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DESENVOLVENDO SOLUÇÕES DA INDÚSTRIA 4.0 PARA PRODUÇÃO DESCENTRALIZADA: UMA NOVA ABORDAGEM PARA UNIDADES DE FABRICAÇÃO ADITIVAS

DEVELOPING INDUSTRY 4.0 SOLUTIONS FOR DECENTRALIZED PRODUCTION: A NEW APPROACH FOR ADDITIVE MANUFACTURING UNITS

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Comunicamos que devido à pandemia do Coronavírus (COVID 19), o VIII SINGEP e a 8ª Conferência Internacional do CIK (CYRUS Institute of Knowledge) foram realizados de forma remota, nos dias **01, 02 e 03 de outubro de 2020.**

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Objetivo do estudo
Este artigo discute como essa revolução é abordada pelo Projeto FASTEN, abordando melhorias no processo de fabricação pelo uso de Manufatura Aditiva e Robôs Colaborativos integrados por meio de uma Plataforma IoT, a fim de trazer à tona os conceitos e verificar perspectivas, desafios, melhorias e adesão dessas práticas de fabricação descentralizada ao mercado brasileiro.

Relevância/originalidade
Mudanças nos processos de produção vêm ocorrendo ao longo dos anos. A quarta revolução industrial - denominada Indústria 4.0 - se baseia na inclusão de tecnologias como: Sistemas Ciber-Físicos (CPS) e Internet das Coisas (IoT) nos processos produtivos, permitindo maior autonomia na tomada de decisões e maior transparência nas relações relações homem-máquina.

Metodologia/abordagem
Apresentação e discussão do Projeto FASTEN. A FASTEN foi criada para desenvolver, demonstrar, validar e disseminar uma estrutura integrada e modular para a produção eficiente de produtos personalizados. É um projeto financiado na quarta Europa - com recursos administrados no Brasil pela Rede Nacional de Educação e Pesquisa (RNP) e na Europa pela Comissão Europeia.

Principais resultados
Uma rede SRAM, como proposta neste projeto, poderá lidar com as peças atuais de design complexo e eliminar processos não sincronizados, reduzindo custos e melhorando os níveis de serviço fornecidos a locais estratégicos no Brasil e em outros países da América do Sul. Com base em um serviço de fabricação flexível, uma rede SRAM poderá prestar serviços a diferentes empresas industriais, reduzindo a dependência de instalações de produção centralizadas para fabricar peças de reposição.

Contribuições teóricas/metodológicas
segurança e privacidade são considerados grandes desafios para aplicativos IoT descentralizados, como o setor 4.0. Para fornecer suporte a esse modelo descentralizado, o Projeto FASTEN explora abordagens de segurança como Conhecimento do Contexto e Blockchain (DORRI et al., 2017). Como resultado, o FASTEN IoT Broker pode confiar nos dados detectados, melhorando as informações em tempo real sobre o processo de fabricação, mantendo os clientes industriais informados sobre a produção de suas peças de reposição.

Contribuições sociais/para a gestão
A plataforma FASTEN IoT deve fornecer um modelo de produção confiável, reduzindo a incerteza na previsão de demanda de peças de reposição, prazo de entrega e custos de produção, melhorando assim as demandas de produção de última hora e a eficiência de manutenção.

Palavras-chave: Indústria 4.0, FASTEN, Manufatura Descentralizada, IoT

DEVELOPING INDUSTRY 4.0 SOLUTIONS FOR DECENTRALIZED PRODUCTION: A NEW APPROACH FOR ADDITIVE MANUFACTURING UNITS

Study purpose

This paper discusses how this revolution is approached by the FASTEN Project, addressing improvements in manufacturing process by the use of Additive Manufacturing and Collaborative Robots integrated through an IoT Platform, in order to bring up the concepts as well as verify perspectives, challenges, improvements and adherence of these decentralized manufacturing practices to the Brazilian market.

Relevance / originality

Changes in production processes have been occurring over the years. The fourth industrial revolution - called Industry 4.0 - based on the inclusion of technologies such as: Cyber-Physical Systems (CPS) and the Internet of Things (IoT) in production processes, allowing greater autonomy in decision-making and greater transparency in human-machine relations.

Methodology / approach

Presentation adn discussion of FASTEN Project. FASTEN was created to develop, demonstrate, validate and disseminate an integrated and modular structure for the efficient production of customized products. It is a project funded in the fourth Europe - with resources managed in Brazil by the National Education and Research Network (RNP) and in Europe by the European Commission.

Main results

An SRAM network, as proposed in this project, will be able to handle current complex-design parts and eliminate non-synchronized processes, reducing costs and improving service levels provided to strategic locations in Brazil and in other South American countries. Based on a flexible manufacturing service, an SRAM Network will be able to provide services to different industrial companies, reducing the reliance on centralized production facilities to manufacture spare parts.

Theoretical / methodological contributions

security and privacy are considered major challenges to decentralized IoT applications such as industry 4.0. In order to provide support to this decentralized model, the FASTEN Project explores security approaches as Context-Awareness and Blockchain (DORRI et al., 2017). As a result, the FASTEN IoT Broker can trust in the sensed data, improving real-time information about the manufacturing process, keeping industrial clients informed about the production of their spare parts.

Social / management contributions

The FASTEN IoT Platform shall provide a reliable production model, reducing uncertainty in spare parts demand forecast, lead time and production costs, thus improving last-minute production demands and maintenance efficiency.

Keywords: Industry 4.0, FASTEN, decentralized manufacturing, IoT

1. Introduction

A fourth industrial revolution is currently taking place, shaping a future that will heavily rely on data acquisition and sharing throughout supply chains (BARATA; RUPINO DA CUNHA; STAL, 2018; BRETTEL et al., 2014; COMISSION EUROPEAN, 2016). This vision of interconnected business services, processes, and information systems (IS) is only possible due to technological developments in Big Data & Analytics and Cyber Physical Systems (DALMARCO et al., 2019) which leads to the concept of Industry 4.0.

The Industry 4.0 concept has its origins in Germany, and it is also recognized by other leading industrial nations like the United States, known as "Connected Enterprise", and "Fourth Industrial Revolution" in the United Kingdom (EVANS; ANNUNZIATA, 2012). In Germany, the term "Industry 4.0" originated as a strategy to mitigate growing competition from abroad and differentiate Germany and European Union industries from other international markets (LEE; KAO; YANG, 2014). Industry 4.0 is related to what is called the "smart factory" (EVANS; ANNUNZIATA, 2012), where decision making is decentralized (Bonomi et al., (2012). In an intelligent operating system, the debate about Industry 4.0 is growing rapidly as a result of intense discussions about digitization and the Internet of Things (IoT) (LA MORA, 2014; LIN et al., 2018). These debates are driven towards the best way to exploit the rapid pace of technological innovation (LA MORA, 2014) with a view to improve operational processes.

The same debate is currently happening in Brazil, where industries are moving from standard assembly lines to high-level automation (LEUNG et al., 2015). This paradigm shift between a conventional and static assembly line to an interconnected manufacturing system is not simple, as there are facilitators and limiters that can influence the adoption of innovative practices. The current recession in Brazil´s internal market led local companies to focus on the international market, shifting production standards to a new competitive level. Consequently, the adoption of new technologies as IoT or Cyber Physical Systems improves the operational processes of companies (OSAKWE; CHOVANCOVÁ; AGU, 2016).

In this scenario, Brazil needs to establish a long-term vision in line with the opportunities derived from Industry 4.0 technologies (OSAKWE; CHOVANCOVÁ; AGU, 2016). The National Confederation of Industry (CNI) argues that the advance of Industry 4.0 in

Brazil will rely heavily on knowledge and digitalization[1] as means of improving productivity, flexibility, reducing time-to-market and opening new business models opportunities. The use of Industry 4.0 allows the development of customized products at competitive prices, managing production complexities that were once a barrier. Here the use of IoT technologies[2] is the base of Industry 4.0, as it makes use of the increasing availability of communication infrastructure to form large networks, connecting the most diverse type of equipment (LEUNG et al., 2015).

Thus, to stimulate the development of Industry 4.0 technologies in Brazil, partnerships with European organizations are encouraged through cooperation agreements. An example of the result of this incentive is the FASTEN Project. FASTEN was created to develop, demonstrate, validate and disseminate an integrated and modular structure for the efficient production of customized products. It is a project funded in the fourth Europe - with resources managed in Brazil by the National Education and Research Network (RNP) and in Europe by the European Commission.

2. FASTEN Industrial Challenges

Industry 4.0 has the potential to create digital networks and ecosystems that in many cases will expand regional frontiers, but retain distinct regional footprints. The use and adaptation of Industry 4.0 technologies will lead to the implementation of decentralized business processes in the supply chain, which is at the core of the Information Systems and enterprise information management (DWIVEDI; MUSTAFEE, 2010; PAUL, 2007). In this sense, European Institutions (SMIT et al., 2016), Industries (ISAKA et al., 2016), and multinational consulting companies (GEISSBAUERE; VEDSO; SCHRAUF, 2016) address real-time integration in decentralized supply chains as the top demand in Industry 4.0 agenda. In fact, the rising popularity of Industry 4.0 across the fields of operations, production, industrial engineering and computer science has guided research in different technologies. For example, the use of virtualization in processes and supply-chain management, ensuring supply chain flexibility, visibility, and achieving end-to-end digital integration (BRETTEL et al., 2014). The

[1] The use digital information (from different sources, formats or systems) to implement improvements in the manufacturing process, supply chain, products or services (BRECHER et al., 2017; BÜYÜKÖZKAN; GÖÇER, 2018; PORTER; HEPPELMANN, 2015).

[2] Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications (GUBBI et al., 2013).

authors also mention that the use of individualized traced data will leverage technologies and concepts less common in old supply chains, such as Internet of Things, Cloud Computing and Big Data & Analytics. Industry 4.0 will be a big step into digital integration of manufacturing technologies, expanding company's boundaries to international supply chains.

Companies, however, must create transition plans for Industry 4.0 considering supply chain requirements - namely, suppliers, partners, and customers. Decentralization of production creates new challenges for real-time integration of business processes. Moreover, the emergence of digital ecosystems (BHARADWAJ et al., 2013) based on Cyber Physical Systems and IoT, has the potential to change supply chain configurations in short periods. In addition, a major technological change is underway in the form of additive manufacturing (AM), also referred to as 3D printing. AM will transform many aspects of production, distribution and the dynamics of supply chains. Decentralization and additive manufacturing enable the creation of "temporary supply chains" for specific products (eventually, a single product), constantly changing business partners and information management requirements.

The FASTEN Project foresees an industrial vision for industry 4.0 in which the use of digital technologies will improve the way manufacturing companies interact with their supply chain. Applications based on Internet of Things, Additive Manufacturing and Collaborative Robots leads to the implementation of Intelligent Manufacturing Systems, able to deal with the expectations of a new type of informed and sophisticated customer. By using industry 4.0 technologies, companies are able to deliver innovative products and services in a cost-competitive way.

3. The FASTEN Project – Development of a Decentralized Additive Manufacturing Network

The FASTEN project adds the concept of decentralized manufacturing to the possibilities of industry 4.0, developing an open and standardized structure to produce and deliver custom made spare parts. In a country as big as Brazil, a centralized manufacturing unit has a big effort in logistics, as it needs to send spare parts to distant locations. FASTEN will apply the decentralized manufacturing concept to improve on-site maintenance services – situation when it is too complex to send the product back to the company's headquarters. Additive manufacturing units will improve this concept, being capable of operating autonomously and delivering one-of-a-kind parts produced close to the client. This will be achieved through effective pairing of products integrated into an additive manufacturing process. The network will be managed by decentralizing decision-making and data exchange tools, using technologies for self-learning, self-optimization and advanced control. FASTEN will provide operational convenience by promoting the transition from current manufacturing systems to new patterns of decentralized manufacturing in a viable manner, both in terms of economic performance and long-term sustainability.

For manufacturing companies, the benefits of joining the FASTEN project are evident: The use of a decentralized manufacturing network reduces logistics costs and production lead-time, as spare parts can be manufactured close to the client. The use of additive manufacturing technologies and robots adds flexibility and autonomy to the manufacturing unit, improving production schedule efficiency.

For companies that need to perform maintenance in complex equipment with long life cycles (what impacts in spare part management), additive manufacturing emerges as an opportunity not only to provide flexibility in production, but also to increase parts accessibility. Such complex equipment have a large number of components, so keeping stocks of all components necessary for preventive and corrective maintenance is expensive and unpractical. Additionally, these parts can be highly complex or have a very specific configuration, making it harder to achieve in regular production schedules.

With the introduction of 3D printing (and other) technologies, incorporated into a flexible manufacturing system embedded in an Industrial IoT Cloud Platform (proposed as FASTEN IoT Platform), the company would see several benefits when operating:

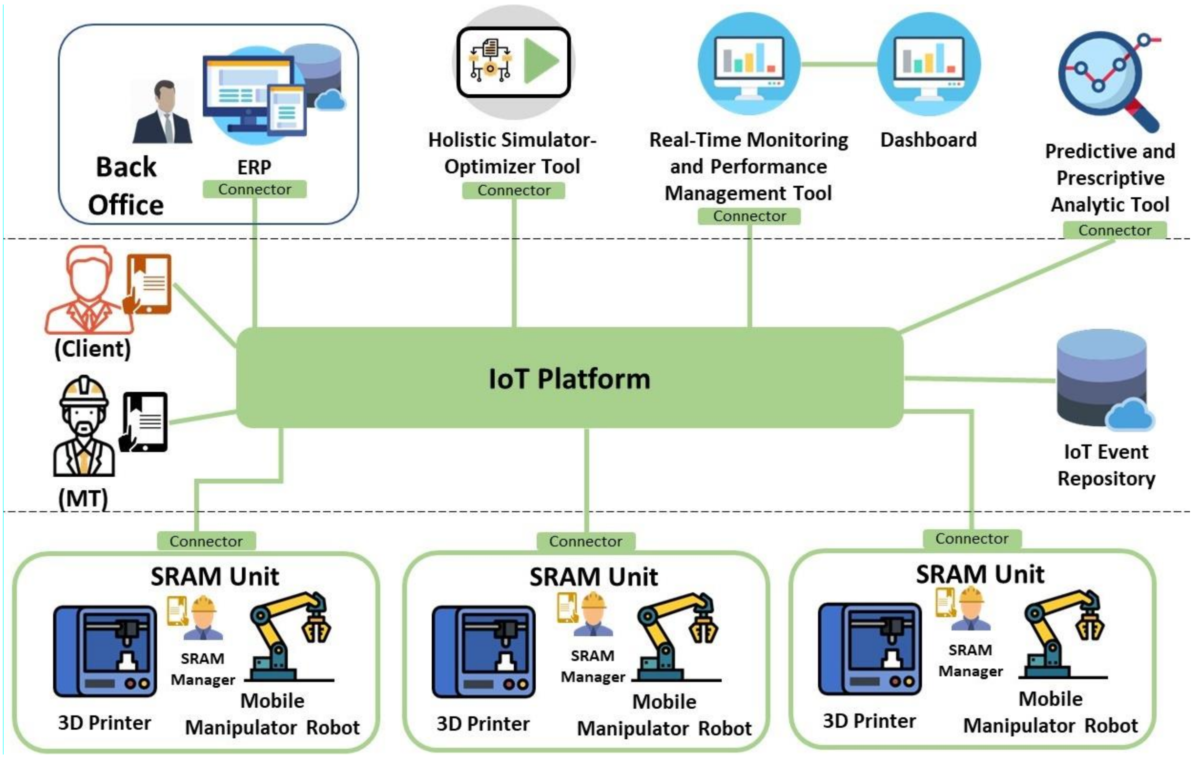
- Parts would be manufactured faster, as there is no need for long machine/line setup;
- With a flexible, self-adaptable system capable of on-of-a-kind production, producing a single or multiple piece (in small batches) would not affect system performance;
- Customer services and satisfaction would significantly be improved, with immediate availability of replacement parts, even for outdated models.

As presented in Figure 1, the entire FASTEN IoT Platform encompasses a range of different components. Such components are connected by means of an IoT Platform, also called IoT Broker. The IoT Broker is a software based on FIWARE open source platform, that explores a Publish-subscribe[3] model to manage all information exchanges between FASTEN

[3] Messaging pattern based on subscribe model that enable efficient and scalable data distribution (HAPP et al., 2017).

components. Furthermore, the company's Enterprise Resource Planning (ERP) software can be connected to the IoT Broker in order to provide the company direct access to FASTEN components.

Figure 1 – FASTEN components



Source: the authors 2019

For FASTEN Industrial testing, the ERP was used to manage all production orders that were sent to the different SRAMs, including current production jobs running, jobs in error status and manufacture queue. Between the functionalities provided to the company ERP the other FASTEN components that can be accessed are described bell ow:

- **SRAM Unit:** Where the parts will be printed, the units are equipped with 3D printers and a Mobile Manipulator Robot (MMR)
- **Advanced Plant Model (APM):** It is a virtual representation of the SRAM unit.
- **Holistic Simulator-Optimizer Tool:** Used to arrange an optimal SRAM Network and, during production scheduling, to define the optimal SRAM to produce a certain part.

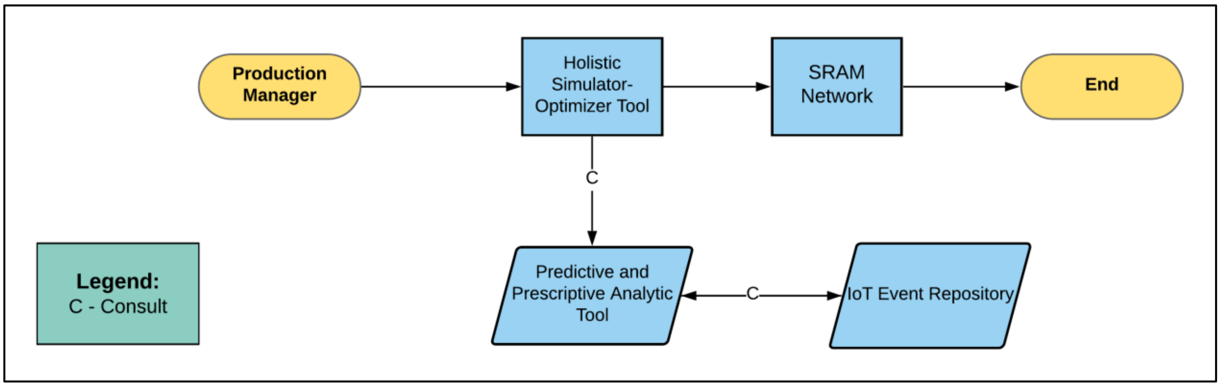
- **Real-time Monitoring and Performance Management Tool:** This software component will display in a dashboard real-time information about the activities being accomplished in the SRAM unit by the 3D Printer and the MMR, and present performance indicators.
- **Predictive and Prescriptive Analytic Tool:** Responsible for analyse data and predict spare part demands.
- **IoT Event Repository:** Responsible for storing all data from sensors and manufacturing orders.

3.1. Running the FASTEN IoT Platform

In order to operationalize the developments of FASTEN, a functional test platform was developed encompassing two SRAMs located in different cities in Brazil – one in Porto Alegre (RS), the other in Salvador (BA).

The operationalization of the FASTEN IoT Platform starts by the configuration of a SRAM Network (Figure 1), which demonstrates the use of the Predictive and Prescriptive Analytic Tool on a strategic level. Using all the gathered data from the FASTEN IoT Event Repository, the FASTEN Predictive and Prescriptive Analytic Tool analyses the spare parts demand including seasonal patterns, thus providing information about future demands and suggesting the best cities to operate a SRAM unit. This process is started by Production Manager (PM), who runs the FASTEN Holistic Simulator-Optimizer tool. This tool provides data regarding the number of SRAM units needed, where these SRAM's will be located, and how many 3D printers will be installed at each SRAM unit. After the configuration of the SRAM Network, the FASTEN IoT Platform is ready to be used.

Figure 2 - Smart Manufacturing Network configuration process

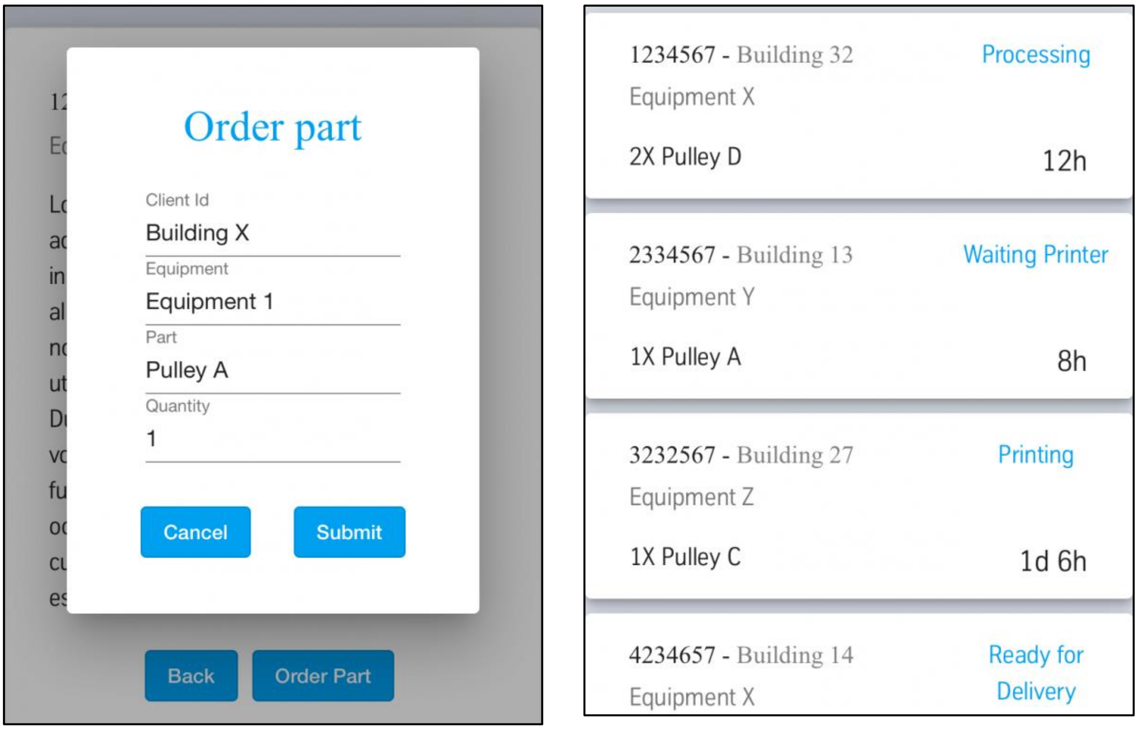


Source: the authors 2019

To test the functionalities of the FASTEN IoT Platform, an industrial experiment was conducted to simulate the full operation of an equipment maintenance. The process starts when the client reports a product's malfunction or broken part through his mobile App (figure 3). At the client, the Maintenance Team (MT) reviews the equipment and orders, if necessary, new parts to replace worn out or broken ones. The MT also uses a mobile APP to order spare parts, which is connected to the company's ERP.

Figure 3 – a) Ordering part in the app. b) Information of the spare part production status

(a) (b)



Source: the authors 2019

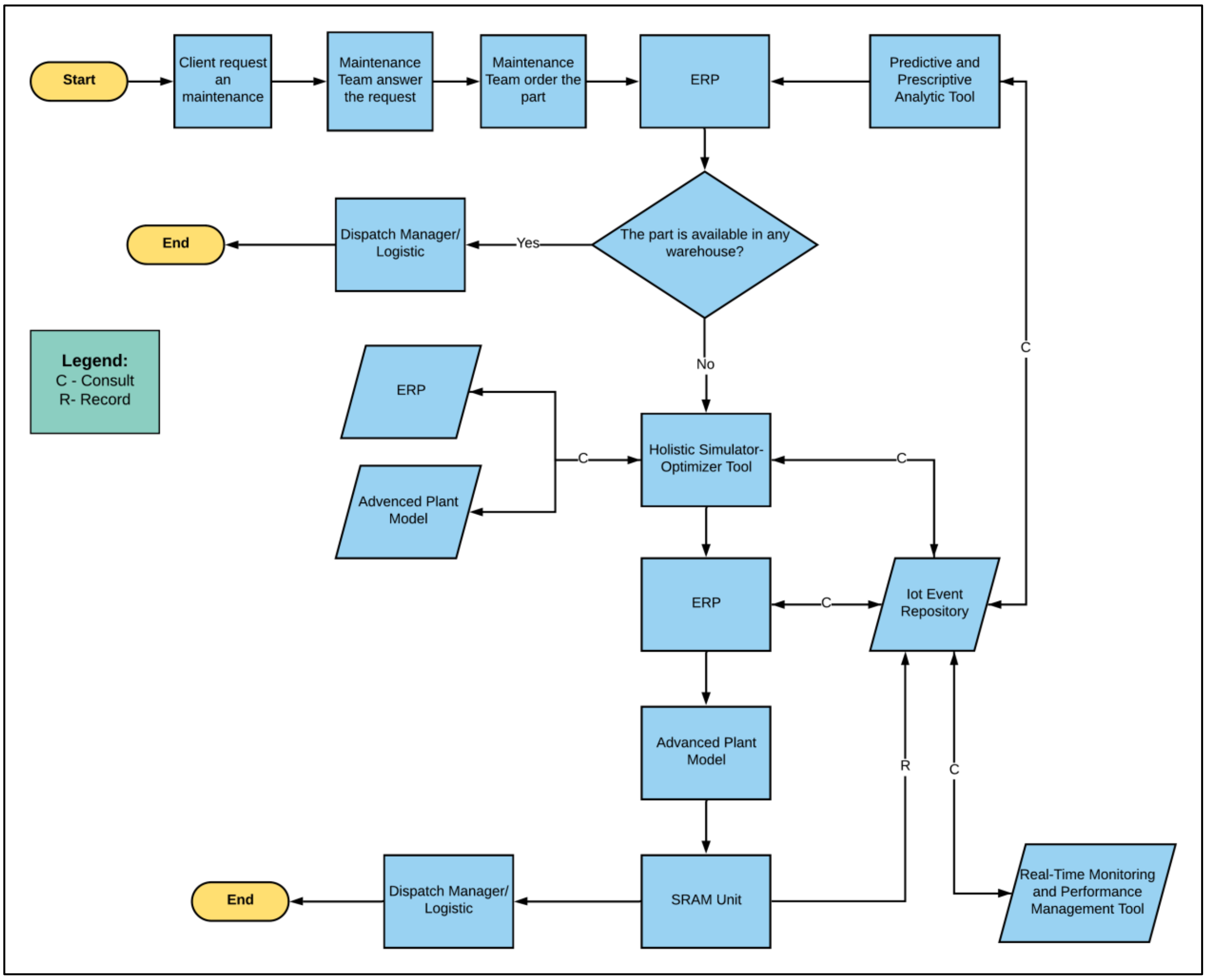
The APP also displays the part's production status, representing the use of 3D printers in the manufacturing process. Both the Client and the MT will receive different production updates, as follows:

- **Processing:** Waiting the Holistic Simulator-Optimizer Tool ,define the optimal SRAM to produce the specific spare part.
- **Waiting printer:** Waiting the 3D printer availability according to the SRAM printing queue.
- **Printing:** The spare part is currently in printing process.

- **Ready for Delivery:** The spare part is already printed and being transported by a robot to the SRAM shipping area.
- **Shipping:** The spare part is on route to the due client´s location.
- **Delivered:** The spare part is under maintenance team possession, the process of print and delivery the spare part is complete.

After the MT reports a spare part request, the full manufacture process is managed by the company´s ERP (figure 4).

Figure 4 - Diagram of complete FASTEN Operation



Source: the authors 2019

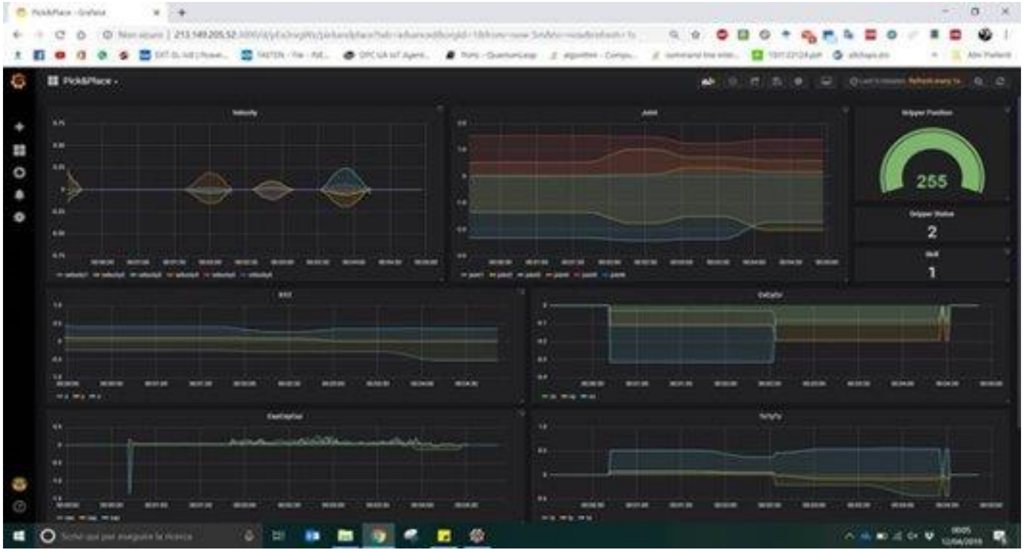
As mentioned before, the company's ERP is the main responsible for managing the manufacturing process. After the order is reported at the ERP system, it will check if the part is available at any warehouse or if it needs to be manufactured. The warehouses used by FASTEN are Smart Warehouses[4], having all the stock controlled by an automated system. When the part is available at a warehouse, it is shipped to the MT as soon as possible. If the part is not available, the ERP sends a Manufacturing order to the FASTEN IoT Platform.

The manufacturing process starts through an optimization request to the FASTEN Holistic Simulator-Optimizator tool. This request is necessary as the Holistic Optimization-Simulation tool will inform which SRAM unit is available (considering the type of part, type of client, SRAM availability, lead-time, cost, capacity, maximum number of 3D printers in a SRAM, time of producing the spare part, cost of acquiring the same spare part from an External Supplier (ES), suppliers' delivery time to the warehouse, suppliers' delivery costs and internal order cost) to produce that part.

After concluding the analysis, the FASTEN Simulation-Optimization tool informs the ERP to which SRAM the order should be sent. In the functional test, the client was located in Rio de Janeiro, and the system decided to produce the part in Salvador. The ERP then informs the Advanced Plant Model (APM) responsible for the SRAM assigned, which is in charge of allocating the manufacturing order to the specific 3D printer and to the robot, after the part is printed. This order arrives directly in the SRAM that will then start printing the requested spare part. While the SRAM is producing the order, the Real-Time Monitoring and Performance Management Tool (Dashboard) presents real-time data coming from the 3D printer and from the Robot (Figure 6), also the ERP monitors the IoT Event Repository to know when the SRAM becomes idle.

[4] A warehouse that explores Cyber Physical Systems to automate operations of pickup, delivery or bookkeeping, resulting in an automated, unmanned and paperless warehouse (LIU et al., 2018).

Figure 6 – Dashboard performance information



Source: the authors 2019

Once the printing process is finished, the 3D printer sends the status to the APM, who then assigns the picking order to the robot. The robot will pick the printed spare part up from the 3D printer autonomously and place it at the SRAM shipping area for Dispatch Manager/Logistics. The final step is done once the MT receives the spare part and installs it in the machine, closing the service.

4. FASTEN Industrial Improvements

The use of Smart Robotic Additive Manufacturing Units – based on 3D printers, mobile robots and IoT features - may provide to manufacturing companies a flexible production solution for different types of spare parts. In their results (BRETTEL et al., 2014; LIN et al., 2018) highlight the critical role of IT in technology adoption for Industry 4.0. This implies the need to exploit the driving forces behind adoption, as well as to evaluate their benefits for companies (BARATA; RUPINO DA CUNHA; STAL, 2018; BRETTEL et al., 2014; COMISSION EUROPEAN, 2016).

However, aspects such as lack of qualified labor and reduced efficiency/quality in production process (DALMARCO et al., 2019) are still barrier to those who want to adopt industry 4.0 technologies. Today, the manufacturing process is mostly based on a centralized model where plastic parts are produced by an injection-molding operation. An SRAM network, as proposed in this project, will be able to handle current complex-design parts and eliminate non-synchronized processes, reducing costs and improving service levels provided to strategic locations in Brazil and in other South American countries. Based on a flexible manufacturing service, an SRAM Network will be able to provide services to different industrial companies, reducing the reliance on centralized production facilities to manufacture spare parts.

Nevertheless, to ensure trust in a decentralized production, aspects such as information security require special attention. Due to the model of decentralized production, traditional approaches, as cryptography, became insufficient to ensure trust in such environments (GUBBI et al., 2013). Hence, security and privacy are considered major challenges to decentralized IoT applications such as industry 4.0. In order to provide support to this decentralized model, the FASTEN Project explores security approaches as Context-Awareness and Blockchain (DORRI et al., 2017). As a result, the FASTEN IoT Broker can trust in the sensed data, improving real-time information about the manufacturing process, keeping industrial clients informed about the production of their spare parts. The FASTEN IoT Platform shall provide a reliable production model, reducing uncertainty in spare parts demand forecast, lead time and production costs, thus improving last-minute production demands and maintenance efficiency.

In conclusion, FASTEN industrial tests were able to reduce the lead-time from 90 days to only 4. The flexibility of 3D printers also affects the price of spare parts, reducing the need of buying 10 to 100 parts from suppliers (third parties) when only one is really needed to solve the equipment’s problem. This may also improve support to outdated equipment. In these situations, the original Bill of Materials is usually no longer available, reinforcing the need of producing one of a kind part. Future developments of the SRAM units may encompass different types of 3D (Jayavardhana Gubbi, 2013)printers, upgrading the capacity of the manufacturing unit. As prices of 3D printers falls, and technology improves, using Additive Manufacturing 3D Printers will influence not only maintenance services, but also the whole production process.

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