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Using Internet of Services to Stablish a Service-Oriented Manufacturing Architecture model in Industry 4.0

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Abstract
The manufacturing industry has been reshaping its operations using digital technologies for a smart production towards a more customized demand. Nevertheless, the flexibility to attend the production plan changes in real time is still challenging. Although the Internet of Services (IoS) has been addressed as a key element for Industry 4.0, there is still a lack of clarity about the IoS contribution for advanced manufacturing. Through a case study, the paper aims to validate the adherence of a theoretical model named Service-Oriented Manufacturing Architecture (SOMA) in two manufacturing companies that have been already engaged in Industry 4.0. As main results, it was concluded that IoS could suit in one case of Industry 4.0 flexible production process but not in a mass production one. Considering the scarcity of research that exemplifies the IoS contribution, the present paper brings an important assessment on a real manufacturing scenario.

Keywords
Internet of services, Industry 4.0, Production planning, Service-Oriented Architecture, Service bus.

Introduction

The first three industrial revolutions have brought important changes in manufacturing from steam engines to automated electrical and digital production (Wahlster, 2012). It has evolved as a result of mechanization, electricity, and Information Technology respectively (Kagermann et al., 2013).

In 2011, the German Federal government introduced a new program called Industry 4.0 with the aim of strengthening and direct the advances of manufacturing through the application of Information and Communication Technologies (ICT) (Alcácer and Cruz-Machado, 2019; Baena et al., 2017; Hermann et al., 2016; Kagermann et al., 2013).

By encouraging the introduction of the Internet of Things and Services into the manufacturing environment, the German program paved the way to a fourth industrial revolution (Kagermann et al., 2013). Through such advanced application of information and communication systems in manufacturing, the factory environment might become smart. In order to attend customers' needs and desires, the production process should have flexibility, reduced setup time, small batch sizes and mass customization (Sanders et al., 2016).

Nevertheless, after some time that Industry 4.0 was first coined, companies are still looking for the best approach and trying to understand this new paradigm, mainly because there is a need for clarification of Industry 4.0 related concepts and technologies (Alcácer and Cruz-Machado, 2019).

Among the set of technologies that evolve Industry 4.0, the main ones would be the Cyber-Physical Systems – CPS, Internet of Things – IoT, and Internet of Services – IoS (Hermann et al., 2016; Hofmann and Rüsch, 2017; Kagermann et al., 2013; Satyro et al., 2017). While CPS and IoT deal with tangible sensors, actuators, and objects (Jazdi, 2014), the IoS covers an abstract set of functionalities, from a more intangible standpoint which is natural from services (Cardoso et al., 2009). In scientific literature, the applications of IoT and CPS in Industry 4.0 are exhaustively discussed, however, there is still a lack of clarity on how the IoS fulfills the Industry 4.0 requirements on a manufacturing shop floor scenario.

By exploring the root of the IoS concept and its correlation with Industry 4.0, the main foundation is SOA – Service-Oriented Architecture (Schroth and

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Janner, 2007). SOA is a logical model that reorganizes logical applications into a set of interacting services, centered in the notion of service-orientation (Papazoglou, 2003). The service-orientation has two principles: (1) Interface related principles, which are related to technology neutrality and protocol standardization; and (2) design principles, which address the real business needs, and make services adaptable, easy to use and manage (Sprott and Wilkes, 2004). The present paper aims to cover the design principles.

Another concept enabling SOA, thus enabling IoS, is the Enterprise Service Bus (ESB). ESB is the service registry that enables a fully integrated and flexible end-to-end SOA by describing the service requestors, service providers, and their operations through the information flow (Schmidt et al., 2005).

In order to bring value to customers, Industry 4.0 produces an increased number of product types and looks for smaller production batches. However, the vast number of setup changes, in addition to the inevitable production scheduling adjustments, can be a burden for the operator and the production control. Imagine the production schedule is a sequence of operations requirements linked to the machine, and one batch is inserted. The operator has to identify that, modify the machine setup and amend the production schedule. The idea of service inherent to SOA's design principles and ESB use can reverse the rationality. In this case, the process requirements are linked to the product, and at the different workstations, it "requests" the necessary operation, enabling reconfiguration through adapting or changing production requirements (Bonilla et al., 2018).

Although there is a solid research on service-oriented architectures for developing and exploring methodologies in order to achieve higher flexibility in manufacturing, the assessment of a service-oriented model in a real manufacturing scenario is still missing.

The research question is: How could the IoS improve the production flexibility and product customization at the shop floor?

Employing a case study, it has been assessed the role of IoS in a smart factory shop floor, extending the study of the Service-Oriented Manufacturing Architecture (SOMA) model (Reis and Gonçalves, 2018) through its evaluation and validation in a real manufacturing scenario. The proposed conceptual model addresses how IoS and SOA can provide the production flexibility at the PPC (Production Planning and Control) level.

This paper aims to validate an application of an IoS-based SOMA model in a flexible manufacturing shop floor, regarding to a flexible PPC, small size (or unitary) batches and product customization. The expected impact is a better response to the unexpected changes of customer demands which is one of the goals of Industry 4.0 for a smart production.

Literature review

Industry 4.0

The term Industry 4.0 was rooted in the German Federal government's strategy in 2011 (Kagermann et al., 2013). Such initiative had the aim of strengthening the manufacturing by advanced application of information and communication systems.

Industry 4.0 is defined as a collective term for technologies and concepts of value chain organization (Hermann et al., 2016). Among this set of technologies, the protagonist ones would be CPS, IoT and IoS (Hermann et al., 2016; Hofmann and Rüsch, 2017; Kagermann et al., 2013; Satyro et al., 2017).

CPS are sensors and actuators that monitor physical processes and create a virtual copy of the physical world (Jazdi, 2014). Over the IoT, CPS communicate and co-operate with each other and humans in real time. The CPS and the IoT are linked with the IoS which present the distributed intelligence, completing this complex eco-system. Consequently, the demand for interoperability among all systems, devices, and processes down from factory shop floor up to the enterprise and business systems – is rapidly growing (Givehchi et al., 2017. Through the IoS, both internal and cross organizational services are offered and utilized by participants of the value chain (Hermann et al., 2016).

The promoters of the German program explain that Industry 4.0 involves the technical integration of IoT and IoS as enablers to create networks, incorporating the entire manufacturing process that converts factories into a smart environment (Kagermann et al., 2013).

Industry 4.0 is called to pull applications and push technologies enabling the factories of the future (Lasi et al., 2014). The main technologies are Internet-based, as the IoS, favored by new developments in computational power, leading to cloud computing and services. "These technologies have the potential to give rise to a new generation of service-based industrial systems whose functionalities reside on-device and in-cloud" (Ganzarain and Errasti, 2016). Other technologies would be: Big Data, Simulation, Augmented Reality, Cybersecurity, Additive Manufacturing, and Autonomous Robots (Alcácer and Cruz-Machado, 2019).

Within the Industry 4.0 concept, "the Internet and supporting technologies serve as a backbone to integrate physical objects, human actors, intelligent machines, production lines, and processes across organizational boundaries to form an intelligent, networked agile value chain" (Ganzarain and Errasti, 2016).

Internet of Services

The term Internet of Services (IoS) was raised from the convergence of other two concepts: Web 2.0 and SOA (Schroth and Janner, 2007). The intersection of these two fields is the notion of reusing and composing existing resources and services.

Web 2.0, the first concept, is characterized by four aspects: interactivity, social networks, tagging, and web services (Treese, 2006).

- Interactivity, which comes from two technologies: AJAX (Asynchronous JavaScript and XML) that allow the communication and the dynamic manipulation of data between a server, and the web browser.
- Social networks, based on common interests, making the information from each network available through different ways.
- Tagging, through which users can add a keyword as a tag to certain web content, making this tag easily reachable when searched by other users.
- Web services, which allow that other software makes use of the features offered by a web application, being available not only to people but also to machines.

The second concept that forms the IoS is the SOA (Schroth and Janner, 2007). SOA is a way of designing and building a set of Information Technology applications where application components and web services make their functions available on the same access channel for mutual use. In order to satisfy these requirements services should be (Papazoglou, 2003):

- Technology neutral: they must be invoked through standardized common denominator technologies that are available to almost all IT environments. This implies that the invocation mechanisms (protocols, descriptions, and discovery mechanisms) should comply with widely accepted standards.
- Loosely coupled: they must not require knowledge or any internal structures or conventions (context) at the client or service side.
- Support location transparency: services should have their definitions and location information stored in a repository such as UDDI and be accessible by a variety of clients that can invoke the services irrespective of their location.

Besides this more technical foundation based in SOA, the IoS has also a business connotation. From a business standpoint, IoS is seen as a collaborative business ecosystem or global market where services from diverse providers are offered, discovered, and consumed in combined use (Givehchi et al., 2017; Huang et al., 2013; Kritikos and Plexousakis, 2014). It is also seen as a future Internet that detects and uses contextual information to adapt perfectly to an unpredicted scenario, allowing the ad-hoc configuration of new IT business models (Balakrishnan and Sangaiah, 2017; Bucchiarone et al., 2017; Papageorgiou et al., 2014).

Service-Oriented Architecture

The Service-Oriented-Architecture SOA can also be explained through two different perspectives. From a business standpoint, it represents a set of services that improve the capability of the enterprise to conduct business with customers and suppliers. From a technology point of view, it is a project philosophy characterized by modularity, separation of concerns, service re-use and composition, as well as a new programming method based (Ordanini and Pasini, 2008).

Web Services technology constitutes the main vehicle for the SOA. Web Service is defined as "a software system designed to support interoperable machine-to-machine interaction over a network" (W3C). It has an interface described in a machine-process format that informs what the service does and how to call its functions. Basically, web services delivery functionalities (called *services*) offer simple input and output interfaces, hiding the internal structure and programming language that can be used by other web service, software application, or machine (W3C).

Through the concept of SOA, new applications can be assembled from the available components and services. In analogy to Lego^{TM}, grouping these elementary and inter-connectable entities allows for building complex systems, which are modular, reconfigurable, and evolvable. In fact, the reconfiguration is achieved due to the easy re-organization of the entities and the services they provide, reflected by the modification of the connections between the devices presented in the system (Mendes et al., 2012).

The integration of devices into the business through SOA has been considered a promising approach to connect physical objects and to make them available to IT-systems. This can be achieved by running instances of web services on these devices, enabling them to interact and create an IoS that enables a service-oriented manufacturing (de Souza et al., 2008).

In SOA, all applications in an organization can offer and consume services in a unique and integrated communication channel, called Enterprise Service Bus, as a simple way to facilitate integration (Bhadoria et al., 2018).

Enterprise Service Bus

The Enterprise Service Bus (ESB) is a software architecture that has a set of key characteristics (Chappell, 2004):

- Message routing and control across enterprise components
- Decoupling of various modules by asynchronous messaging, replacing point to point communication with the common bus architecture
- Promote reusability of utility services, reducing the number of redundant services across the enterprise
- Provide transformation and translation of messages to allow easy integration of legacy applications
- Provide an engine for workflow execution

The definition of service is wide; it is not restricted by a protocol, such as SOAP (Simple Object Access Protocol) or HTTP (Hypertext Transfer Protocol), which connects a service requestor to a service provider. It does not require the service to be described by a specific standard such as WSDL (Web Services Description Language), though all these standards are major contributors of the ESB/SOA evolution. A service is a software component that is described by meta-data, which can be understood by a program. The metadata is published to enable the reuse of the service by components that may be remote from it and that need no knowledge of the service implementation beyond its published meta-data (Schmidt et al., 2005).

The ESB enables the SOA by providing the connectivity layer between services. Descriptions of the services available from a service provider can be made accessible to developers at the service request, possibly through shared development tools. The ESB formalizes this publication by providing a registry of the services that are available for invocation and the service requestors that will connect to them. The ESB is the connectivity layer for process engines that choreograph the flow of activities between services. The process engine is responsible for ensuring that the correct service capabilities are scheduled in the correct order (Schmidt et al., 2005).

Communication and integration

The basic principle to a smart factory or a smart production is the integration of the production facilities, both software and hardware, like Information Systems and machines. Strljic et al. (2018) point that the communication and integration of software components are essential to establish a reconfigurable production system or facilitate functionalities in the Industry 4.0 context. To achieve this, communication standards, like OPC UA, are crucial for data exchange. The OPC UA is a platform-neutral standard for data exchange in industrial automation. It establishes a SOA to integrate, through web services, machines, equipment and enterprise systems (e.g. ERP) (Leitne and Mahnke, 2006).

The research that applies OPC UA focus in the shop floor and production facilities configuration and deployment, but not in the production execution, neither into PPC for product customization.

The OPC UA is a key standard of RAMI 4.0 which is a model that augment existing physical facilities with communication technology to make the information available to all the hierarchy levels and lifecycle phases. RAMI 4.0 is not explicitly motivated by the design of new CPS systems or opportunities from exploiting functional requirements of such systems (Yli-Ojanperä et al., 2019). Nevertheless, since OPC UA is intrinsically compatible with SOA, it can be the technical base to support the SOMA model in the practice.

Related works

Before the advent of Industry 4.0, the SOA has already been considered a promising approach to achieve higher flexibility in manufacturing (Legat et al., 2010). Table 1 lists some important SOA models, their proposal and analyzed limitation.

The SOA and its related standards for web services have been proposed for automation control (Bohn et al., 2006), working as the middleware for the integration between the shop floor and back-end applications, such as Enterprise Resource Planning (ERP) (de Souza et al., 2008). Although these approaches were a first step towards more adaptive manufacturing systems, they applied the traditional top-down focus of business process integration which, for instance, is too static for highly customized products with small lot sizes (Legat et al., 2010).

Legat et al. (2010) introduce a SOA in which an intelligent product passes through several production sites and requests the required processing operations as services from the available resources. The product could be manufactured by a priori unknown and changeable manufacturing systems, but the research is based on an abstract model without implementation details. Other similar SOA product-based models

Table 1
SOA models

SOA models	Model proposal	Analyzed limitation
SIRENA Service Infrastructure for Realtime Embedded Network Devices (Bohn et al., 2006)	Middleware for the integration between the shop floor and back-end applications	Top-down focus of business process integration which is too static for highly customized products with small lot sizes
SOCRADES Integration Architecture (de Souza et al., 2008)	Architecture to facilitate the querying and discovery of real-world services from enterprise applications	Focus on integration between the shop floor and Enterprise Resource Planning with no validation
Abstract Manufacturing Service Model (Legat et al., 2010)	Abstract model combining service-orientation to achieve bottom-up supply chain integration by intelligent products	Focused on mathematical bases to create an abstract level between machine and supervision layers but with no validation on real business
Service-Oriented Operator 2.0 architecture (Nagorny et al., 2012)	A prototype that allows the virtualization of a shop floor, making feasible to proceed controlling and monitoring	Focused in a better monitoring control through the virtualization of the resources
MSB – Manufacturing Service Bus (Morariu et al., 2012)	Middleware to distribute work among connected components, assuring loose coupling between modules at shop floor level	The event communication works from shop floor to upper levels but mainly for monitoring purpose
Real-time monitoring SOHOMA (Service-Oriented, Holonic and Multi-Agent manufacturing Systems (Morariu et al., 2014)	The target system is a manufacturing shop floor, where each component of a system (resource of product) is linked to a monitoring agent. These agents send monitoring data via a monitoring data stream	The solution provides a monitoring portal where system administrators can track key performance indicators in real time. The paper discusses the strategies for handing the monitoring data in real time
eScop approach based on Plug & Produce (Strzelczak et al., 2015)	Architecture proposed to combine the power of embedded systems with ontologies for a fully opened manufacturing environment	Work to allow the inclusion of new equipment by easy and fast commissioning of new plants, not focusing on production plan
SOIMS Service-Oriented Intelligent Manufacturing Services (Giret et al., 2016)	Design of artifacts that facilitate the various manufacturing resources to be intelligently connected into the internet	Focused on notations to support the identification and specification of the system components, pending validation
SoHMS (Service-Oriented Holonic Manufacturing Systems (Gamboa Quintanilla et al., 2016)	Modeling framework that creates families of products from their customizable specifications based on manufacturing services.	Focused on computational model for the possible specifications of the products, and let the focus on flexible production plan for future works
Cloud Manufacturing Service Bus (Răileanu et al., 2018)	Solution based on private cloud infrastructure that collects data in real-time from intelligent devices associated to shop-floor resources and products	It is an experimental evaluation of the data collection process from measuring devices embedded on robots and of the data transfer in the cloud
Plug and Produce for Industry 4.0 (Madiwalar et al., 2019)	Solution combining Software-defined Networking and OPC UA to add more intelligence to the device discovery	Enables the fast integration of new devices, focusing on the fast inclusion of new equipment to the shop floor but not focusing on production process in the execution time

have been proposed (Nagorny et al., 2012), but only the monitoring level has been explored.

The Manufacturing Service Bus (MSB), an adaptation of the ESB for manufacturing enterprises, has been presented as a concept of bus communication for the manufacturing systems (Morariu et al., 2012). The MSB acts as a middleware to distribute work among connected components, assuring loose coupling between modules at shop floor level. The main role of the MSB implementation is to perform the event dispatch operation allowing shop floor components to exchange information in an event driven fashion. The event communication works from shop floor to upper levels but mainly for monitoring purpose and do not enable an adaptive production yet.

The event communication aims to measure the performance of machines and plants in real-time to quickly recognize and correct errors and waste (Gruber, 2013). It complements standard ERP-software on the planning level (top floor) using objective performance data coming directly from all factory assets (shop floor) from one single machine to multiple plants worldwide. A similar approach called Intelligent Enterprise Service-based Bus (iESB) (Marin et al., 2013) has been proposed to interconnect several factory systems to each other. The architecture is based on intelligent services defined as independent pieces of software that are expected to provide a particular result, either produced by the intelligent service itself or by requesting support from other intelligent services.

Although the ontologies and description languages have also been studied in the manufacturing context, Gamboa Quintanilla et al. (2016) explain that they are designed for web applications, which have different use from those found in manufacturing applications. Web applications are mainly focused on interoperability, while in manufacturing, the exploration of process flexibility comes more into play during the stage of process planning.

The IoS or cloud services are presented as an evolution of a networked and service-oriented manufacturing model through which shop floor items may access a shared pool of computing devices (Kubler et al., 2016). Cloud computing has been adopted by manufacturing enterprises mainly on the higher layers of business processes for supply, digital marketing, and ERP (Borangiu et al., 2019; Helo et al., 2014).

The main SOA models, as listed in the Table 1, have been tested for event communication from shop floor to upper levels for monitoring purposes. The SOMA model instead addresses the flexibility to adapt to the changes in the production plan.

Moreover, the research of cloud manufacturing service is focused on theoretical framework and prototypes. It is missing though the evaluation and validation of such conceptual models in the real industrial environment to assure a readiness level to the industry.

Some research explores the concept of Plug and Produce to describe how a SOA can be used to design and to deploy a flexible factory layout, replacing and integrating machines and systems with well standard protocols. Atmojo et al. (2020) present a product-centered and flexible assembly line using OPC UA. Strzelczak et al. (2015) propose an open automated manufacturing environment using ontology that allow the fast commissioning of new plants, and the inclusion of new equipment. In the same line of research, Madiwalar et al. (2019) propose an OPC UA-based integration model to support flexible and agile production facilities capable of accommodating changes to product specification, enabling the integration of new devices by Plug and Produce.

The main difference between the Plug and Produce concept and the SOMA model is that SOMA is concerned with the production execution flow and not with the design and deployment of the production facilities.

Materials and methods

The research method is divided in two phases. The first is related with the bibliographic review, presented in "Literature review" and "Related works" sections, to support the concepts related with SOMA model, its relevance, and differences when compared to other models. The second is related with the case studies that evaluate SOMA in real operational context in two industrial companies.

The bibliographic review is also divided in two parts. The first part was exploratory, looking for the relevance and originality of the subject, and was done to better understand the role of the IoS in the Industry 4.0 manufacturing environment. The second part of the bibliographic review was done to evaluate the SOA application in manufacturing, gathering the foundation concepts of IoS. It was used the string ("*service oriented architecture*" OR "*service-oriented architecture*") AND *manufacturing* only in the Web of Science and performed a non-exhaustive inclusion or exclusion selection. From this result, two research lines were identified, and two other searches were conducted specifically to explore these lines. The Table 2 shows the queries, the purpose, and the results.

Based on the literature review and a theoretical model that represent the SOMA (Reis and Gonçalves, 2018), two case studies were evaluated to answer the research question.

It was utilized the case study methodology to evaluate if the theoretical model SOMA can be verified in practice and the implications of the concept to production flexibility and product customization at the shop floor. The case study methodology is often used in the Operation Management area to better understand a particular condition, problem, or solution adopted or occurred in the unit of analysis, like a company. The advantage is the depth of the study but, given the condition, the generalization of the results is not possible. The case study has two research proposes: in the *inductive mode*, to create theory; in the *deductive mode* to evaluate in real conditions a theory or model (Barratt et al., 2011). In this paper, the case study was utilized in the deductive mode to evaluate the SOMA model.

Two representative cases of Industry 4.0 have been selected to assess the model's adaptability by validating if the manufacturing process in the factory shop floor would match the SOMA model.

Table 2
Boolean Strings used for the research

Search query	Purpose	Results
("service oriented architecture" OR "service-oriented architecture") AND manufacturing	Identify the literature related with SOA and manufacturing.	317 papers founded, 228 of them were proceedings papers. Two lines identified: related with production operation and related with factory deployment and integration ("plug and produce")
("service oriented architecture" OR "service-oriented architecture") AND "plug and produce"	Characterize the difference between SOMA and the integration or factory deployment models	4 proceedings papers founded
("service oriented architecture" OR "service-oriented architecture") AND "production planning"	To obtain other models or concepts related with SOMA and their similarities and differences	4 articles and 5 proceedings papers founded

The two case studies were carried out according to a known case research methodology (Voss et al., 2002), which consists of semi-structured interviews with workers of the organizations and observation carried out *in loco*. It was followed the deductive or theory-testing process explored by the same author in a more recent paper (Voss et al., 2015). From the theory or concept which is the SOMA model, the authors addressed the following research question: How could the IoS improve the production flexibility and product customization at the shop floor?

Both case studies were conducted with interviews and observation *in loco*. In a first moment, the authors presented the SOMA model to the interviewers and asked if the SOMA model reflects what the companies have in the production flow. In case of affirmative answer, the authors asked how, and which services were invoked. If negative, the authors asked how the production flow worked. In a second moment the authors visited the factories. The observation was done at the shop floor during the production flow (real-time production observation) because the goal was to understand how IoS has been used in the real-time production flow and how it can provide flexibility. This way the authors investigated deeply how the production flow worked in both companies. The authors were able to look for similarities and differences from the productive process against the SOMA model.

The two organizations profile and the reasons for their selection for this study are explored below:

- ALPHA is a multinational company that develops solutions and products for automation sectors, such as electronic and mechanical sensors, rotary and linear displacement transducers, and identification systems. ALPHA counts with approximately 4000 employees and it is represented worldwide in more than 60 countries. The plant visited produces inductive, optical, and mechanical sensors, also providing customization for the local market. It is a medium size factory, and the movement into connected processes was gradual. The previous process was organized in cells and used several lean production tools to schedule, visualize, and control production. But because they have a wide variety of product models, these activities were not easy to accomplish. Sometimes, they lost the production batch because, in some operations, a wrong configuration of parameters was used. So, the decision to implement Industry 4.0 projects aimed to free the operators from this task, and, as a result, they reduced errors and increased efficiency. In addition, a part of the workers was trained in the new process and felt relieved with the job's simplification. The organization has been chosen for the case study because it has been gradually inserted into Industry 4.0 scenario, moving from a manual productive process to an automated and robotic plant. Moreover, ALPHA is a partner for industrial automation solutions to make possible their own customer's revamp to Industry 4.0. The first semi-structured interview has been done remotely with the product manager and complementary questions have been answered by the engineering supervisor during the coordinated visit to the plant.
- BETA is an automobile manufacturer within a large multinational industrial group that develops industrial and service activities. It currently employs more than 100,000 people in more than 50 countries. The car plant visited produces passenger and utility vehicles. It is a large factory with a mass production, continuously manufacturing large quantities of vehicles, using assembly lines and a mix of robots and human operators. Despite the automation, the production plan decisions are taken pre-

viously based on existing manufacturing resources, and robots execute the plan. The implementation of Industry 4.0 has been supporting the operators in their tasks, with equipment such as exoskeletons that support the body of operators to reduce physical effort, and collaborative robots that work without fences in activities such as applying glue to glass or tightening screws. Moreover, BETA has been creating an effective and safe workspace by adopting virtual assembly and simulation through augmented reality. Being globally inserted in the context of Industry 4.0 has been part of BETA's strategy since Industry 4.0 emerged, is the reason why the authors have chosen it for this case study. The first semi-structured interview has been done remotely with the digital product manager and complementary questions have been answered by the integrated process operator during the coordinated visit to the plant.

The Service-Oriented Manufacturing Architecture conceptual model

In the computer science domain, the service-orientation defines the principles for conceiving decentralized control architectures that decompose computational processes into sub-processes, called services. The focus of SOA is to leverage the creation of reusable and interoperable function blocks to reduce the amount of reprogramming efforts (Gamboa Quintanilla et al., 2016).

In a cloud manufacturing system, various manufacturing resources and abilities can be intelligently sensed and connected to the wider Internet utilizing SOA principles (Giret et al., 2016). SOA is centered on the notion of service-orientation, i.e. the entities provide their functionalities and skills in the form of services that may be searched, requested, and used by other entities (Mendes et al., 2012). As a metaphor, it is like a shopping mall underground floor in which various services such as barbershop, cell phone repair, tailor's shop are offered in the same physical location, facilitating customer access (Reis and Gonçalves, 2018).

Bhadoria et al. (2018) complement that, in SOA, all applications in an organization can offer and consume services in a unique and integrated communication channel, called Enterprise Service Bus, as a simple way to facilitate integration. Since the advent of Industry 4.0 brings an increasing number of smart objects interconnected to the manufacturing environment, another challenge is the increasing complexity of managing such networked smart objects. Schel et al. (2018) suggest that a *Manufacturing Service Bus* (MSB) could offer a solution.

The model shown in Figure 1 utilizes a Service Bus, where different production workstations or facilities, like robots, machines, manual tasks, and information systems are available as service providers for the manufacturing processes.

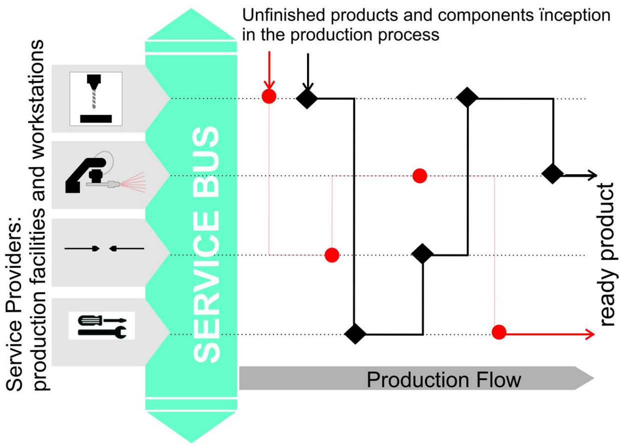

Fig. 1. Service-Oriented Manufacturing Architecture (SOMA), adapted (Reis and Gonçalves, 2018)

The different services can be accessed, matched, and integrated by discovery and composition applications creating the SOMA model, which is an approach to understand how IoS can be used during the production flow in an Industry 4.0 smart manufacturing shop floor environment (Reis and Gonçalves, 2018). It is related with a flexible and agile PPC, from the inception to the end of the production process (ready products).

In the SOMA model, the products invoke the necessary services, which are shared through the Service Bus following a flexible and modular smart productive chain. Each offered service can be parameterized in accordance with the product demand in real time. By running in the production flow, each product invokes the appropriated service, informing parameters and instructions.

This way, the products batches can attend different demands from clients and can be reduced until the unitary size, or individual product customization. The PPC becomes more agile and flexible, responding quickly to new demands or changes.

In this sense, many production features or capabilities related with the Industry 4.0 can be addressed.

SOMA model is a dynamic model that shows the orchestration of the services along the production flow, where each product (or batch) in the line has its own "music score" to be played.

Although the SOMA is a conceptual model, at the implementation level, the service bus can be established based in universal communication and integration protocols, like OPC UA, that is intrinsically SOA based (Leitne and Mahnke, 2006).

Results

By means of interviews and observation within the two selected organizations, it has been assessed the model's adaptability and validated if the manufacturing process in the factory shop floor matches the SOMA model.

Validation at the company ALPHA

As mentioned in Materials & Methods, the Company ALPHA produces sensors, an essential component of Industry 4.0. Nonetheless, most of the manufacturing processes are still manual since ALPHA produces a wide product mix with customized batches. Digital Poka-yoke is used in almost all the workstations to avoid human errors while workers are assembling the products, since all assembling operations are handmade. But there are also automated systems to assure that only the authorized and capable worker can login and operate the machines, thus avoiding production errors. The main products are industrial sensors, but the company also produces many products in the Industry 4.0 context and, sometimes the shop floor is used as a showroom.

Through event communication, some machines can trigger alarms of high utilization or operation errors. The Internet is widely used for dashboard publication and remote access to these data so that managers and stakeholders can consult them for decision making.

A specific process that is already automated and matched to the SOMA model is the kiln process, illustrated in Figure 2 and here explained further.

When the components enter the shop floor, called the baptism step, the tray receives an RFID tag linked to the system that says which sensors (products) are contained therein. Then through the tray number, the system knows all the features of those components. For example, in tray 37 there will be sensors of type M8. They go through the component assembling process (represented by only 3 assembling workstations in Figure 2) and the resin is placed. In each step, the product in process requests the supervision service by the digital *poka-yoke* (represented in Figure 2 by the traced line, since the product has no physical movement, only information flow). The products pass to a control station and goes to the drying. In the drying process, the products go to the specific kiln with the required drying time, temperature, and pressure

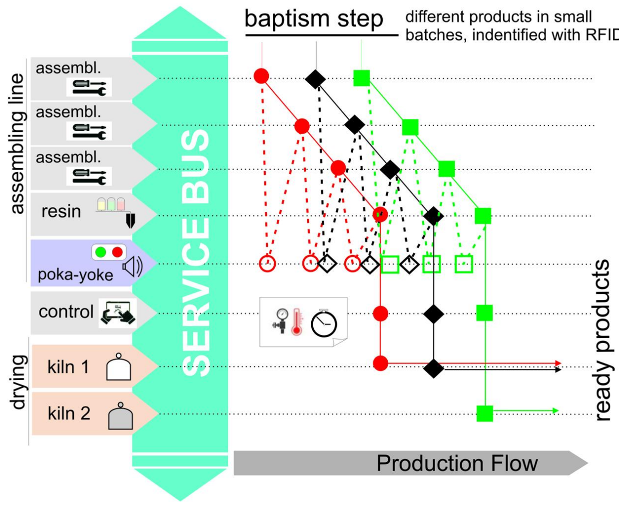

Fig. 2. Company ALPHA production flow

setup. There is a total of three kilns and the selection of which one will be used depends on the type of sensor contained in the tray. The selection process of the kiln is automated as follows: At the reception of the components in the dry kiln room, there is an RFID antenna that reads the RFID tag on the tray. The system looks for the RFID tag number and, since the tag number is already known from the previous baptism step, the system is already able to match the information of sensor type with the kiln that the tray should be sent to and how long the material should remain there, under which temperature and pressure. At the door of each kiln, there is also an antenna and when the tag passes through it, the counting of the necessary drying time will start. The kiln number, the tray number, and the counting time, all appear on the monitor for controlling.

This way, the company ALPHA can obtain flexibility given the agility in realizing fast setup of the machines and operations, parametrized by the information linked with the product RFID.

It is noticeable that there is a product intelligence being able to invoke the kiln service once this selection has been made by the products in process. In addition, internal users and external vendors also have access through the Internet to the operation of the kilns and the traceability of these products. There is also a plan for this to be made available via an App through which salespeople carry out a marketing campaign to show potential customers how the process works.

This kiln process matches the SOMA model because intelligent products arrive at the factory shop floor, request manufacturing services running the necessary tasks and processes. Based on a description of the required task, the production system can determine matching services fulfilling the requested process requirements as well as available configurations of the manufacturing services.

Validation at the company BETA

As mentioned in Materials & Methods, the Company BETA produces passenger and utility vehicles. The factories are more automated since the products are standardized through mass production. Simulation and augmented reality are used for worker's trainings and ergonomic tests. With this information, the organization takes the right decision on the best layout for the workstations and the best position for the workers to avoid fatigue or absenteeism. Through the simulation, for example, the worker can feel if the car is too high and if he would be forcing his arms on the workstation.

In the plant visited, there is a system like a Service Bus that manages the production, however the planning for what will be produced is on the robots, whose programming is previously set by the human operators. The Service Bus system has a menu, and the operators choose the recipe. For example, they need to produce 300 front doors for the model X car and 300 rear doors for the model Y car. The operators start that recipe through the system that triggers the PLC and the robots. Ultimately, at company BETA, the intelligence is not on the products nor in the Service Bus because it does not program the robots. The bus just activates the robot that already has an internal program to perform the tasks given to it. It is the Service Bus that has the recipe for what needs to be produced what means the Service Bus is the orchestrating system. And the way this will be done on the factory floor is already known because the robots already have the program for execution.

All the production plan decisions are taken previously based on existing manufacturing resources and their local states. Previously planned activities are considered and the robots, based on their local policy, will know which and when specific tasks need to be performed. The products themselves do not interfere in production flow decisions.

If it is necessary some change in robots' setup, BETA's digital product manager explains that it requires an extra effort and cost, in addition to the various quality certification processes that need to be followed. Several restrictions must be considered in each process. For example, in painting, each change of paint color has a cost. If the robot is going to paint white instead of red, it is necessary to pass a solvent. In the past, this loss was greater, and the company improved on this matter. Today, the loss is minimal due to the optimal configuration. The system makes the ideal recipe because there is no point in painting only white doors and when it arrives at the assembly, there is no way to assemble yet due to the unavailability of resources in the next step. So, to make better use of these resources over time, the system is already programmed considering the optimal configuration for each product.

The production information regarding the quality condition of the manufacturing equipment as well as its performance monitoring is distributed throughout many information systems such as Manufacturing Execution Systems (MES) for manufacturing process control and systems for management tasks like ERP, warehouse management and others depending on the area of application. However, the manufacturing process does not change automatically from a configuration demand of the back-office systems nor from the CPS or products themselves. If any re-programming of the production plan is necessary, this is done manually by the operators.

Comparing the case study with the SOMA model, it was concluded that at company BETA there is not a scenario of flexible manufacturing, with the services being invoked directly and contextually from the shop floor.

Discussion

Although many papers explore the emerging Industry 4.0, there is still a need for clarification of its concepts and how the technologies have been applied in the manufacturing industry (Alcácer and Cruz-Machado, 2019).

According to the literature review, IoS is an important pillar for Industry 4.0 and it aims to be an Internet that detects and uses contextual information to adapt to an unpredicted scenario, allowing the ad-hoc configuration of new business (Balakrishnan and Sangaiah, 2017; Bucchiarone et al., 2017; Papageorgiou et al., 2014).

By exploring the new cloud manufacturing system proposed by Industry 4.0, various manufacturing resources and abilities can be intelligently sensed and connected into the wider Internet through SOA and Service Bus principles (Giret et al., 2016).

The SOMA conceptual model proposes: a conceptual model about how IoS and SOA can provide the production flexibility at the PPC level.

Preliminary models of the Manufacturing Service Bus (MSB) have been presented as a concept of bus communication for the manufacturing systems exploring more the event communication through agents in the shop floor level (Gruber, 2013; Morariu et al., 2012). It works from the shop floor to upper levels but mainly for monitoring purposes, for example, to measure the performance of machines and plants in real-time to recognize and correct errors and waste. Such a vertical approach from the shop floor to the cloud systems for events communication is already a reality in some manufacturing systems.

Through the SOMA model, besides the events communication, it' s possible also having a service-oriented solution to create flexible production working on a two-way vertical integration. This way the CPS participate actively on the production process decision-making when invoking the services themselves.

Although there are other researches proposing theoretical frameworks and prototypes for implementing flexible manufacturing with CPS using SOA, they lack an evaluation and validation of such conceptual models in real industrial environment in order to assure a readiness level to the industry.

By employing case studies in two organizations that have been already inserted in Industry 4.0 scenario, it has been assessed the SOMA model's adaptability and validated if the manufacturing process in the factory shop floor matches the model.

In the company ALPHA, which presents a more customized production, there is a manufacturing process in the shop floor that is contextualized on the flexible manufacturing scenario of Industry 4.0. For example, when the tray arrives with components in the kiln, a sensor detects the associated RFID tag, and this information is sent to the system. The system then sends back some information so the tray will follow the line to the best kiln for its components. Consequently, ALPHA has intelligent products arriving at the factory demanding manufacturing services for the necessary tasks and processes. Based on a description of the required task, the production system can determine matching services, fulfilling the requested process requirements as well as available configurations of the manufacturing services. In this sense, it was concluded that the company ALPHA case is in accordance with the SOMA model.

In the company BETA, the system delivers to the robots a recipe with the information for production steps. Only previously planned activities are considered since the offering process is based on pre-existing manufacturing resources and their local states. The robot receives the script and performs the specific tasks with no adaptive approach. Anyway, in parallel, there are a bunch of new technologies of Industry 4.0 in other parts of the plant where human workers are, and on training centers. The technologies focus on the operator's efficiency like the use of exoskeleton, simulation, and augmented reality.

This brings the discussion on what should be analyzed to consider that a factory is already inserted in Industry 4.0 context. Through the research regarding Industry 4.0 and mainly regarding the IoS, there should be a service-oriented and internet-connected production that is adaptive to a flexible scenario.

With the case studies in different manufacturing techniques, one more customized and the other a mass production one, it can be said that an automatized and robotized industry, using many concepts of Industry 4.0, is not necessarily inserted in a flexible manufacturing scenario.

In proposed conceptual models close to the SOMA model, the connected smart objects publish events to the Manufacturing Service Bus or receive operation requests from the Service Bus, but it doesn't mean that the production is following an adaptive process.

This is what the present study aimed to validate to have the research question answered. The research question was: How could the IoS improve the production flexibility and product customization at the shop floor? The found answer is that the IoS, as a pillar of Industry 4.0, would have the function of enabling, through the SOA and the Service Bus, alternative and parameterized production features (e.g. machine operations, manual assembling, digital poka-yoke support, drying) that can be invoked by the products or the production planning directly at the shop floor in the real-time production flow, reducing the batches and customizing products.

Nevertheless, our results with the BETA company had shown some difficult implementing this concept in a mass production manufacturing environment.

Conclusions

This paper explores the concepts of Industry 4.0, CPS, IoS, SOA, and Service Bus giving more emphasis to the service domain of manufacturing environment, evaluating the conceptual model SOMA in real cases of utilization. The proposing of SOMA model is to be a simple model to understand how and why services provided by production facilities and workstations can provide flexibility and customization along the production flow.

Besides filling the gap of giving more clarity on IoS role in Industry 4.0 by linking the IoS key foundation concepts on a theoretical model, the paper evaluates and validates the model in a real industrial environment.

In the first organization, it was found that the SOMA model serves to attend the flexible production process. Through the services offered in the ESB, small batches and customizations can be done, and all manual assembling operations are assisted by the *poka-yoke* service, providing quality and assurance that different components are connected, in a non-repetitive task. The services are parameterized by the information associated with the product RFID along the production flow. There is a much more customized production due to the wide product mix and variations in each product with small batches.

In the second organization, it was found that the SOMA model does not apply since the production recipe is ready, with no adaptations throughout the process. Flexibility is much less, and products are more standardized with mass production. The SOMA model becomes more useful when seeking greater flexibility.

The SOMA model is a conceptual model to improve flexibility and adaptability at the shop floor. It is not a new protocol or model for automation or IT-OT (information technology / operational technology integration) and a future research about how to utilize this concept in the implementation level could be done. The paper is also limited by the two study cases, given the scarcity of cases with the possibility of access to information and personal visits by researchers.

Regarding the social implications of our research, the flexibility proposed with the SOMA model may decrease in waste, resources, and energy consumption, what is understood as a more sustainable production. Moreover, the SOMA model does not exclude the human, but it is well-compatible with a hybrid human-automation process at the shop floor. As social implication, this brings a discussion about the impact to the workforce in the Industry 4.0. It was observed in the ALPHA company that workers are currently more satisfied to work with the digital poka-yoke and other features of the SOMA than the former condition of manual assembly.

The main contribution of this paper is the conclusion that the implementation of the IoS, the heartwood of Industry 4.0, could suit in one case of Industry 4.0 flexible production process but not in a mass production one. In this same line of reasoning, the SOMA model could as well be useful to a mass production industry; however, this use was not observed in the case. In this sense, a discussion about the application of IoS for non-flexible process and mass production remains open for future studies.

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