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A CONFIGURATION MODEL OF THE SMART MANUFACTURING COMPANY

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Abstract: *The paper aims at illustrating the new developments of information technology applied in production management and at providing a conceptual model of the configuration of the intelligent or smart enterprise. After a brief overview of Industry 4.0 addressed in the introduction, the paper presents the concept of smart manufacturing, where the role of 5G connection, Internet of Things (IoT), artificial intelligence (AI) and digital twin is explained. Next, a conceptual model of the smart manufacturing company configuration is proposed, with examples from the Bosch company. The paper ends with conclusions highlighting the qualities and usefulness of a smart manufacturing company.*

Key words: *AI, IoT, digital twins, smart manufacturing company's configuration model.*

1. Introduction

The increase in global competition and the need to develop the green economy has determined the management of companies to implement innovation in production flows based on AI, IoT and digital twins.

Research conducted in 2012, identified several interesting open challenges for the future; energy efficient data delivery with small delays, data distribution in local and mobile clouds, distributed, real-time data security for industrial robots and assembly line, and convergence between the two main scientific fields (Raptis et al., 2019). In 10 years, technology has developed huge advances.

The evolution of markets and customer requirements with the highest level of precision, has been created with the help of technology and information systems. However, a new way of doing operations has been developed in companies, so that only companies with the ability to adapt more quickly to new technology and through innovations will remain on the market.

The latest industrial revolution, known as industry 4.0, perceives operations as a holistic system; it represents a challenge, especially for companies that compete with global ones, and which must be met and faced in order to achieve stability and permanence on the market. In the organizational and business area all the operations

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must be linked to computer systems and management of information in the network, which brings about greater efficiency in the flow (Indri et al., 2018).

The fourth industrial revolution (4IR or 4.0) introduces the concept of smart factories. In these futuristic factories, connected devices can perceive their environments and interoperate with each other, making decentralized decisions (Tomas, 2021a).

The fourth industrial revolution, which has become a reality in recent years, profoundly changes production processes and will lead to the creation of smart factories, which will benefit from the design principles of Industry 4.0, respectively: interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity (Indri et al., 2018).

The manufacturing industry needs to lead innovations to face the global competitive pressures in the advent of intelligent manufacturing across the broad range of manufacturing sectors (Jardim-Goncalves et al., 2017).

Technologically advanced devices, such as accurate robotic elements, sensing systems, smartphones, smart glasses, and GPS-enabled cameras, are already having a transformative effect on the development of I4.0 enabled industrial ecosystems by interlinking the cyber and physical worlds and leading to an industrial cyber-physical (Conti et al., 2012).

In order to address the upcoming challenges of the cyber-physical convergence in the frame of I4.0, as well as to increase the efficiency of the digital twin, several pivotal technological enablers have emerged. Novel assembly lines used in the production process are expected to boost the reconfiguration of automated manufacturing systems and provide robust operation and short production lifecycles needed by manufacturing firms so as to stay competitive in the marketplace (Cupek et al, 2018).

The global Smart Factory market is expected to grow by USD 90.1 billion, driven by a compound growth rate of 8%, and will reach USD 214.2 billion by 2026, of which China will reach USD 43.2 billion (globenewswire .com).

In this context, the work aims to present:

a. the concept of smart manufacturing, based on IoT, artificial intelligence and digital twins, as defining components of industry 4.0 and
b. the conceptualization of a configuration model of the intelligent enterprise, based on the experience of the Bosch company.

The research methodology consists in the investigation of the bibliographic references available on the Internet, the analysis of the collected data, own interpretation and the conceptualization.

2. The Concept of Smart Manufacturing

2.1. Characteristics

Smart Manufacturing means bringing the elements of intelligent technology – sensing inputs, computing power, always-on connectivity, artificial intelligence and advanced data analytics – into the traditional manufacturing process (instrumental.com).

The novelty in intelligent enterprises consists in replacing old technologies with digital technologies and intelligent components (sensors, IoT, simulation, digital twins, robots, etc.). Smart manufacturing includes digital technologies, which characterize Industry 4.0 (Industry 4.0), but also digitizes the business outside the factory (Rovito, 2022).

Decision-making algorithms based on artificial intelligence, robotic wireless sensors, networks and real-time production logistics based on the Internet of Things are decisive in the development of intelligent cyber-physical production systems (CPPS) and production systems based on Industry 4.0 (Andronie et al., 2021a).

In the smart manufacturing model, autonomous manufacturing units can communicate with other factory locations and facilitate the integration of existing industrial infrastructure with IoT and cloud computing. This transformation is expected to be based mainly on the capabilities of next-generation 5G networks.

2.2. 5G networks

Industrial 5G, capable of meeting the exact performance requirements of mission- and business-critical applications, is still evolving as relevant international organizations finalize standards for important features (rcrwireless.com). With a private 5G network, factories can rapidly implement AI and machine learning without having to disrupt the production line and supply chain through infrastructure changes (enterpriseiotinsights.com).

5G networks give manufacturers the opportunity to build smart factories and truly take advantage of technologies such as automation, artificial intelligence, augmented reality for troubleshooting and the Internet of Things (IoT). The low latency, high reliability and increased speed of 5G networks are essential to support emerging technologies and their new applications in this field, such as process automation, remote monitoring and collaborative robots, among others (Tomas, 2021a).

5G technology also allows greater flexibility, lower costs and shorter lead times for factory production reconfiguration, layout changes and modifications, which will lead to significant improvements in terms of production (Resnik, 2022).

2.3. IoT, AI and big data

Sensors and connected input devices – things like tracking devices in trucks, environmental monitors in factories or cameras on the assembly line – make up the Industrial Internet of Things (IoT) and are designed to monitor supply chain steps, machine health and factory conditions. Often these devices consist of a sensing element, an efficient microprocessor brain, and a radio or other way to communicate information back to a centralized hub. With the continued miniaturization of technology, these devices are now small, efficient and cheap enough to be installed everywhere in the factory and along the supply chain.

But, just collecting data is not enough. To be useful, the information collected by the sensing devices must be able to be analysed, leading to useful information. This is where artificial intelligence and big data come into play. With enough data, machine learning and artificial intelligence (AI) platforms can be trained to identify anomalies in production quality or standard procedures. On the assembly line, this can mean speeding up problem discovery and solving problems before they happen. Decision support systems based on the Internet of Things, big data analysis based on artificial intelligence and wireless sensor robotic networks configure smart manufacturing and cyber-physical manufacturing systems in sustainable industry 4.0 (Nica et al., 2021).

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2.4. Digital twin

A digital twin is a virtual model designed to accurately reflect a physical object. A digital twin is a virtual representation that serves as the real-time digital counterpart of a physical object or process, which was designed to improve the simulation of the physical model of spacecraft in 2010. The concept, which has had several different names, was later called the “digital twin” by John Vickers of NASA in a 2010 roadmap report (Piascik, 2010).

The digital twin concept consists of three distinct parts: the physical product, the digital/virtual product, and the connections between the two products.

Digital twins are virtual replicas of real-life assets, processes and businesses and are key enablers of digital transformation. Designed as a lever to deliver greater sustainability and a circular economy at speed and scale, the digital twin solution uses advanced data-driven programs and artificial intelligence to help drive innovation and agility through monitoring, diagnostics and forecasting to optimize better performance and asset utilization.

According to the precise definition of the Digital Twin Consortium, digital twins are “virtual models of a process, product or service that enable data analysis and system monitoring through simulations” to make data-driven decisions regarding maintenance, sustainability, efficiency and performance (Resnick, 2022).

The digital twin can be created with any device if enough historical data is collected (design, component origins, factory conditions, tests and processes). It integrates geometry, real-time telemetry, engineering analysis, sensors, connectivity, artificial intelligence, machine learning and software analysis into a unified spatial model to create a living digital simulation that can update and change as their physical counterparts it changes. In manufacturing in particular, digital twins could be created to focus on a single component within the manufacturing process or a single piece of equipment on a production line. They can also be deployed at a production site to monitor and improve an entire production line or even to monitor the entire manufacturing process, from product design and development to production (Tomas, 2021b).

Computerized manufacturing with digital twins and the cognitive loop rapidly redesigns customized requests into the monitoring parameters of the cyber-physical manufacturing system that significantly improves operational efficiency from preparation to production. The digital twin integrates a storage inspection connection that includes big contextual data about distinct components and statistical allocations to the assembly of components (Andronie et al., 2021b).

The connections between the physical product and the digital/virtual product are data that flows from the physical product to the digital/virtual product and information that is available from the digital/virtual product to the physical environment.

The object under study is equipped with various sensors related to vital areas of functionality. These sensors produce data about various aspects of the physical object's performance, such as energy production, temperature, weather conditions, and more. This data is then fed to a processing system and applied to the digital copy. Once informed with such data, the virtual model can be used to run simulations, study performance issues, and generate possible improvements, all with the goal of generating valuable information—which can then be applied back to the original physical object.

Digital twins can be used to provide a virtual mock-up of products, machines or facilities for simulation purposes, but also to clearly visualize real-life procedures and processes. These uses lead to a better understanding of the way of operation, to virtual testing and optimization of processes or systems (boschrexroth.com).

Although simulations and digital twins both use digital models to replicate the various processes of a system, a digital twin is actually a virtual environment, making it considerably richer for study.

The difference between digital twin and simulation is largely a matter of scale: while a simulation typically studies a single process, a digital twin can itself run any number of useful simulations to study multiple processes.

Simulations typically do not benefit from having real-time data, but digital twins are designed around a two-way flow of information that occurs first when object sensors provide relevant data to the system processor and then again when the information created of processor are shared back with the original source object.

Among the companies that use digital twins we exemplify: Microsoft Corporation, Bosch, General Electric Company, IBM Corporation, Siemens, Oracle Corporation, Cisco Systems, Dassault Systems, Ansys, PTC Inc. (emergenresearch.com).

3. The Smart Factory Configuration. Bosch example

As presented above, the smart enterprise includes 5G connectivity, software, IoT and last-generation machines, but also from modernized and connected traditional ones, artificial intelligence, digital twin and robots.

Considering the theoretical aspects presented by different authors, the practical example provided by the Bosch company and their own analysis and interpretation, a new configuration of the company is proposed (figure 1).

Specific to this business model is the fact that the entire logistics chain, including production, is intelligently connected. The connection is 5G with reference to a platform/portal. The equipment is digitized by experts, and the data is collected by sensors in the database and stored in the cloud, which at the same time are processed by digital twins providing feedback in real time, and artificial intelligence operates robots.

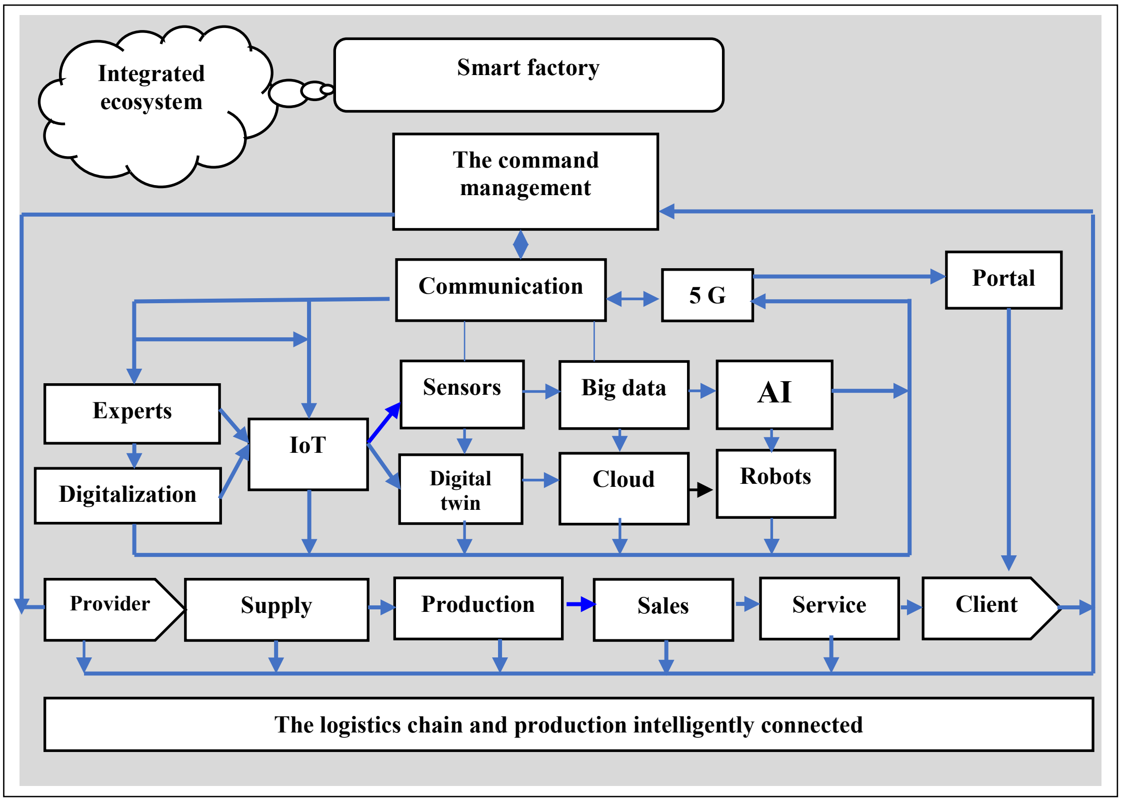

Fig. 1. *A model of smart manufacturing company's configuration*
(Author's conceptualization)

An example of a smart factory is the Bosch company, where the components of the proposed model are actually implemented (Bosch.com).

- *5G connection and communication*: Bosch is using 5G to run sensors on cars in real-time, allowing them to fix problems on the production line before they happen. An added benefit was the installation of a network of collision detection sensors, making the factory and its products much safer for employees.
- *Big data, software and cloud:* Bosch uses its own software called Nexeed, which helps to connect all data flows in production and logistics in an intelligent way. Since plants and machines are connected via IoT and their data is read in real time, the entire value-added chain is transparent at all times. With a clear overview, it quickly becomes apparent where resources can be saved and how processes can be streamlined, identifying critical deviations. This can help prevent unplanned production shutdowns. Data is processed from connected devices in the Cloud, which allows machines to communicate with their environment and take on more and more tasks that are too monotonous or too stressful for humans.
- *Latest generation technology and equipment*: Bosch uses complex technologies with the Nexeed software solution, which collects, analyses and prepares an overview of production and logistics data. In order to get a complete perspective, all production data is downloaded directly to the tablet or smartphone by the person assigned to

the production. It also turns data records into key performance indicators on energy and resource efficiency. This allows consumption to be compared, weaknesses to be identified and improvements to be implemented.

- *Sensors and Digital twins:* It enables applications to manage the digital twins of IoT devices in a simple, convenient, robust and secure way to anticipate machine maintenance or to simulate different technical solutions to choose the best for the real application.
- *Artificial intelligence:* Using data mining, with the help of special data visualizations and artificial intelligence, new insights can be extracted from this data with absolute precision, because micrometric deviations of individual components often determine quality along the entire production line. The assembly process is documented by countless sensors. In addition, data is transmitted from cameras that check every step of the assembly process. In 24 hours, approximately 1 million data messages are processed. In this way, there is the certainty that no defective component leaves the line.
- *Robots:* Robots navigate among humans, intelligently considering people's habitual and future behaviours and other dynamic obstacles, although generating safe and legible robot movements is still an open research problem. Through planning and automatic learning, which is a fundamental subfield of artificial intelligence, decision-making problems are solved, such as moving packages to a certain location by the robot (Palmieri, 2022).

Horizontally, Bosch collaborates with its suppliers, customers and partners, transforming the networks of partners and suppliers into a connected IoT ecosystem, because only by ensuring the use of common standards can the interoperability of industrial platforms and solutions be ensured. The company offers its customers concepts and methods aimed at improving the entire service chain, where automation is a key part of the solution. Instead of implementing these steps individually, Bosch integrates them from one end to the other, resulting in a set of rational solutions" (Nordmann, 2019). All processed information is stored and made easily available to all authorized users in the cloud. In addition, historical analyses over time make it possible to compare today's values with those of the past. This data can be used either for immediate customer benefits or for new service offerings.

Managing devices as a two-way communication flow brings obvious benefits; on the one hand, the control and servicing of the devices in terms of automatic campaigns, updates and backups and on the other hand, the devices help to track the history of each asset. This includes remote health monitoring, remote configuration, mass management, and fully automated error notifications and diagnostics. Therefore, device management is much more than just an update; it provides important information for business optimization.

4. Conclusions

The advance of information technology led to the advance of engineering, so that a new configuration of the manufacturing enterprise was developed, called smart. This is based on artificial intelligence (AI), the internet of things (IoT) and big data, which allow unexpected connections, flexibility, independence in decisions, automatic control determined by predetermined rules and increased productivity and efficiency, and also contributing to the development of the ecosystem

The intelligent enterprise is specific to industry 4.0, in which the real world is combined with the digital one and allows the implementation of processes in which people work together with robotic elements and in which the simulation advances to the digital twin.

Smart manufacturing refers to the digitization of production at all levels: product design, supply chain, production, distribution and sales. By analysing data from all stages of the manufacturing process through machine learning, artificial intelligence and connected robotics, manufacturers can remain agile and make rapid adjustments to their business models (Rovito, 2022).

The transition to intelligent manufacturing starts with bringing analogue data into a digital database. Smart manufacturing is a technology-based approach that uses internet-connected machinery to monitor the manufacturing process. Its purpose is to identify opportunities to automate operations and use data analysis to improve manufacturing performance (Burns, 2022).

It has been highlighted that companies in almost all industries are looking to digital twin technologies to drive meaningful business results across the entire product development lifecycle, from ideation and production to production, support and maintenance (Altran, 2018). A digital twin is essentially a computer program that uses real-world data to create simulations that can predict how a product or process will perform. These programs can integrate the IoT, AI and software analytics to improve results.

Digital twinning in automation can best be defined as a digital copy of an automated process that resides in a separate repository to the robotics process automation (RPA) platform where the actual automation is developed, deployed and orchestrated (Shimmerman, 2023).

Smart manufacturing offers a number of benefits, including improved efficiency, increased productivity and long-term cost savings. In a smart factory, productivity is continuously improved (Burns, 2022). The intelligent enterprise also has an important role in the development of the eco-system, substantially reducing energy consumption. In the new type of enterprise, management changes its role and must adapt to the challenges.

Today's manufacturers are looking for efficiency in production and at the way to transform their business through Industry 4.0 and further 5.0. To realize the new industries the firms do not have to apply a major overhaul of the infrastructure that costs a lot of money. Smart factory solutions have the ability to connect and extract data even from disconnected legacy systems and compute and visualize data for intelligent management and data-driven digital transformation. (advantech.com).

In the smart factory, the manufacturers need to invest in the solid infrastructure with reliable, durable and accurate smart devices and in talented people that needs to operate, maintain and upgrade the smart ecosystem (Rovito, 2022). In addition, a proper cyber risk management system is needed to ensure the system security and privacy issues, as well (Negulescu et al. 2022).

The example of the Bosch company is instructive for the realization of intelligent production. It collects data about products from the assembly line and correlates test results to find anomalies in real time. Machine learning algorithms can find problems that are not currently being looked for so they can be fixed quickly. All data are consolidated in one place through a close collaboration, in real time, with their partners and suppliers. Therefore, Bosch applies innovation for performance, supporting open-source and standards as a strategy to increase the value of the activity, but, at the same time, it also represents a win for the entire industry.

The conceptual model proposed regarding the configuration of the intelligent enterprise implies strategy, connectivity and integration. It can be a useful tool for the managers of companies that are based on creativity, innovation, digitization and flexibility in order to increase the competitive advantage.

The research will continue with change management in the smart factory.

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