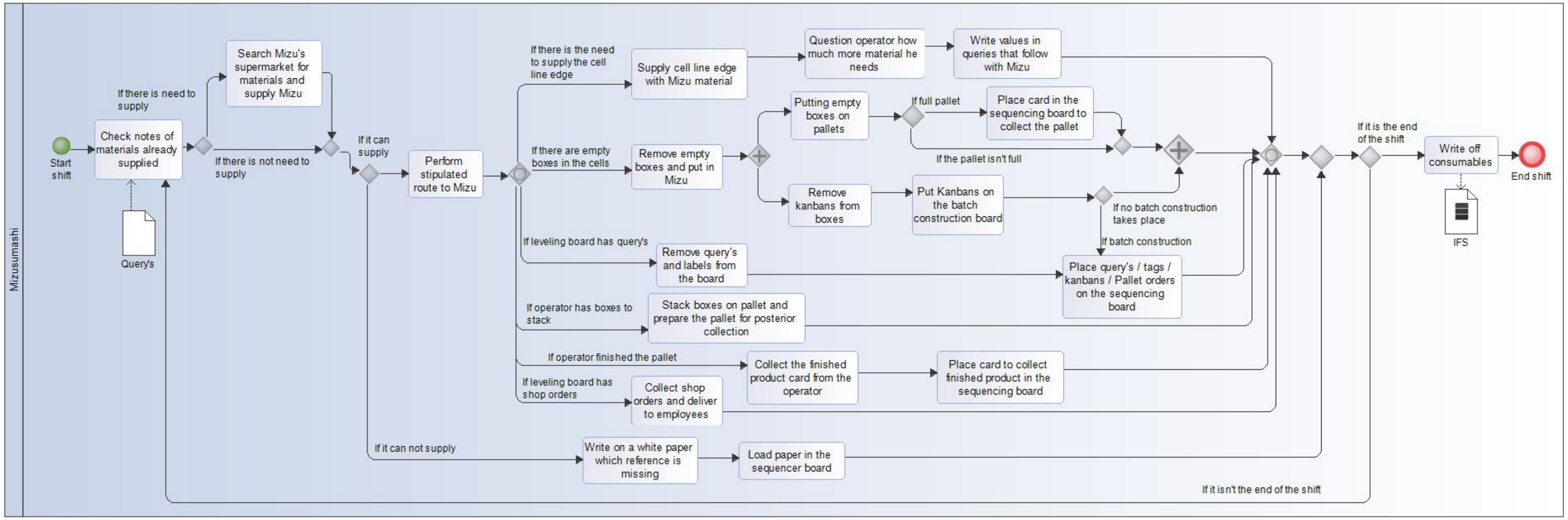

Figure 30- Mizusumashi working instructions based on BPMN 2.0

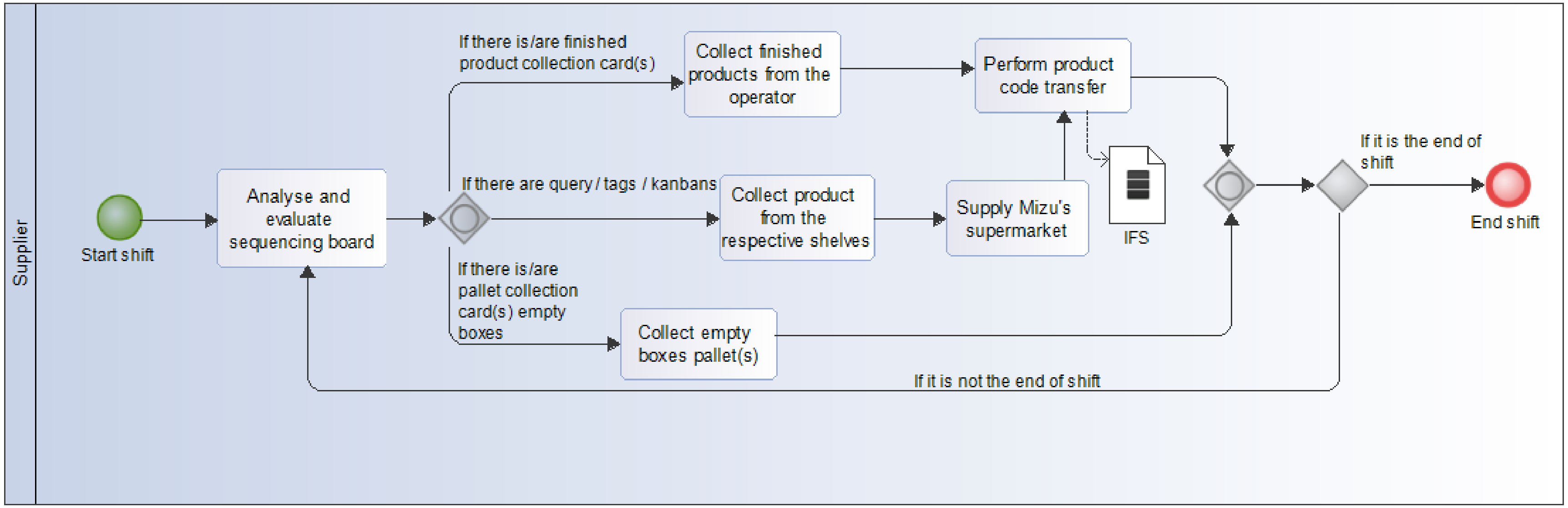

Figure 31- Supplier working instructions based on BPMN 2.0

Appendix II- Chapter V

The software specification presented in this appendix may constitute a module of an entire MES system, such as that shown in the article's content (Chapter V). The inspiration for this software specification was based on the company's injection area used for the case study in the Chapter V.

Beginning with the use case diagram (Figure 32), the person responsible for the shift and / or the area manager must register the shop orders (“Register shop order”), immediately allocating the necessary equipment to them (“Allocate equipment to the shop order”), and DMCPs are automatically created (“Create a DMCP”). In addition, these two actors have the possibility to view the shop orders’ status in production (“Visualize shop orders’ states in production”), create standard tasks (with a view to sustaining knowledge management also shown in the article- “Create standard task”), view and monitor active equipment’s KPIs (“Visualize machines’ KPIs”), create new quality control parameters (“Create quality control parameter”) and register new operators (“Register operator”), at the same time that it is possible to insert their skills for the different standard tasks created (“Insert competency by task”).

Since this is an area whose equipment works mostly in automatic mode, the operator's role is mostly to monitor the machines. However, they must have warnings to carry out quality control and be able to view and perform those same checks (“Quality control notice”, “Visualize executed quality controls” and “Execute quality control”). This member also has the function of activating the production (“Activate production”), depending on the DMCP he receives and, immediately, he has access to consult the shop orders active in the system (“Consult active shop orders”). The causes of non-conformity of the parts must be entered by the operator (“Record causes of non-conforming parts”) and actions requests for maintenance are also to be recorded (by triggering a maintenance warning), such as consumables necessary for production (“Register action request”, “Register consumable order” and “Trigger warning”).

All production must also have to be declared (“Declare production”), and it may only involve confirmation of the amount counted by the equipment. This declaration involves three types, conforming parts, non-conforming parts and parts that need to wait for quality department decision.

The start of a manual task (since the rest is automatic and there is a need to count the time of manual tasks - which involve the hand of the operator or injection technician), can also be displayed, with confirmation of the collaborator's competences for the task to be performed (“Confirm operator’s competencies”). The completion of the manual task also exists (“Finish manual task”), which causes (as in starting the task) to change the state of the task (“Change task state”). Also, in case of starting a manual task, the operator can consult the knowledge repository, which serves as a task support tool (“Visualize tasks bank”).

The injection technician can also start and end manual tasks, create maintenance plans for the equipment (“Create maintenance plan for every equipment”), as well as maintenance actions that will constitute the maintenance plan (“Create maintenance action for a maintenance plan”). It should also be noted that both the injection technician and the maintenance technician have access to actions requests that can originate manual tasks.

Looking now at the class diagrams, Figure 33 shows what kind of software the company currently employs (only the class diagram is presented). Figure 34 in turn shows outlines in red, in the classes that nevertheless remained in the specification proposal.

It should be mentioned that each shop order will have numerous associated events (“Events” class), that have name and description derived from the “Events Bank” class. In addition, there will be associated quality controls that (“Executed control”), in the same line of thought as the previous one, will have an associated name and description (coming from the “Controls Bank” class). Each shop order (“Shop order” class) has an injection machine associated with it (“Equipment” class), which can, in turn, present different equipment (namely peripherals). Each shop order will have several associated parameters (“Parameter” class), that are attached to just one equipment. Each shop order can have several production declarations, from compliant (where the declaration goes to "WIP crates"), to non-compliant ("Not comply parts” where it is necessary to indicate the cause of non-compliant-" Not comply causes bank ") and the declaration of parts for the waiting decision area (which after verification by the quality department can migrate the values to the declaration of "WIP crates" or "Not comply parts"). Each shop order corresponds to a die mold,(“Mold” class) and this connection originates a mold change plan (“Mold change plan” class), since the same mold can be used in more than one shop order and a shop order can have more than one mold associated.

Shop orders may have associated actions requests (due to problems identified for example) that they can originate tasks or actions (“Tasks/Actions” class) that in turn, consult a kind of knowledge repository ("Tasks Bank") to support them. It should also be noted that each operator has a level of competence (“Competency” class) associated with tasks in the repository ("Tasks Bank"). In addition, each equipment has one or more preventive maintenance plans (“Maintenance plan”) that include several maintenance actions (also associated with the knowledge repository – “Tasks bank” class). Each sector (made up of several machines) can also hold different consumable orders (“Consumable order” class), whose types and descriptions are already stored in a consumable bank (“Consumable bank” class), making it easier to update them.

The proposed structure (Figure 32 and Figure 34) differs greatly from the existing one (Figure 33), adding characteristics of knowledge management, tracking of equipment parameters and consumable orders, preventive maintenance (with action requests), superior control of the production declaration, preventive maintenance plans, human resources management (with the possibility of associating competencies) and also monitoring DMCPs.

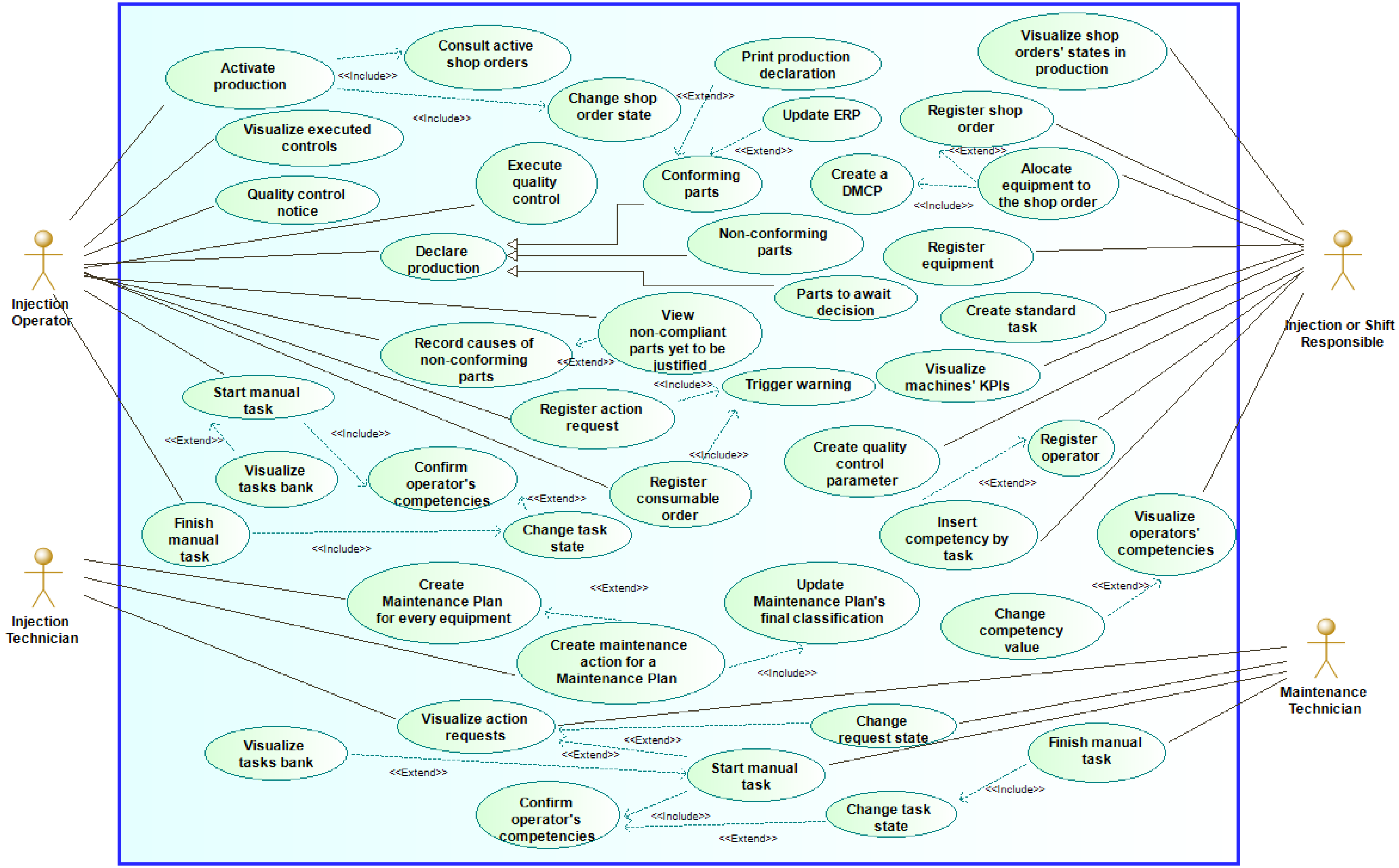

Figure 32- MES (Injection Area) Use Case Diagram

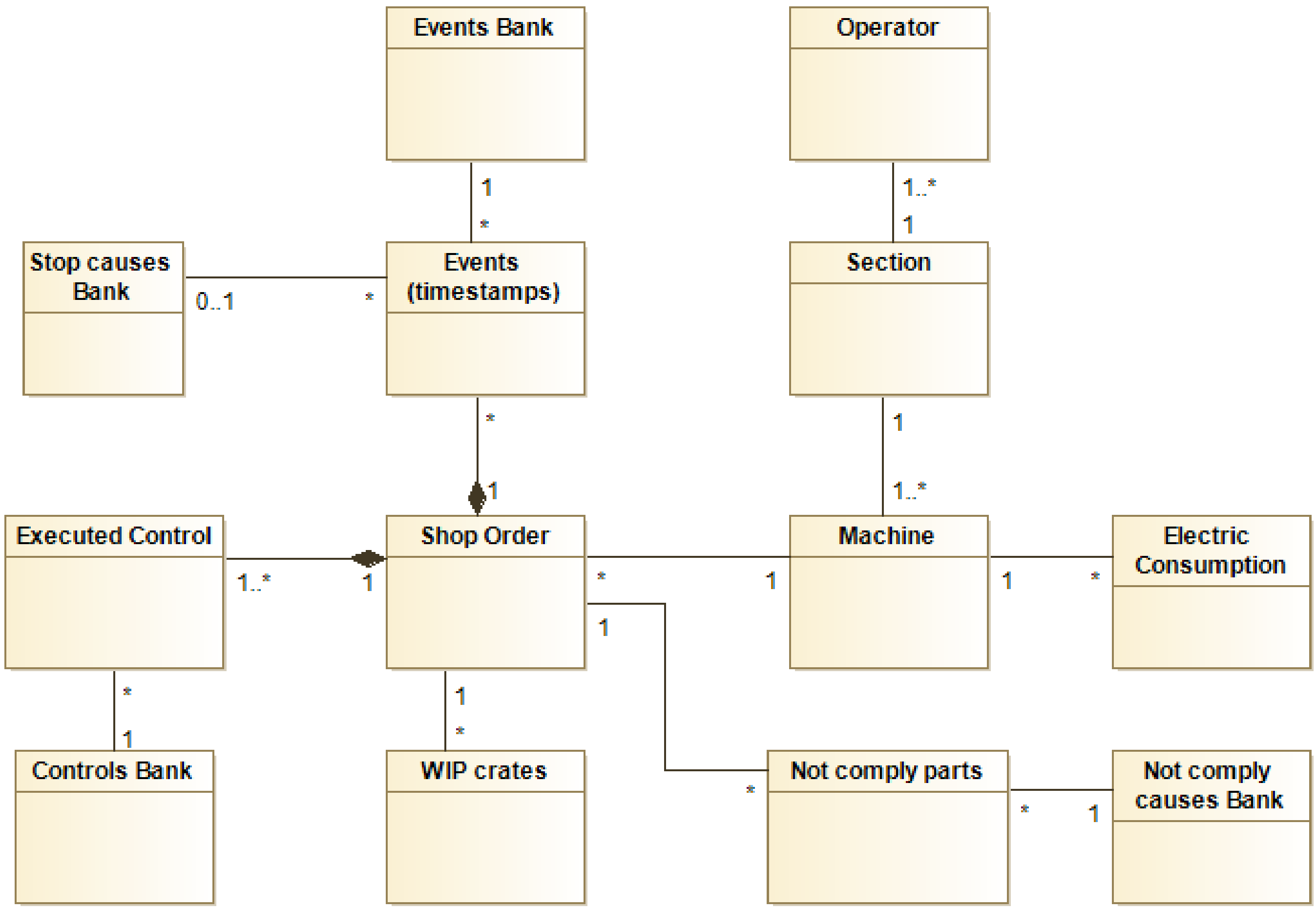

Figure 33- MES (Injection Area) Class Diagram- Company's current version

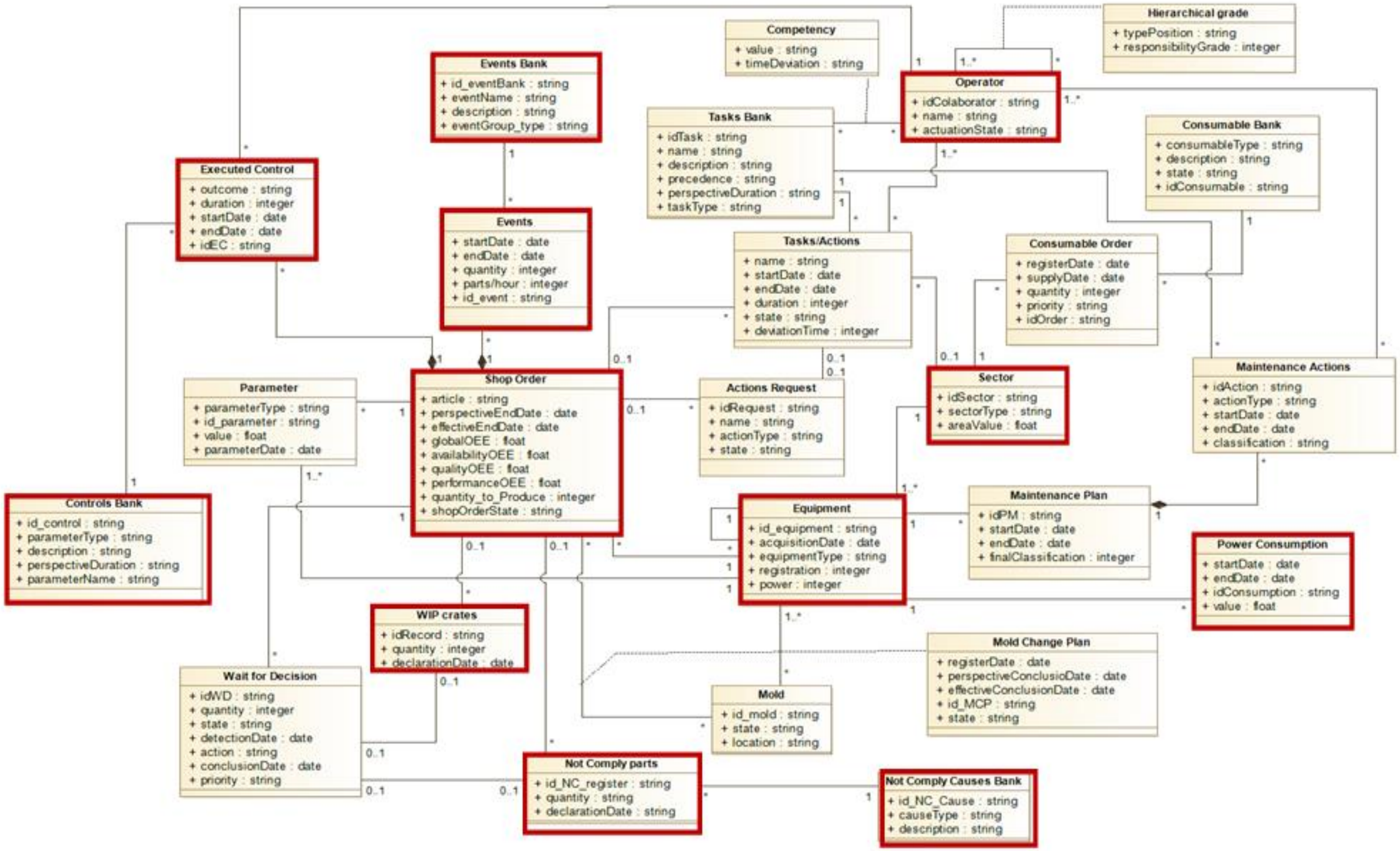

Figure 34- MES (Injection Area) Class Diagram - Proposed Version