# *Industry 4.0* in Volkswagen Autoeuropa

## Study of the effects of *Industry 4.0* in the launching process of a new model

**Miguel da Silva Villalva**

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## Mechanical Engineering

Supervisors: Prof. Carlos Baptista Cardeira

Prof. Elsa Maria Pires Henriques

**Examination Committee**

Chairperson: Prof. Paulo Jorge Coelho Ramalho Oliveira

Supervisor: Prof. Elsa Maria Pires Henriques

Member of the Committee: Prof. João Miguel da Costa Sousa

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# Abstract

Currently the release of a new car model to the market is a very long and expensive process that no longer meets the growing need of the customers for customized products with increasingly reduced time-to-market. It is necessary to reformulate this process and go along with the evolution of technology. To do so, the implementation of *Industry 4.0* in this process can be the future and the way forward.

This research was based on the release of the 2017 Volkswagen T-Roc in Volkswagen Autoeuropa in order to analyze how the current process is carried out and why, and to understand how *Industry 4.0* can be implemented and establish a roadmap that can guide this evolution. Finally, a prediction of the evolution of this process is made with the goal at the year of 2025.

The development of *Industry 4.0* within the automotive industry is only just beginning, however, it is already possible to predict that this implementation will revolutionize automotive production from its core. In the case of the process of launching a new car model, this whole process will undergo an enormous revolution with reductions in its duration and production of waste, and in improving its effectiveness and productivity.

**Key words:** *Industry 4.0*, automation, customization, industrialization, Volkswagen T-Roc.

# Resumo

Atualmente, o processo de lançamento de um novo modelo automóvel é um processo muito longo e dispendioso que já não atende às crescentes necessidades dos consumidores para produtos personalizados e com cada vez menor *time-to-market*. É necessário reformular este processo e acompanhar a evolução da tecnologia. Para isso, a implementação da Indústria 4.0 neste processo pode ser o futuro e o caminho a seguir.

Esta investigação baseou-se no lançamento do Volkswagen T-Roc de 2017 na Volkswagen Autoeuropa, a fim de analisar como o processo atual é realizado e o seu porquê, e para entender como a Indústria 4.0 poderá ser implementada e estabelecer um *roadmap* que possa orientar esta evolução. Finalmente, é realizada uma previsão da evolução deste processo com o objetivo no ano de 2025.

O desenvolvimento da Indústria 4.0 na indústria automóvel está apenas no início, no entanto, já é possível prever que esta implementação revolucionará por completo a produção automóvel. No caso do processo de lançamento de um novo modelo automóvel, todo o processo sofrerá uma enorme revoluçã com redução na sua duração e produção de sucata, e na melhoria da sua eficácia e produtividade.

**Palavras-chave:** Indústria 4.0, automatização, personalização, industrialização, Volkswagen T-Roc.

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# List of Acronyms

* English / *German*

| | |
|---|---|
| **0S*** | 0-Series / *Null Series* |
| **AGV** | Automated Guided Vehicle |
| **AM** | Additive Manufacturing |
| **AR** | Augmented Reality |
| **CC** | Cloud Computing |
| **CIM** | Computer Integrated Manufactuing |
| **CLI** | Command Line Interface |
| **CPPS** | Cyber-Physical Production Systems |
| **CPS** | Cyber-Physical Systems |
| **DSG*** | Direct Shift Gearbox/ *Direkt-Schalt-Getriebe* |
| **EB** | Exabyte |
| **EOP** | End of Production |
| **GDP** | Gross Domestic Product |
| **GUI** | Graphical User Interface |
| **ICT** | Information and Communication Technologies |
| **IIoT** | Industrial Internet of Things |
| **IoS** | Internet of Services |
| **IoT** | Internet of Things |
| **IP** | Internet Protocol |
| **IST** | Instituto Superior Técnico |
| **IT** | Information Technologies |
| **IWN** | Industrial Wireless Network |
| **JIS** | Just-in-Sequence |
| **KPI** | Key Performance Index |

| | |
|---|---|
| **LTF*** | Stress-Test/ *Leistungstest Fertigung* |
| **M2M** | Machine to Machine |
| **MC** | Mass Customization |
| **ME*** | Market Launch/ *Start auf dem Markt* |
| **MES** | Manufacturing Execution Systems |
| **MKx** | Mark x |
| **MP** | Mass Production |
| **MPV** | Multi-Purpose Vehicle |
| **MQB*** | Modular Transversal Toolkit/ *Modularer Querbaukasten* |
| **MTSOP** | Months to SOP |
| **NIST** | National Institute of Standards and Technology |
| **PEP** | Product Emergence Process |
| **PHS** | Production Handbook of Standardization |
| **PLC** | Programmable Logic Controller |
| **PP**[1] | Product Process |
| **PVS*** | Pilot Series/ *Produktions-Versuchs-Serie* |
| **RFID** | Radio Frequency Identification Device |
| **RM** | Rapid Manufacturing |
| **RP** | Rapid Prototyping |
| **SOP** | Start of Production |
| **SUV** | Sport Utility Vehicle |
| **TDI** | Turbocharger Diesel Injection |
| **TIS** | Time in System |
| **TKB** | Technical Concept Description |
| **TPB** | Product Description Book |
| **TSI** | Turbo Stratified Engine |
| **VFF*** | Pre-Series Approval Vehicles/ *Vorserien-Freigabe-Fahrzeng* |
| **VR** | Virtual Reality |
| **VTM** | Virtual Technology Model |
| **VW** | Volkswagen |

# 1. Introduction

## 1.1. Motivation

Today, a concept has been gaining momentum in the world of industry as the future and the way forward. Starting in Germany, *Industry 4.0* is a term that represents the 4th industrial revolution that promises to completely alter today's production paradigm.

With the change in consumer demand, manufacturing is no longer the simple production of "better" physical products. Consumers no longer just want to settle for mass-production products but rather want products suited for them individually. Demand is shifting towards personalization, customization and creation.

Along with the change in the consumer demand, also the actual products are going through a transformation. Added sensors and connectivity turn "dumb" products into "smart" ones, through connectivity, intelligence and responsiveness

This new stage in the industrial history of the world constitutes an evolution of the manufacturing paradigm that seeks to leverage the existing technology and market potential to improve processes, productivity and efficiency. The core idea of this new concept is to use the current technologies, especially the emerging Information and Communication Technologies (ICT), to implement the Internet-of-Things (IoT) and Services (IoS) and create a basis for integration and communication allowing production to become extremely flexible and efficient.

This evolution of the manufacturing paradigm is leading to the convergence of the physical world with the virtual world through the development of Cyber-Physical Systems (CPS), intelligent systems with extreme communication capabilities that will reconfigure the way products are manufactured.

Following the trend of *Industry 4.0*, the automotive industry is undergoing drastic changes both in automotive production where digitization is helping manufacturers to connect their factories and take advantage of the data produced to improve processes and products.

The process of launching a new car model in a factory is an extremely complex and time-consuming process where implementing this new concept can improve the way this process is performed. At an early stage, it is important to identify the potentialities of implementing these concepts in the launch process and the greatest difficulties that may arise and must be overcome in order to prepare how new technologies should be implemented, and how this evolution should be carried out.

## 1.2. Contextualization

Volkswagen as one of the biggest automotive brands and Volkswagen Autoeuropa as one of the largest companies in Portugal, are both in the forefront of future developments in this area in order to both keep themselves always at the vanguard of technology and in the path towards the future.

The release of a new car model to the market is a long and expensive process with several phases until the new model is implemented in the factory plant, and it is produced in mass. The duration of this process is constantly being the target of investigations and researches in order to reduce as much as possible the time-to-market of the new model. Besides this, the reduction of costs is also very important in this process, once until the release of the new model several prototype vehicles are produced, and some have extremely high production costs. Some of the objectives of the Volkswagen brand in its strategy until 2025 are to try to reduce the duration and costs of this process.

This way, *Industry 4.0* and its related concepts may play an important role to reach the goals of the Volkswagen Brand.

## 1.3. Objectives

The objective of this thesis is the study of the effects of the concepts of "*Industry 4.0*" and "Factory of the Future" in the process of prototyping and releasing of a new car model in Volkswagen in order to try to reduce several characteristics of a launching process such as the number of cars produce in pre-series stages, waste/scrap production, and duration of the whole process.

## 1.4. Methodology followed

This thesis consists on a prediction of the evolution of the launching process in the automotive industry having its basis the Volkswagen Autoeuropa factory process of launching of the 2017 Volkswagen T-Roc.

Firstly this process is analyzed and described in order to fully understand how it is carried out today and why. The launching process was accompanied by close in the factory. After that, and taking into account the current customer needs that are constantly changing, a prediction of the evolution of this process is made with the goal at the year of 2025. The evaluation of this evolution is made through the use of Key Performance Indexes that enable a comparison between the current process and the prediction made.

All the data that is analyzed and shown in this thesis was provided by Volkswagen Autoeuropa. In order to protect the interest of the company and taking into account that the study to be carried out focuses on the evolution of the process and not on the actual value of the KPI's, all the data provided have been normalized and not correspond to real values but only representative values of the reality.

## 1.5. Thesis Organization

This thesis is organized as follows: Chapter 1 makes a brief contextualization of the situation, the objectives of the work and how the thesis is organized; Chapter 2 analyzes previous works and researches made around the relevant themes for this thesis; Chapter 0 describes the case study: the current launching model in Volkswagen Autoeuropa and the launching process of the 2017 Volkswagen T-Roc; Chapter 4 analyses the possibilities for the future model launching and future production lines taking into account several technologies and concepts of *Industry 4.0*; Chapter 0 analyses future trends and R&D guidelines for future researches; Chapter 6 makes a conclusion on the work developed; and Chapter 7 shows all the references used for the development of this work.

# 2. State of the Art

Throughout the history of mankind there have been some significant improvements on manufacturing process that led to the evolution of industry and production processes. Western civilization has already witnessed three industrial revolutions, which could also be described as disruptive leaps in industrial processes resulting in significantly higher productivity. Manufacturing has been one of the key drivers in advancing technology, changing society, and shaping the world around us, that has brought society to the brink of the fourth industrial revolution.

## 2.1. Historic contextualization

The first industrial revolution began at the 1780s when the development of mechanical production equipment and a shift on power sources allowed a significant increase on productivity. The iron and textile Industrys suffered major changes as these Industrys left private homes and developed towards central factories production raising a new vision for the industry (Drath & Horch, 2014). As an example, rail transports with the support of steam engines heated by coal enabled efficient handling of logistics. Manual labor was replaced and the workers began to operate the first machine tools on history. With this new power source and due to the mechanization of the factories, the economy suffered a significant growth, along with more opportunities for employment, thus influencing some social and cultural aspects of the life, mainly in Germany and the USA (Gehrke, et al., 2015).

The second industrial revolution began about 100 years later in the slaughterhouses in Cincinnati, Ohio but found its higher point with the famous Ford assembly line for the production of the Ford Model T in the United States. The introduction of the conveyor belts and the division of labor is the basis for this revolution (Drath & Horch, 2014). The assembly line revolutionized how products were produced by decreasing the time it took to manufacture an item. During this revolution the development of transportation technologies enabled better transportation of goods and the start of mass consumption. Trains shortened travel times between cities and the development of cars during this time improved mobility within cities. All this led to an even bigger increase on manufacturing productivity (Gehrke, et al., 2015).

The third revolution happened in 1969 when Modicon presented the first programmable logic controller (PLC) that enabled digital programming of automation systems. The employment of electronics and information technology (IT) allows an increased automation of manufacturing processes (Drath & Horch, 2014). The development of transistors, industrial robots, and digitalization and computer technology led to automation of manufacturing and thus transforming the qualification of the factory worker. The integration of computers into planning and production processes with the objective to control the entire production process, called Computer-Integrated Manufacturing (CIM), was also developed during this revolution (Gehrke, et al., 2015).

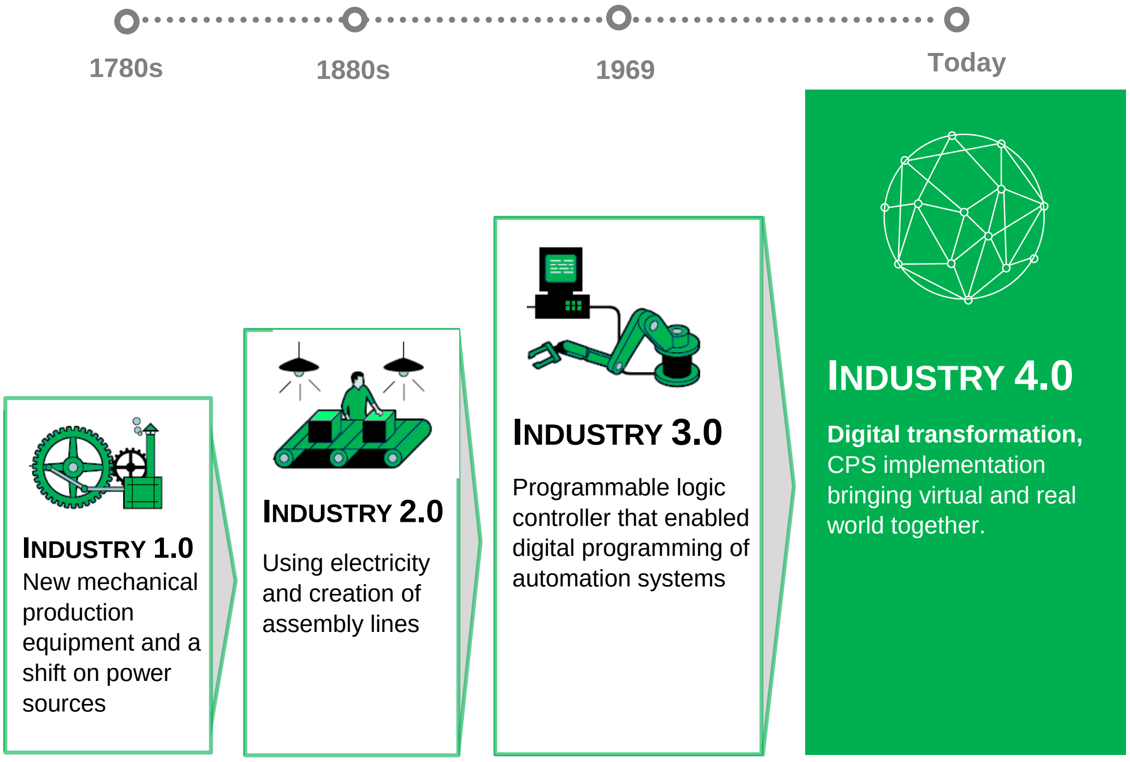


***Figure 2.1*** *- Industrial revolutions timeline*

At the present day, manufacturing is on the brink of the Fourth Industrial revolution, also called *Industry 4.0*. It is predicted that it will become a reality in the next decades. The introduction of the Internet of Things and Services, along with the development of Cyber-Physical systems (CPS), into the manufacturing environment is ushering to this change on the industrial paradigm (Gehrke, et al., 2015). **Figure 2.1** resumes the industrial revolutions that mankind suffered throughout history.

## 2.2. Need for Change

Manufacturing is facing a transformation in the production paradigm. The growing need of the customers for customized products with increasingly reduced time-to-market is pushing the development of *Industry 4.0*.

Up until now, manufacturing has firstly turned from craft production to mass production where producers focused on simply increase outputs and productivity without paying attention to the consumer needs fluctuations. However, this production vision is becoming completely outdated and is underway a paradigm shift (Hagel III, Seely B., Kulasooriya, Giffi, & Chen, 2015).

Manufacturing is no longer the simple production of “better” physical products. Consumers no longer just want to settle for mass-production products but rather want products suited for them individually. Demand is shifting towards personalization, customization and creation. Production is turning from a product-centered production to a buyers’-centered production, focusing on the interest and needs of the costumer that begins to express them right on the creation phase of the product that they are buying (Hagel III, Seely B., Kulasooriya, Giffi, & Chen, 2015).

Consumer need for individualization can lead to extreme cases of individual products, also called “batch size one”, and companies need to be able to manufacture this individual product in a batch size of one with the economic profitability of mass production (Lasi, Fettke, Feld, & Hoffmann, 2014). This phenomenon is often called Mass Customization (MC), a production strategy that has the objective of manufacturing personalized products, in small batches or even in size-one batches, in mass through flexible processes, modularized product design and integration between supply chain members along the value chain (Brettel, Friederichsen, Keller, & Rosenberg, 2014). MC is forcing industry to transform, adapt and evolve to new production concepts and processes. Customers need for personalization is bringing a new need for flexible, agile and scalable production systems that are able to deal with highly product variability with real-time reactivity but with a reasonable cost (Leitão, Colombo, & Karnouskos, 2016).

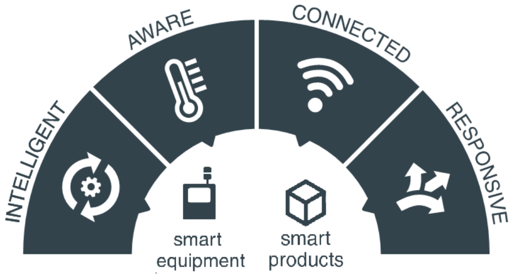


***Figure 2.2*** *- Characteristics of smart products and equipment*

Along with the change in the consumer demand, also the actual products are going through a transformation. Added sensors and connectivity turn “dumb” products into “smart” ones, through connectivity, intelligence and responsiveness, while products increasingly become platforms – and even move into the realm of services. Products are becoming as much about software than its physical form (Hagel III, Seely B., Kulasooriya, Giffi, & Chen, 2015). Equipment is following the trend and becoming ever more connected, ***Figure 2.2***.

Products lifecycle is continuously decreasing and needs further transformation towards organization structures that can deal with the increased complexity (Brettel et al, 2014). Besides this, time to market need to be reduced along with the development and innovation periods, in order to companies to be able to keep up with the increasingly irregular and sudden fluctuations of the market (Lasi, Fettke, Feld, & Hoffmann, 2014).

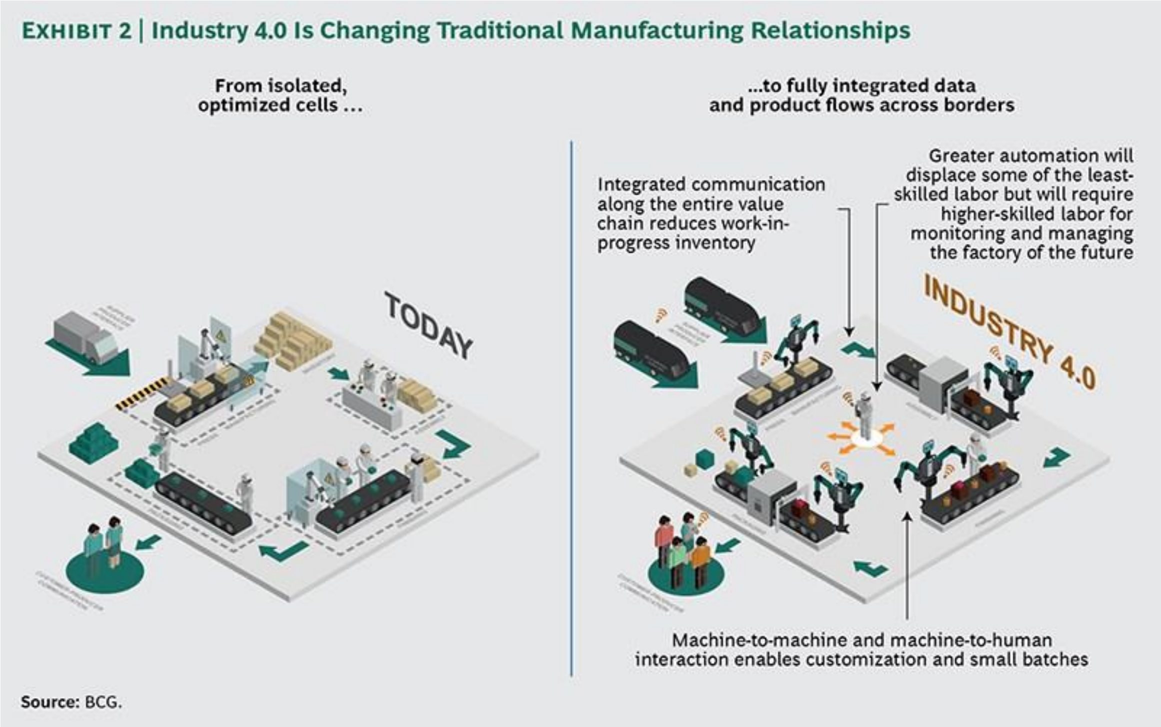
*Industry 4.0* might be an answer to the challenges lying ahead. The fourth and new digital industrial revolution describes the vision of tomorrows manufacturing: Smart factories, machines, raw materials, and products communicate with each other and cooperatively manage production processes.

## 2.3. Industry 4.0

The term “*Industry 4.0*” was first introduced in 2011 at the Hannover Messe Trade Fair by a working group established by the German Federal Government and has been discussed intensively in every industry-related fair, conference, or call for public-funded projects. This term was used to define this new stage on the industrial production evolution and according to the promoters of this idea, *Industry 4.0* is expected to deliver fundamental improvements to all industrial processes related to manufacturing, engineering, material waste and supply chain and lifecycle management (Kagermann, Wahlster, & Helbig, 2013).

This new stage in the industrial history of the world is not a complete change of the manufacturing paradigm but merely an evolution, seeking to leverage the existing technology and market potential to improve processes, productivity and efficiency (Heng, 2014). The core idea of this new concept is to use the current technologies, especially the emerging Information and Communication Technologies (ICT), to implement the Internet-of-Things (IoT) and Services (IoS) and create a basis for integration and communication allowing production to become extremely flexible and efficient with high quality at low cost (Wang, Wan, Li, & Zhang, 2016). The widespread adoption by manufacturing and traditional operations of ICT is leading to the convergence of the physical world with the virtual world through the development of Cyber-Physical Systems (CPS) (Kagermann, Wahlster, & Helbig, 2013).

The implementation of these systems leads the development of factories to intelligent environments, with agile and flexible capabilities to respond to disruptions and failures (Weyer, Schmitt, Ohmer, & Gorecky, 2015). MC is enabled due to the ability to rapidly reconfigure the machines layout and tools to adapt to the next costumer-specific product (European Parliament, 2015). Factories are going to evolve to such intelligent and conscious systems that are able to control production processes, to predict failure and maintain machines, and to manage the factory system. In addition, many manufacturing processes, such as product design, production planning and engineering are simulated as modular and connected end-to-end being controlled independently (Qin, Liu, & Grosvenor, 2016).



Source: (Rüβman, et al., 2015)

***Figure 2.3*** *- From the current production to Industry 4.0*

With *Industry 4.0*, components of the production system are no longer simply physically connected and sharing physical information, but also communicate, analyze, and use the information gathered to take intelligent decision to execute in the physical world (Sniderman, Mahto, & Cotteleer, 2016). Products in this new manufacturing paradigm are embedded with sensors, identifiable components, and processors that carry information about their current and target state, and they steer themselves through the production process, informing the machines what the next step in its production (Qin, Liu, & Grosvenor, 2016) (Hermann, Pentek, & Otto, 2015). Products in the middle of their processing, components, and machines in idle or manufacturing some product collect and share data in real time, leading to a massive exchange of information across the factory (Shrouf, Ordieres, & Miragliotta, 2014).

Productivity will suffer an increase due to advanced analytics in predictive maintenance programs that avoid machine failures and reduce downtime by around 50% and increase production by 20% (European Parliament, 2015).

Many authors (Wang, Wan, Li, & Zhang, 2016; Stock & Seliger, 2016) associate three key characteristics that need to be accomplished to reach *Industry 4.0*:

- ✓ Horizontal integration through value networks,
- ✓ Vertical integration and networked manufacturing systems, and
- ✓ End-to-end integration of engineering across the entire value chain.

Firstly, horizontal integration allows the cooperation among several companies to form an efficient ecosystem. Companies need to concur and collaborate with other corporations, so information, finance, and material need to flow between them. Secondly, vertical integration describes the intelligent cross-linking and digitalization within the different hierarchical levels from the manufacturing cells to the marketing and sales department. Finally, incorporation of engineering through all phases of the lifecycle of the product is essential to accompany the product development in every stage (Wang, Wan, Li, & Zhang, 2016) (Stock & Seliger, 2016).

The concept of *Industry 4.0* is widely used across Europe, particularly in Germany’s manufacturing sector. In the United States of America and the English-speaking world more generally, the terms “Industry 4.0”, “Internet of Things”, “Internet of Everything”, “Industrial Internet” or “Smart Factory” are associated to this phenomenon (Schlaepfer & Koch, 2015).

*Industry 4.0* is expected to have a major effect on global economies. It can deliver estimated annual efficiency gains in manufacturing of between 6% and 8%. The Boston Consulting Group predicts that in Germany alone, *Industry 4.*0 will contribute 1% per year to GDP over ten years, creating up to 390 000 jobs. Globally, expert estimates that investment on the Industrial Internet will grow from US$20 billion in 2012 to more than US$500 billion in 2020 and that value added will surge from $US23 billion in 2012 to US$1.3 trillion in 2020 (Davies, 2015).

As a leading market in embedded systems and security solutions, Germany is in the “pole position” of the development of this new production paradigm. Its embedded system market currently generates an income of around EUR 20 Billion annually and it is predicted that this value will rise to EUR 40 Billion by 2020 (European Parliament, 2015).

Research initiatives in this area are currently founded with 200 million euros from government bodies. The United States has established a National Network for Manufacturing Innovation with a proposed US$1 Billion of public funding to bring together national research centers investigating topics related to *Industry 4.0* (European Parliament, 2015).

## 2.4. Enabling Technologies

In order to implement this new manufacturing paradigm, some technologies are in the basis of this evolution. Their break through progression is fundamental for the growth of the concept of *Industry 4.0*.

### 2.4.1. Cyber Physical Systems (CPS) and Cyber Physical Production Systems (CPPS)

CPS is one of the most important and more investigated technology that enables the growth and implementation of *Industry 4.0*. According to the definition, *Industry 4.0* aims to take advantage of ICT combining it with CPS to make manufacturing processes even more intelligent (Wan, Cai, & Zhou, 2015).

These systems are smart systems that use cyber technologies embedded in physical components to interact with them, featuring a combination of mechatronics, communication and information technologies, integrating computation, communication and control over an information system (Leitão, Colombo, & Karnouskos, 2016). These systems are able to gather, process and storage data regarding the environment conditions and their own situation, and then exchange with all other CPS's (Monostori, 2014).

**(a)**

Source: Siemens

**(b)**

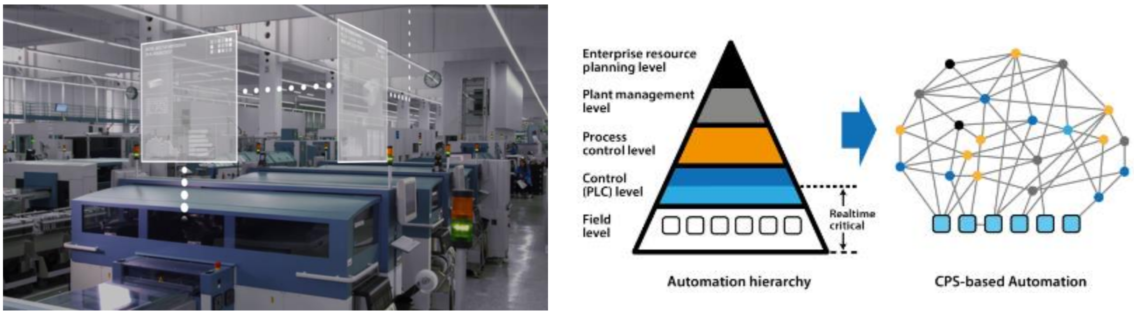
Source: (Monostori, 2014)

***Figure 2.4** – **(a)** CPS system carrying information about the environment and itself; **(b)** Representation of the communication between the CPS system and a human*

CPS's can be machines in the factory plant, components, production resources or even the products themselves as depicted in ***Figure 2.4 (a)*** where a product in the production line carries information about itself, its manufacturing history and its future processing in the factory, exchanging this information with all other CPS's in the way. These systems constitute an evolution from embedded systems since they also incorporate communication and interaction capabilities with humans and other systems through some interface (Leitão, Colombo, & Karnouskos, 2016), ***Figure 2.4 (b)***.

A production system where its elements are considered CPS's is called CPPS – Cyber-Physical Production System that consists of autonomous and cooperative elements and sub-systems that communicate between each other and adapt their behavior in situation dependent ways. As shown in ***Figure 2.5 (a)***, environments of CPPS are rich in information exchanged between all its components that allows it to self-control its tasks and processes (Monostori, 2014).

Due to the increasing complexity of some production systems, coupled with the growth of the CPS's, it is increasingly difficult to centrally control the entire system. Unlike what is currently applied, where a central control system keeps the productive system running through top-down communication, in a CPPS, control is decentralized and distributed across all its elements as shown in ***Figure 2.5 (b)***. These elements control its own tasks taking into account all the information exchanged across the factory (Monostori, 2014).



**(a)**

Source: Siemens

**(b)**

Source: (Monostori, 2014)

***Figure 2.5*** *-* ***(a)*** *CPPS system in communication;* ***(b)*** *Current control vs CPPS control*

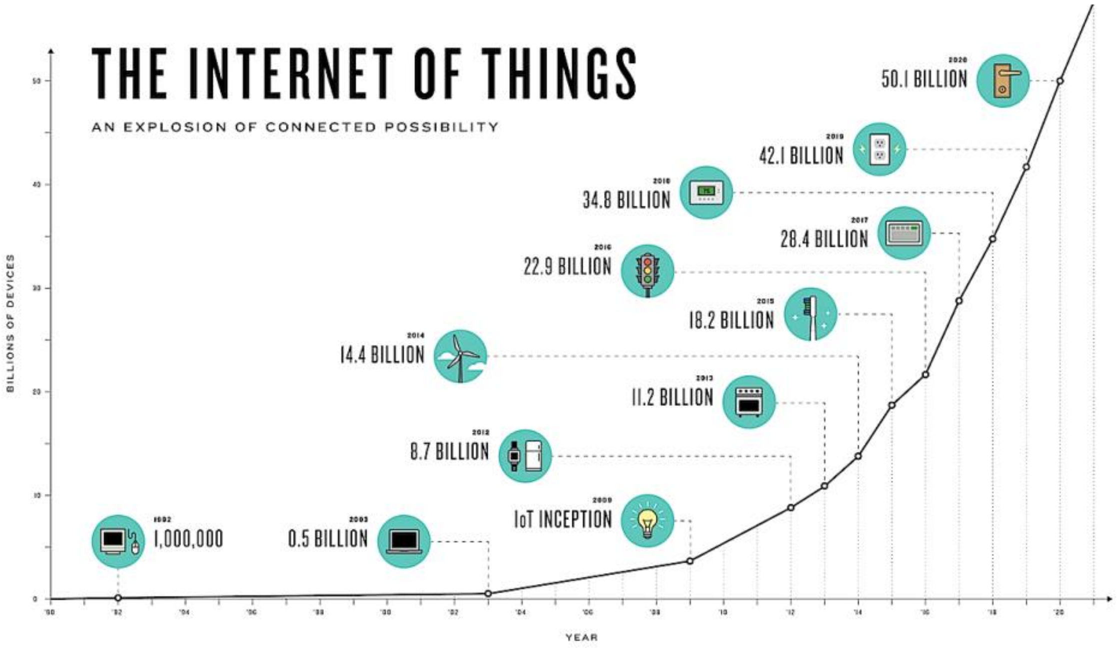
Production lines, according to the CPPS concept, will become highly modular and flexible in a way that even a size one batch can be produced under the condition of mass production. Furthermore, CPPS are based in *plug-and-play* technologies that enable these systems to be re-configurable in case of reconfiguration of the production line or just because of a machine malfunction (Weyer, Schmitt, Ohmer, & Gorecky, 2015).

## 2.4.2. Internet of Things (IoT)

Today, there are roughly 1.5 Billion Internet-enabled PC's and over 1 Billion Internet-enabled cell phones establishing the "Internet of PC's". However, the vision for the future is that 50 to 100 billion devices will be connected to the Internet by 2020 moving towards the "Internet of Things". Considering not only machine-to-machine communications but communications among all kinds of objects, then the potential number of objects to be connected to the Internet arises to 100,000 billion. (Sundmaeker, Guillemin, Friess, & Woelfflé, 2010). ***Source:***

**Figure 2.6** shows this increasing number of connected devices in the world since 1992 to 2020.

IoT can be defined as a dynamic global network infrastructure with self-configuring capabilities where all physical and virtual objects communicate using standard and interoperable communication protocols, have identities, physical attributes and virtual personalities, and use the information network to make intelligent decisions (Sundmaeker, Guillemin, Friess, & Woelfflé, 2010). It represents a vision of growth and expansion of the Internet in a way that it is embedded in all real objects so that they are constantly connected and can be accessed and controlled remotely (Friedemann & Floerkemeir, 2011).



Source: (Bartos, 2016)

***Figure 2.6*** *- Number of connected devices throughout the years*

The concept of IoT is somewhat related to the concept of CPS since the existence and implementation of IoT allows everyday objects to be connected and become CPS's, maintaining a constant flow of information from itself to others and the other way. This connectivity of everyday objects can be used to improve efficiency of control and management as state information can be accessed in real-time, enabling the observation of previously unattained information and a better understanding of the process. These objects will have the ability to rapidly and automatically react in an informed way to events in the physical world (Friedemann & Floerkemeir, 2011).

From a more technical point of view, the growth of the "Internet of Things" concept is not only due to the emergence of an isolated technology, but to the development of a series of new innovative technologies. IoT is based on advances in microelectronics and communications and information technology, and the continued reduction in the size, price and power consumption of new processors, sensors and other communication devices. Furthermore, internet protocol IPv6 increases the number of IP addresses to $3.4*10^{38}$ and opens a new door for the development of the Internet, once now every object can be connected to the Internet with its own IP address (Anderl, 2014).

#### 2.4.2.1. RFID

There are many communication technologies used to connect objects, sensors and other components, however, one of them is gaining space in the industrial environment as it is being increasingly used in factories all over the world: the Radio Frequency Identification Device (RFID). This technology is a growing force in the market and has experienced exponential growth as global interest in wireless technologies increases.

Many automotive manufacturing companies, such as Volkswagen, have applied RFID technology to improve both supply chain efficiency and transparency and improve their internal processes and assembly lines productivity. (Segura-Velandia, Neal, Goodall, Conway, & West, 2016).

The operating principle of an RFID is a quite simple process. A reader sends an electromagnetic wave to the tag to start communication, and creates an induced current that activates the integrated circuit. The information contained in the memory is modulated into a digital signal with a specific frequency. The reader then converts the digital signal into useful information (Fennani, Hamam, & Dahmane, 2011).

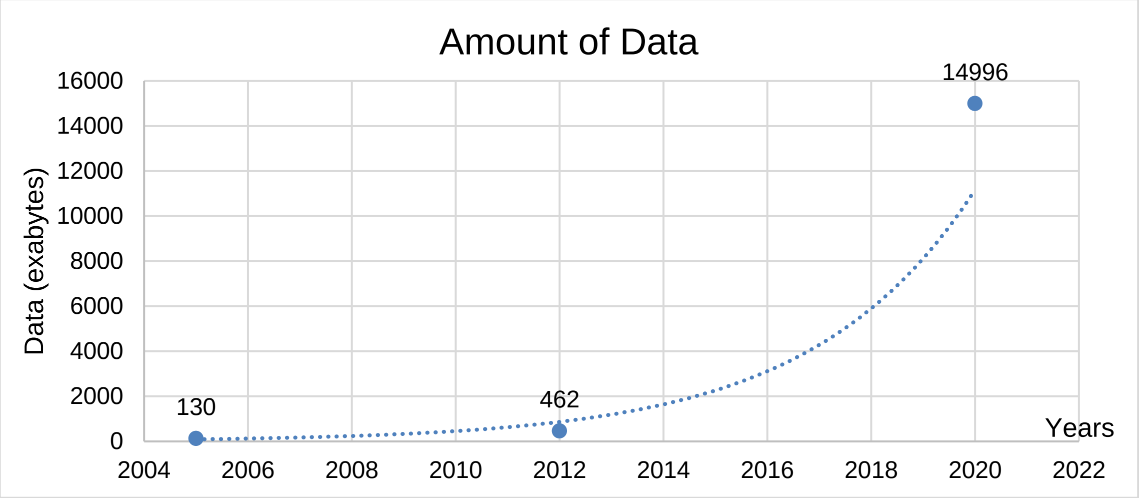
### 2.4.3. Big Data Analytics

The connection of every device, component and product to the Internet, equipped with sensors, will generate an explosion on the volume of data transferred in the future. One or multiple sensors will be installed in every machine, product and factory plant to control the production process, and these sensors will produce and transfer huge amounts of data.

The total amount of data transferred worldwide in 2005 was $130\ Exabytes\ (EB)\ (\approx 10^{18}\ Bytes)$, and that amount grew to $462\ EB$ by 2012. Following the growing trend, it is expected that this value will rise to $14.996\ EB$ by 2020, as depicted in (Webel).

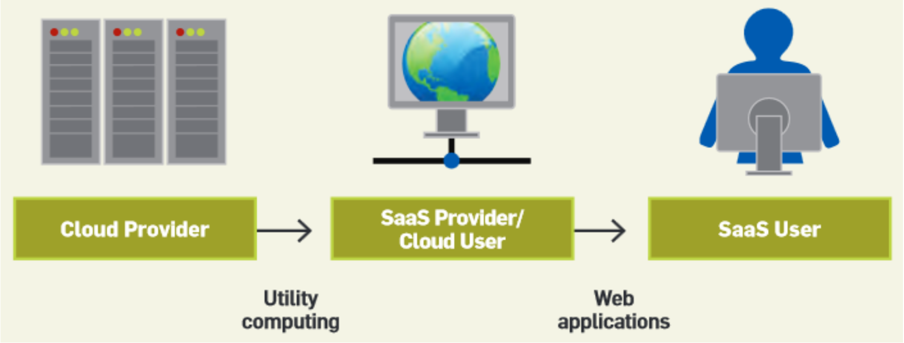
The realization of the Smart Factory needs effective visualization, analysis, exchange and share of various data all across the factory. All the data that comes from sensors and product development is used in simulation and modeling for predictive analysis or to extract value from data (Kang, et al., 2016).

***Table 2.1*** *- Amount of data transferred in exabytes*



Source: (Webel)

All this data that is been created and exchanged needs to be manipulated and treated to be useful and helpful for decision-making, however this requires great computational power that is often not available for manufacturers. Besides this, the investment to make this possible is, at the moment, extremely expensive and inconceivable for many producers.



Source: (Armbrust, et al., 2010)

***Figure 2.7*** *- Users and providers of cloud computing*

This has led to the realization of a new computing model called Cloud Computing (CC) that refers to both the application delivered as services over the Internet and the hardware and systems software in the data centers that provide those services (Armbrust, et al., 2010). A brief representation of the interactions in CC is represented in ***Figure 2.7***. The National Institute of Standards and Technology (NIST) define CC as:

> *Cloud Computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.*

The emergence of cloud computing has made tremendous impact on the IT industry as large companies, such as Google, Amazon and Microsoft are determined in provide more powerful, reliable and cost-efficient cloud platforms (Zhang, Cheng, & Boutaba, 2010).

### 2.4.4. Augmented Reality

Augmented Reality (AR) is considered a variation from the traditional Virtual Reality (VR). VR technologies totally immerse the user inside a synthetic environment without the possibility of see the real-world around him. In the other hand, AR technologies allow the user to see the real-world, but now with virtual objects super-imposed upon it (Azuma, 1997).

User interface have evolved from Command Line Interfaces (CLI) to Graphical User Interface (GUI) with the objective of turning the interaction more direct and intuitive. These systems make use of graphical representations of objects and commands in the screens and enable an instant visual feedback, relieving the need to memorize complex commands (Paelke, 2014).

However, these systems are starting to fall short of the needs because the information that is represented in a GUI is removed from its real-world context where it is really useful and where the user interaction would be direct. In the rapidly changing industrial environment, workers need to have adequate tools that use the massive amounts of information that are created and exchanged in a networked production system, and turn it into usable information to support them in their dynamic tasks (Paelke, 2014).

Augmented Reality devices use the position of the user's point of view with position and orientation coordinates, and then project the information required in some way, e.g. in the lenses of the AR Glasses or in the screen of a mobile device with the real-world in background**.**

The development of mobile devices has also enabled a great growth in these technologies providing tools and platforms for the applications of AR in these devices. For example, as shown in ***Source:***

**Figure 2.8**, Ferrari has developed an app for mobile devices that enables the user to see through its vehicle and customize it in the application to see possible alterations.

**Source:** (Baldwin, 2015)

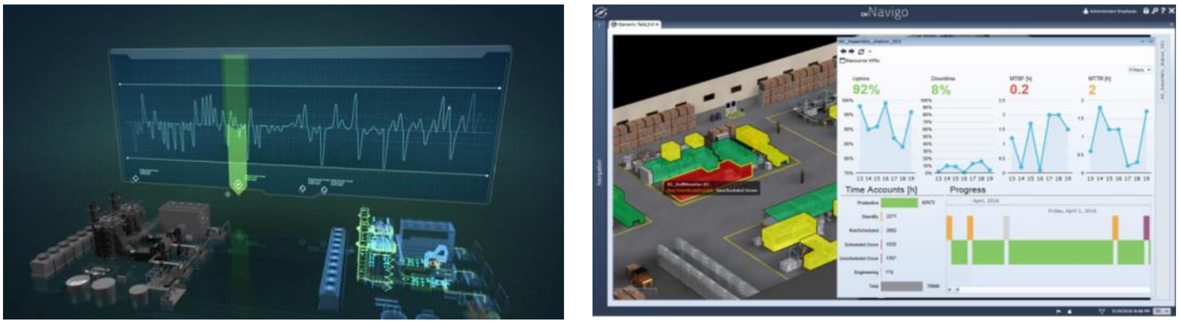
***Figure 2.8*** *- Ferrari's Augmented Reality Application*

The application of these systems, in a production point of view, can bring many improvements. For workers, support of these systems can improve their adaptability and flexibility, once information is continuously provided in 3D drawings superimposed in the reality rather than in manuals and in text with pictures. Furthermore, these systems provide the possibility to control certain systems with a clear visual representation of the events and with instant feedback response visualization (Azuma, 1997).

### 2.4.5. Simulation

In times of increasing cost and time pressures in production, simulation and virtualization technologies are increasingly important in the planning and scheduling phases of any project. Manufacturing industry is constantly facing challenges of producing innovative products at shortened time-to-market, and product development processes are becoming increasingly more complex as products become more versatile, intricate and inherently complicated, so simulation and modelling play an extremely important role. These technologies are conducted in order to gain insight into these complex systems and to achieve the development and testing of new operating and resource policies and new concepts or systems before implementing them, without disturbing the actual system (Mourtzis, Doukas, & Bernidaki, 2014).

With the growth of autonomous systems, such as CPS's, simulation has been gaining different proportions from just being used for design and planning. These autonomous systems have the capacity to make decisions among alternatives for their tasks and for this it is necessary to have information to support their decisions. In order to make the best decisions, these systems have to have access to a very realistic model of the state of the system and its own behavior in interaction with the environment. This model is called Digital Twin and accompanies the system throughout its entire lifecycle, even when the system is in operation (Rosen, von Wichert, Lo, & Bettenhausen, 2015), ***Figure 2.9 (a)***.



**(a)**
Source: (Pomerantz, 2015)

**(b)**
Source: (Critical Manufacturing, 2016)

***Figure 2.9*** *- **(a)** Digital twin exemplification; **(b)** Critical Manufacturing MES*

This virtual model can also be used to control the behavior of a factory after the start of its operation through certain performance measures. These virtual platforms are called Manufacturing Execution Systems (MES), which in turn correspond to information systems that allow:

- ✓ Monitoring and enforcing the correct execution of the production process;
- ✓ Monitoring and controlling the material used in the production process;
- ✓ Gathering information about the production process;
- ✓ Providing the tools for the analysis of the data to optimize efficiency;
- ✓ Delivering and managing work-instructions;

- ✓ Providing the tools to solve problems and optimize procedures.

Many new modelling and simulation software's are being developed and improved by many major companies in order to provide producers with even better tools for prediction and planning. A few examples are Critical Manufacturing MES by Critical Manufacturing, depicted in ***Figure 2.9 (b)***, or Siemens Simatic IT.

### 2.4.6. Collaborative Robots

Collaborative robots, or "Cobots", are robots intended to interact directly with a human worker, handling a shared payload of the work. These robots are expected to have benefits in terms of working ergonomics, productivity and computer interface (Fast-Berglund, Palmkvist, Nyqvist, Ekered, & Akerman, 2016). They act as workforce multipliers, increase productivity and improve quality of the finished products.

***Figure 2.10*** depicts an example of a collaborative robot in the assembly line of Volkswagen Autoeuropa that acts completely autonomous and can sense the presence of a human being in its working area. Automated Guided Vehicles (AGV) is also another type of these robots that follows markers in the floor for autonomous navigation across the factory floor. They can also sense obstacles and react to them, such as a human worker crossing its path.

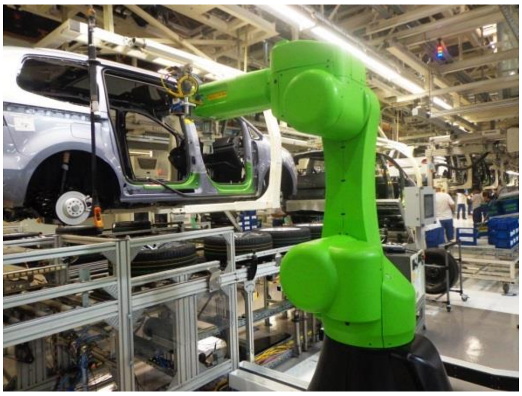


***Figure 2.10*** *- FANUC robot in the assembly line of Volkswagen Autoeuropa*

The potential associated with these robots is unlimited, in a way that many companies, such as KUKA, ABB, FANUC or Universal Robots, have been working and developing new, more reliable, efficient and safe for the human worker "cobots".

These systems have suffered a massive evolution in the last ten years. Today cobots incorporate a great amount of specifications to ensure that the human worker can work side-by-side with the robot without the need of any safety fence such as sensors that allow the robot to stop after a collision, and that keep track of the position and speed of the human worker to prevent contact and allow the worker to invade the working area.

### 2.4.7. Additive Manufacturing

Additive manufacturing (AM), or 3D Printing, is a term that refers to the new techniques of production that combine planar layers of material, sequentially to form a 3-dimensional solid object. This type of production has also been associated also with Rapid Manufacturing (RM) or Rapid Prototyping (RP), due to the commonly use of these technologies to make prototypes of products in early stages of development in a quick and automated way (Campbell, Bourell, & Gibson, 2012).

Specifically in the automotive industry, AM technologies are exploited because of their ability to help new products to get to the market quickly and in a predictable manner, saving time and development costs in vehicle development. They are used in the process of tool development for tool-bridging while mass production is not yet implemented. (Campbell, Bourell, & Gibson, 2012).

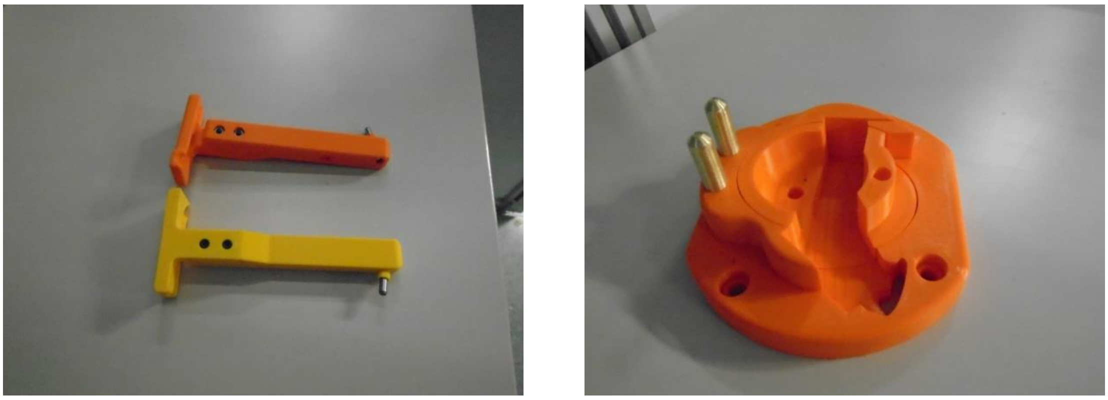


***Figure 2.11*** *- Tools produced in Volkswagen Autoeuropa by Additive Manufacturing (3D Printing)*

The main advantages of this process are (Bak, 2003):

- *Waste* – Unlike subtractive techniques that forms waste, AM processes use little more material than necessary;
- *Inventory* – These processes can produce objects with a various sizes and forms from a pool of powdered material, in opposition to other techniques that require a pre-sized stock;
- *Quality Control* – As it is a fully automated process, the risk of human error is reduced significantly;
- *Set-up* – If a single material is used, the only set-up needed is the change of the CAD file for the product.

### 2.4.8. Cyber Security

With the development of all these technologies, a new concern arises regarding the security of the communications and data transferred in the Factory of the Future. The increased connectivity and use of standard communications protocols that are expected with *Industry 4.0,* will increase dramatically the threat of cyber-attacks on industrial systems and manufacturing lines, resulting on a growing need of cyber security (Rüβman, et al., 2015).

Furthermore, the interconnected nature of *Industry 4.0* mean that cyberattacks can have far more extensive effects than ever before, and manufacturers and their supply networks may not be prepared for the risks (Peasley, Waslo, Lewis, Hajj, & Carton, 2017).

In the smart factory environment, a cyberattack can correspond to a misuse of a production line that can result in high financial losses, a decrease in the product quality or even safety concerns for human workers. Furthermore, these attacks can take other proportions and can lead to confidential information leaks and the release of corporate secrets of processes, products, strategies or workers information (Peasley, Waslo, Lewis, Hajj, & Carton, 2017).

## 2.5. *Industry 4.0* in the automotive industry

Source: Audi AG

***Figure 2.12** - Audi's Modular Assembly Line*

The automotive industry is one of the largest existing Industrys. Fifty years of evolution with improvements in horsepower, safety, and rider experience have helped this industry to grow at an average pace of 3 percent annually since 1964 (Gao, Hensley, & Zielke, 2014). Following the trend of *Industry 4.0*, the automotive industry is undergoing drastic changes both in automotive production where digitization is helping manufacturers to connect their factories and take advantage of the data produced to improve processes and products, such as serious changes in the product concept, that is, developments in the vehicle itself making them more and more connected, efficient and safe (Gao, Hensley, & Zielke, 2014).

In terms of the automobile production, manufacturers are starting to change their production facilities through the implementation of many technologies, mentioned in **Chapter 2.4.** (Gao, Hensley, & Zielke, 2014):

- Connected devices and sensors using RFID technology have been implemented in order to replicate the physical system in digital form (Digital Twin) and to be visualized and localized in real-time;
- Big Data analytics and predictive analytics powered by powerful algorithms that have become sufficiently sophisticated and validated through real-world examples allow real-time decision making and predictions of behavior with good results. Furthermore, future deep learning – a dynamic way of computing where the algorithm can learn patterns and take them into account for future decision-making – will provide even better results.
- The adoption of mobile and touchscreen devices enables a more dynamic and efficient control of the factory plant, and furthermore virtual reality allow for a more intuitive interaction between physical and digital worlds;
- New manufacturing technologies such as 3D printing are being implemented to directly produce from a digital construction to the physical world. Besides this, intelligent and collaborative robots have enabled a new flexible system of production to be imagined;
- Finally, despite the rise in cybercrime, developments in cyber security have given manufacturers the confidence to link their factories to the Internet and store their vast amounts of data in clouds.

A good example of the developments that are being made towards this new production paradigm is Audi's Smart Factory. Audi is convinced that the assembly line is at the end of its days, so they developed a prototype of a modular assembly line where production is composed of small, separate workstations that allow highly flexible working routines in terms of space and time (Audi AG, 2016).

# 3. Case Study Description

## 3.1. Volkswagen Autoeuropa

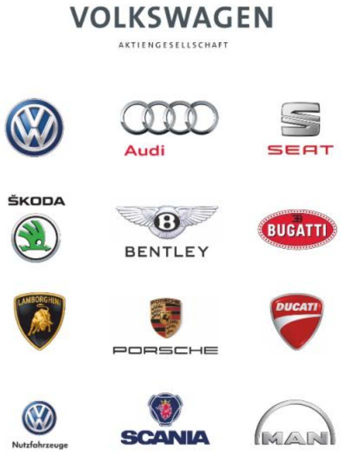


***Figure 3.1*** *- Brands on the Volkswagen Group*

Volkswagen belongs to the Volkswagen Group and has its headquarters in Wolfsburg, Germany. The origin of the company dates back to 1930 in Germany and to the construction of the car that would be known in Germany as "Käfer", in Portugal as "Carocha" and in the United States and Great Britain as "Beetle". Besides the Volkswagen brand, the Volkswagen Group also owns the brands Audi, Bentley, Bugatti, Ducati, Lamborghini, Seat, Porsche, Skoda Auto, MAN, Volkswagen Trucks and Scania, ***Figure 2.1***.

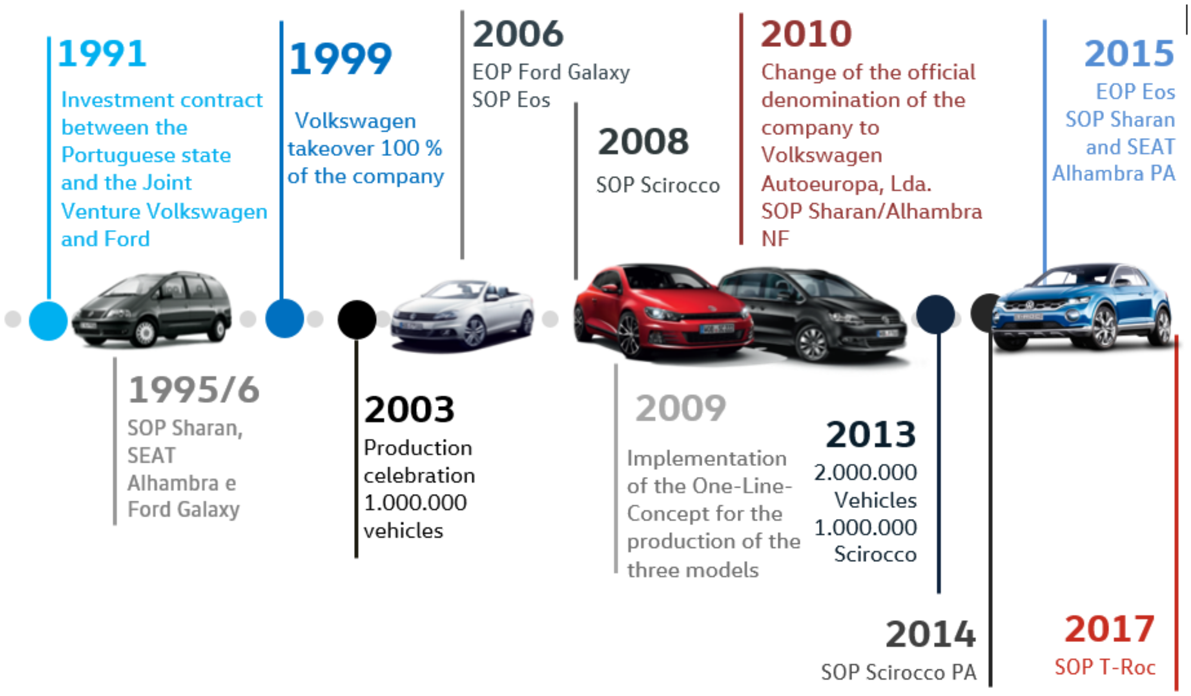
The Volkswagen Group operates 120 production plants in 20 European countries plus 11 countries in the Americas, Asia and Africa. Every weekday, 626,715 employees worldwide produce around 43,000 vehicles, and work in vehicle-related services or other fields of business. The Volkswagen Group sells its vehicles in 153 countries.

Volkswagen Autoeuropa is the production factory of the Volkswagen group in Portugal. It is situated in the region of Palmela and began its effective production in 1995 with the production of the Volkswagen Sharan, Seat Alhambra and Ford Galaxy.

***Figure 3.2*** *- 2017 Volkswagen T-Roc*

The Volkswagen T-Roc is the new Volkswagen SUV model that will be produced at Volkswagen Autoeuropa. It is part of the brand's SUV offensive joining Tiguan and Touareg. This SUV is 4,234 meters long, making it 252 mm shorter than its Tiguan brother, which does not prevent it from offering a rather generous wheelbase for this segment, with 2,603 meters separating the front axle from the rear. Source:

**Figure 3.3** represents the history timeline for Volkswagen Autoeuropa since its creation and SOP of its first cars in 1995, to the current SOP of the T-Roc in 2017.



**Source:** (Volkswagen Group Academy, 2015)

***Figure 3.3*** *- Historic marks for Volkswagen Autoeuropa*

## 3.2. *Industry 4.0* in Volkswagen Autoeuropa

Currently, Volkswagen has a set of goals that wants to see fulfilled by 2025, which are compiled in the company's development strategy, called *TOGETHER – Strategy 2025*. According to Matthias Müller, CEO of the Volkswagen AG since 25 September 2015, this strategy comes from the brand's need to follow the evolution of the times, and it is one of the biggest change process in the company's history, with the focus on transforming the core business through the investment of e-mobility, autonomous driving and connected vehicles.

> *"Our innovation power is also to be enhanced by an initiative dubbed "Organization 4.0" It is common knowledge that Volkswagen is a fairly traditional company. But new times call for new ways of thinking and doing things*."
>
> *--Matthias Müller, Press Conference, June 16 2016*

In **Source:**

**Figure 3.4** are represented the main initiatives included in *TOGETHER – Strategy 2025*, where a few of them, as depicted in the figure, have a close relation with the development of *Industry 4.0*. The main focus is the investment in innovation and in the digitalization transformation of the production paradigm that is expected to be the road to the future. Also, in terms of logistics, the creation of the *Organization 4.0* is an objective for this strategy where logistics takes a step towards a more organized and efficient process.

Volkswagen Autoeuropa, in turn, follows this strategy and tries to position itself as a driver of these developments around *Industry 4.0*. In accordance with the Volkswagen strategy, the main challenges in order to bring *Industry 4.0* to the factory are:

- Increasingly digitalization and its integration in the physical processes – investment in automation and digitalization of process in order to increase efficiency and communication in the production line;
- New skills and training for the line operators – development of new skills of the operators to deal with new technologies and work aids, such as augmented reality, real-time simulation or collaborative robots;
- Knowledge transference sustainability – Standardization and coordination of the knowledge transfer between all parties;
- Financial benefits calculation in short-term – The large investments still needed to make the move to *Industry 4.0* still makes the cost-benefit analysis not very attractive in short-term;
- Information security – cybersecurity for all the information transferred across the factory;
- Stakeholder's relation strengthening to facilitate the third-party participation – horizontal integration of the production process.

**Source**: (Volkswagen AG, 2016)

***Figure 3.4*** - TOGETHER – *Strategy 2025*

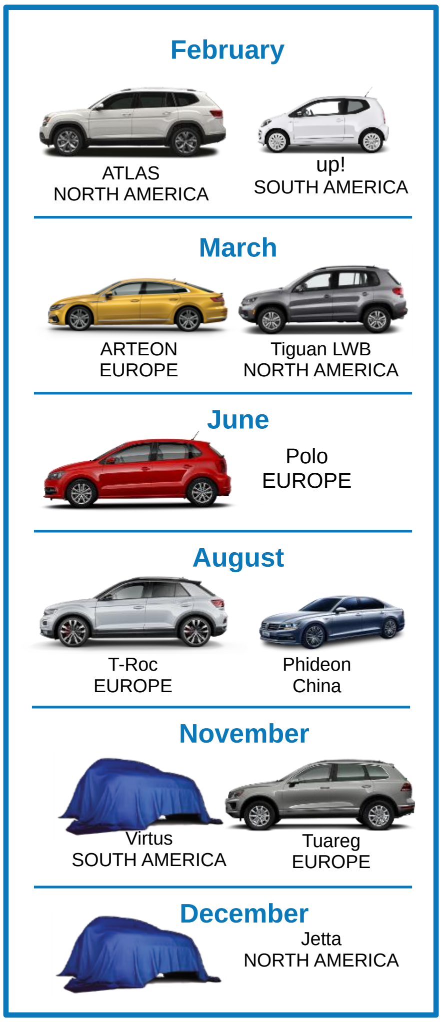
## 3.3. Current New Model Launching Process

### 3.3.1. Product Emergence Process (PEP)

The release of a new car model is a very long and extremely complex process that requires the involvement of several areas of a brand (e.g. financial, engineering, management, design, etc.) in the planning and design of the car, as well as the planning of the actual launching process. The complexity of this process isn’t normally taken into account when the customer buys this new car model.

In order for this process to be coordinated and as fast and efficient as possible, it is necessary to have a well-established launching process with defined milestones that will help all involved in this process to fulfill their duties in the predicted time. In this sense, the Volkswagen Group has developed a guide to accompany a new product to be launched in the market.

At the start of the production time of Volkswagen, the only vehicle produced was the “Beetle”. At that time, its project and development was perfectly controlled without being necessary to implement this type of guidelines. However, nowadays with the increase in the project range to several car models simultaneously, it is necessary to maintain an organized scheme in order to control all the vehicle models in their process of release. As an example, at the moment of writing, Volkswagen has at hand 5 new launches programmed in which 3 are completely new models and 2 are facelifts of previous models, ***Figure 3.5***.



**Source**: (Carimbo, Guerreiro, & Pedaço, 2017)

***Figure 3.5*** *- Graphics of the several processes of the release of a new car model for the year of 2017*

From that time until now, the process of releasing a new product has suffered successive changes trying to improve quality and reduce the time that takes to start producing the new model.

The guideline created by Volkswagen for the development of a new product is called Product Process (PP[1]). It incorporates the entire lifecycle of a product, from the definition of the product strategy to the End of Production (EOP). This guideline establishes all activities for all departments and divisions involved which are required in order to determine the product portfolio, define the product, and to ensure and implement product development and the series support phase.

The Product Emergence Process (PEP), or *Produkt Entstehungs Prozess*, is an important tool in vehicle development and one of the most important and critical phases in the PP[1]. The PEP is a reference process with fixed milestones that is used as guidance for new car model development and release to the market. It describes rules for processes, methods, and responsibilities for vehicle, platform, and engine development that are required for a successful market launch of new vehicle models. Furthermore, it also helps the worker related to this process by relating tasks to working committees and project structures. This process takes place since the idea for the vehicle is accepted until the Start of Production, and successive Market Launch, and is measured in Months to SOP (MSOP).

The factory where the production will take place for the new model starts its interaction with the project in the last stage of the PEP called **Series Preparation** that is divided in 3 stages – the first stage is called VFF, the second PVS and the last 0S.

## 3.4. T-Roc Release

In the process of launching to the market the new Volkswagen T-Roc, there are 4 factors that were determined to be relevant for the characterization of the process and to evaluate it:

- *Pre-series cars produced* – The number of cars that were produced in the factory in the pre-series stages until SOP;
- *Time* – The time that took since the first interaction of the factory with the new model to Mass Production (MP) that correspond to the full implementation of series production of the new model;
- *Waste* – Amount of waste produced in the same pre-series stages just for the production of the pre-series vehicles;
- *Operators Training* – training of the line operators for the production of the new model.

To determine the relevance of these characteristics of the launching process some Key Performance Indexes (KPI) were created in order to measure how the release of the new model was accomplished. These KPI’s were formed with basis in the already established KPI’s for the launching process that exist in the factory. The KPI’s used were:

- *Pre-series cars produced* – Total number of cars produced in Series Preparation.

$$KPI\ (number\ of\ cars) = \sum_{i=1}^{n} c_i, \qquad (1)$$

$$where\ c_i\ is\ the\ number\ of\ cars\ produced\ by\ stage\ i$$

- *Time* – Interval of time between SOP and VFF;

$$KPI\ (time) = SOP - VFF \qquad (2)$$

- *Waste* – Percentage of waste produced by car;

$$KPI\ (waste) = \frac{w}{\sum_{i=1}^{n} c_i}, \qquad (3)$$

$$where\ w\ is\ the\ total\ waste\ produced\ and\ n\ is\ the\ number\ of\ stages$$

- *Operators Training* – Number of Workshops made for this new model

$$KPI\ (op.training) = \sum WS_j \qquad (4)$$

$$where\ WS_j\ is\ the\ number\ of\ Workshops\ per\ area\ j$$

The number of cars produced in these pre-series phases is one of the most relevant characteristics of the launching process. During these initial phases, several vehicles with an extremely high cost are produced in order to prepare the moment when this model is massively produced. To all these vehicles produced before the SOP are called Pre-Series Vehicles.

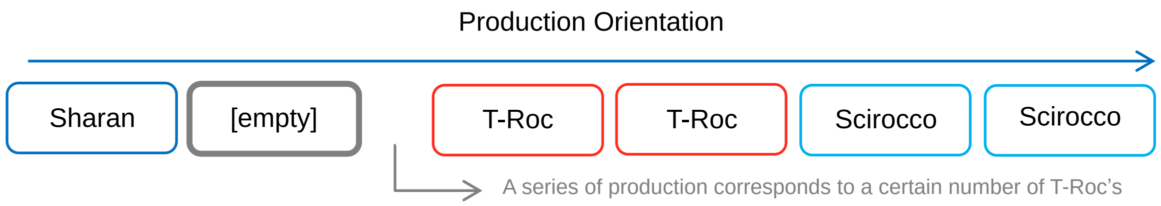


***Figure 3.6*** *- Sequence of vehicles produced in pre-series*

In factories where the One-Line-Concept[1] for production is implemented, like Volkswagen Autoeuropa, during the pre-series stages, the new model is produced in the same production line of the models that are already being massively produced. This means that pre-series vehicles of Volkswagen T-Roc are produced along with the Volkswagen Scirocco and Sharan, and the Seat Alhambra. The sequence in which the T-Roc is produced in small batches is represented in ***Figure 3.6.*** At the end of the T-Roc series is given a car slot of slack with no car to predict possible and inevitable delays in the processes in the new model as operators are learning how to do them. Closer to the SOP, this car slot is removed and the vehicle is slowly introduced in the production line. The sequence of production with the T-Roc being produced in series is represented in ***Figure 3.7.*** In this sequence, and due to the high volume of T-Roc that will be produced, a sequence of 3 T-Roc's is intercalated with an MPV (Volkswagen Sharan/ Seat Alhambra) or a Volkswagen Scirocco.

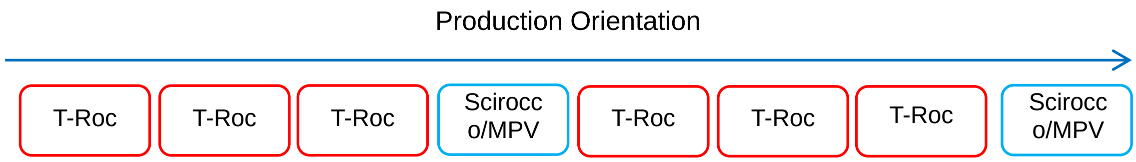


***Figure 3.7*** *- Sequence of vehicles produced when the new model is implemented*

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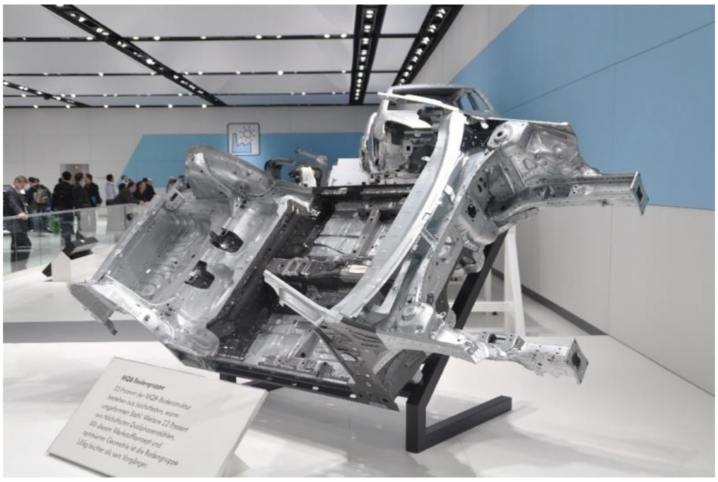
[1] Production concept where a production line is composed by a singular line for all the models/products produced in the factory. Is complementary to the Multiple-Line-Concept where each product is produced in its own production line.

These cars produced in pre-series have many proposes: in VFF the vehicles produced are normally for exhibition, but some have specific customers inside Volkswagen; in PVS many of the cars are used for crash tests and road tests, like the one on ***Figure 3.8***, but again some have already specific customers (internal) that want these pre-series vehicles (for audits, product engineering validation, corrections to the product and processes, and general tests); finally in 0S some vehicles are still used for tests and some have already quality to be homologated and circulate in the streets.

***Figure 3.8*** *- T-Roc on road test with a specific paint to hide the design*

The number of vehicles produced varies from launch to launch in order to meet with the specific test and preparation needs of the factory and the brand for the production of the new model. The quantity of pre-series vehicles depends on certain characteristics of the model itself, but also on factors related to the factory and the brand:

- New platform or not – The Volkswagen T-Roc has a modular platform of the Volkswagen Group called Modular Transversal Toolkit (MQB), *Modularer Querbaukasten* in the original German. This transversal platform is front-engine and front-wheel drive (optional four-wheel drive) and it’s shared by several vehicles such as AudiA3 Mk3, TT Mk3 and Q2, Seat Ibiza Mk5, León Mk3 and Ateca, Škoda Octavia Mk3, Superb B8 and Kodiaq and Volkswagen Arteon, Atlas, Golf Mk7, Passat Mk8, Tiguan Mk2 and Touran Mk2. Besides this, it is predicted that it will also be used by the new models Audi A1 Mk2 and Q3 Mk2, Seat Arona, Škoda Karoq and Volkswagen Polo Mk6, Jetta Mk7 and Scirocco Mk4. It uses a modular core matrix of components that allows several models with different dimensions, styles and engines to be produced in several factories based in this platform. This modular and transversal platform allows the Volkswagen Group to have flexibility to shift production between different factories when necessary without the need for big changes (Volkswagen Group MQB platform, 2017). The Volkswagen T-Roc will have this platform that is well implemented in the Volkswagen Group, however in Volkswagen Autoeuropa the current models produced do not share this new platform, which means that it is an increased difficulty. In the future, a launching process of another vehicle that shares this platform will be facilitated.



Source: (Volkswagen Group MQB platform, 2017)

***Figure 3.9*** *- Volkswagen MQB floor assembly on display at the 2012 Hannover Messe*

- Number of powertrains available: the Volkswagen T-Roc has versions with two-wheel drive and four wheel-drive 4Motion, manual gearbox and automatic DSG gearbox, and 5 different engines: 1.0 TSI (110hp), 1.4 TSI (125hp), 1.5 TSI (150hp and 180hp), 1.6 TDI (115hp) and 2.0 TDI (150hp and 190hp). The number of combinations between all this components influences the number of cars needed to be produced to prepare the production line for the SOP, since all these combinations have to be produced in this location, and therefore, prepared and planned before the SOP. It is natural that with a higher number of powertrains available the brand feels the need to increase the planned number of pre-series vehicles.
- Countries where the model is commercialized: The existence of countries where the new model will be commercialized that have different types of legal compliances or other types of differences, such as right hand driving, also influences the planning of the number of pre-series vehicles.
- Number of paintjobs: The number of existing colors mainly influences the paint department that needs to prepare the mass production of cars with different colors. In addition, the existing two-color combination option that exists in this new model (bi-color – 11 colors for body and 4 for the roof) involves even more combinations and therefore more preparation and planning, in spite not all colors can be combined.
- Novelty for the brand: The fact that the new model belongs in a segment new to the brand and is a novelty in terms of design, new powertrain or other relevant changes, increases the risk of it not being ready at the SOP, so in this way, Volkswagen may choose to increase the number of vehicles produced to prevent some unforeseen event. The Volkswagen T-Roc is a model that is not new for the brand, once it shares several similarities with other models; however it is situated in a segment where Volkswagen is not very experienced that is small SUVs.
- Maturity of the factory: The maturity of the factory itself in terms of years of operation, number of employees, number of previous launching processes, and the actual performance results can influence the number of vehicles produced. Volkswagen Autoeuropa is being operating for 22 years and is considered a very mature company with several successful former releases in its history, like Volkswagen Eos, Scirocco and Sharan, and Seat Alhambra.

Taking into account these factors, for the launching of the Volkswagen T-Roc were produced in each pre-series phase in the factory the number of pre-series vehicles in ***Table 3.1***. The values presented in the table correspond to a proportion relative to the number of vehicles produced in the VFF phase in order to preserve some confidentiality in the values. The duration of each stage is represented between brackets in terms of t periods of time in order to understand the duration of each stage relative to the others.

The analysis of the table shows that the number of vehicles produced increases as SOP approaches, since as more vehicles are produced, the production line and its tools and equipment are optimized and operators gain experience in the new processes for the new model, making the production of each vehicle a faster and cheaper process. With the approach of SOP also the suppliers are more organized and can supply resources almost as if series production is in course. The last phase of the whole process is the phase where the largest number of pre-series vehicles are produced with 48% of the whole pre-series vehicles.

In the early stages the production process of the new model is still an extremely manual process, the tools used are still prototypes since they are also in the process of improvement (these tools are already produced by 3D printing processes that reduce the production time, cost and waste, and increase flexibility for changes), and the cost of production is extremely high and can reach hundreds of thousands of euros.

***Table 3.1*** *- Vehicles produced in each pre-series phase (proportion relative to the VFF of the T-Roc Launch)*

| **Pre-series phase** | **Number of vehicles produced** | **% of cars from total of pre-series** |
|---|---|---|
| Pre-Series Approval Vehicles (VFF)(-2,66*t*) | 1 | 12% |
| Pilot Series (PVS)(-2*t*) | 3.33 | 40% |
| 0-Series (0S)(-*t*) | 4 | 48% |

The number of vehicles produced in pre-series is also defined taking into account the scheme of vehicles that will be produced after the SOP, called Ramp-Up Schedule, that approximates the number of vehicles produced over time to the value that needs to be produced when stability is achieved. This schedule is planned in a way that the implementation of the new model in the production line is as smooth as possible. ***Figure 3.10*** represents the weekly production of vehicles from the SOP until the full implementation of the series production in percentage relative to series production. The full implementation of series production is online implemented *1,66t* after SOP.

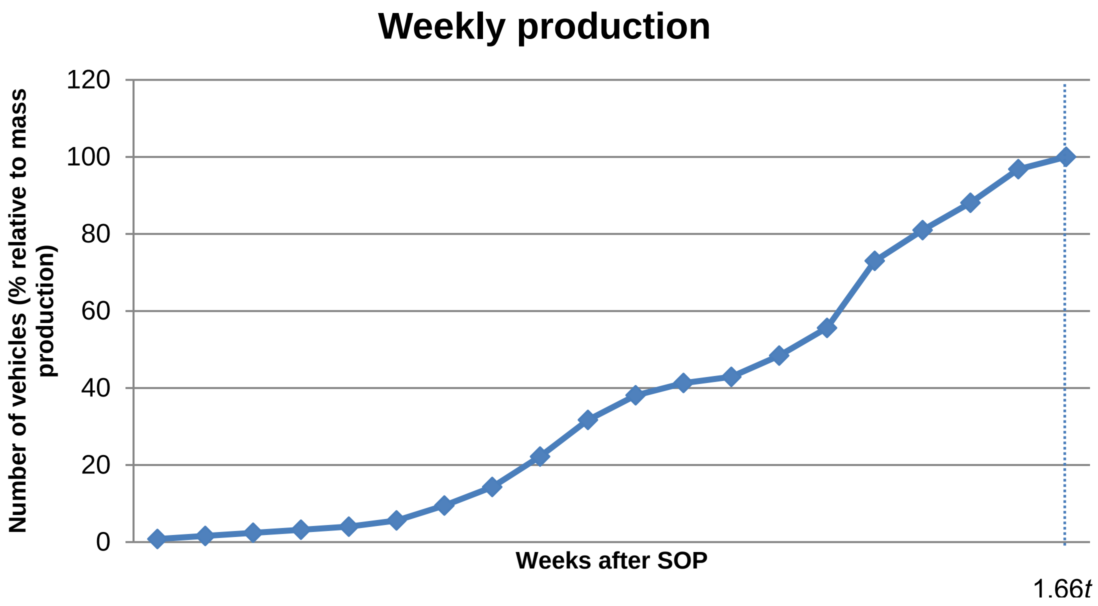


***Figure 3.10*** *- Ramp up schedule for Volkswagen T-Roc in percentage relative to series production.*

To add to all this, as the SOP date approaches, stress tests are initiated where the conditions and sequence of production in the SOP are tried to be replicated. In these tests, called LTF's (*Leistungstest Fertigung* in German), the new model is produced in series along with the other models in the factory, with the future sequence implemented in order to evaluate the production system, conditions of the operators, manipulators and their availability for the new model, quality and logistics. This process is divided into three stages:

1. The first phase lasts about 0.5*t* weeks during the 0-S phase where the interconnection between the production areas and evaluation of the flow of parts and cars is verified;
2. The second phase lasts about 0.6*t* weeks and takes place before the start of series production (SOP). This phase allows to evaluate if the production system is prepared for the SOP, as well as the planned launch curve and consequent gradual increase of the production volume;
3. The last phase starts after the SOP and lasts for 0.4*t* weeks. It is used to assess the capacity of the production system to reach the maximum daily production volume foreseen in the project.

The total number of cars produced in the 3 stages of pre-series represents one KPI for the launching process and its value is, again a proportion relative to the VFF number of vehicles:

$$KPI\ (number\ of\ cars) = 8.33 \tag{5}$$

In the 3 stages of the pre-series, a total of 8.33 times the VFF phase where produced. ***Table 3.2*** compares the launch of the T-Roc with the 3 previous launches in the factory. This comparison has a certain feature that is the fact that the launches of 2013 Volkswagen Eos, 2014 Volkswagen Scirocco and 2015 Volkswagen Sharan and Seat Alhambra correspond to Face-Lifts (FL) which means that they are new versions of existing models that are being produced and commercialized, whilst the Volkswagen T-Roc corresponds to a brand new model for the Volkswagen brand. However, and despite the difference between the launches, it should be noted that the launch of the Volkswagen T-Roc corresponds to a number of pre-series vehicles not much higher than the launches of the FL in the factory. This indicates that in the launch of the Volkswagen T-Roc there is a big improvement in terms of organization in the production scheme, once it was expected that this value should be much higher.

In all the launches, except Volkswagen Eos, the number of pre-series vehicles produced increases as the SOP date approaches, having in mind the ramp-up schedule, the increase in operator routines with the new processes, and the increasingly low cost of production in further phases.

In 2013 the launch of the Volkswagen Eos FL in the factory was an extremely critical process due to the characteristics of the vehicle itself (Volkswagen Eos was the first and only convertible of the Volkswagen Group that had a hard top) hence the number of pre-series vehicles is the lowest of all launches due to the difficulties encountered in pre-production. When the day of the SOP arrived, the model wasn't yet ready to be produced with the quality desired, so lot production was initiated where vehicles are agglomerated by lots and are only approved to be further put on market if every single one of the vehicles in the lot has the quality specified.

Due to the these complications, the number of pre-series produced at this time was very low with only 2.77 times the number of vehicles produced in the VFF of T-Roc.

The launch of the Volkswagen Scirocco FL one year later followed the expected, however due to the low number of the previous launch it corresponded to a growth of 158,5% in the number of pre-series vehicles. Furthermore, is possible to note a huge difference between the first two phases of pre-series and the last phase that shows that, in order to prepare the workers for the mass production, a great number of vehicles were produced in the last phase to compensate the low number of vehicles produced in the first two stages and assure that the production was ready at SOP. As shown by the table, in total, the number of vehicles produced in the Volkswagen Scirocco FL process is similar to the MPV or T-Roc processes; however these vehicles were produced with some delay in phases very close to the SOP.

The launch of the 2015 Volkswagen Sharan and Seat Alhambra was a much more fluid and organized process than the previous ones. Quite due to the fact that it was the launch of two models, although similar in many characteristics, it would be expected a large number of pre-series vehicles , however this value only increased by 6.4% relative to the launch of the Scirocco FL which already indicated good signs of progress in the process.

In the Volkswagen T-Roc launch, the team responsible for the whole process decided that it would be beneficial to have one prototype of the new model in the factory the sooner as possible in order to avoid the discrepancy and delay that occurred in the Volkswagen Scirocco launch process. By having an example at an early stage of the process it was possible to begin planning the necessary tools and changes on the assembly line as quickly as possible, hence this process was much more fluid and better distributed along the pre-series phases.

Despite being a completely new model for the brand and the factory, this launch only experienced a growth of 9.3% relative to the launch of MPV two years earlier. This reveals how the process of launching a new model is evolving and has grown at the factory gaining more maturity and organization.

***Table 3.2*** *- Comparison of number of cars released in previous launching processes (proportion relative to VFF of the T-Roc)*

| **Pre-series phase** | **T-Roc (2017)** | **VW Sharan / Seat Alhambra (2015)** | **Scirocco FL (2014)** | **Eos FL (2013)** |
|---|---|---|---|---|
| **Pre-Series Approval Vehicles (VFF)(-8)** | 1 | - | 0.1 | - |
| **Pilot Series (PVS)(-6)** | 3.33 | 3.56 | 0.93 | 1.5 |
| **0-Series (0S)(-3)** | 4 | 4.06 | 6.13 | 1.27 |
| **Total** | 8.33 | 7.62 | 7.16 | 2.77 |
| **% relative to previous** | +9.3% | +6,4% | +158,5% | - |

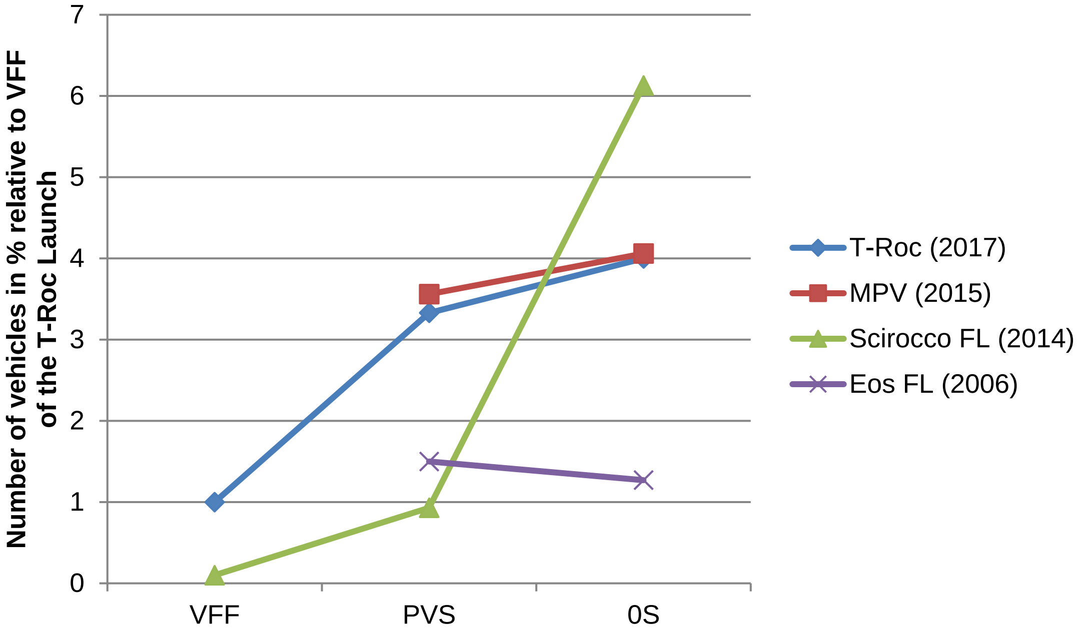


***Figure 3.11*** *- Graphic representation of Table 3.2*

In terms of duration of the sequence of phases of pre-series, the Volkswagen T-Roc launch followed the program established in the PEP in a way that it began 2,66*t* before the SOP with the VFF phase and finishes 1,66*t* months after when full capacity is achieved according to the ramp-up schedule in **Figure 3.10**. The KPI obtained for this launch in relation with the time was:

$$KPI\ (time) = 4.33t \tag{6}$$

Not all the vehicles that are produced in pre-series reach the final stage where they are delivered to a specific customer or used for tests. Mainly along the initial stages, scrap is inevitable and many vehicles/parts/components/resources are wasted in the production process. This is due to the lack of experience of the operators on the processes that need to be carried out in the new model, but also due to the lack of maturity in tools and equipment that are not yet operational. Even in vehicles that eventually reach the final stage, many resources are spoiled in the production of the specific vehicles since the processes are not yet routinized.

The launch of this new model was a much cleaner and more efficient process (in terms of scrap production) than the last launch in the factory. This may be due to increased automation since the last launch that facilitated the implementation of the new model in the production line and reduced the risk of scrap production.

The KPI for waste will be used for future comparisons and its value is merely representative, hence it appears as a proportion relative to itself:

$$KPI\ (waste) = SC \tag{7}$$

The greatest difficulties encountered during this whole process (as for any of the previous processes in the factory) was the training of the operators. This process is quite time-consuming since currently this training is carried out individually to each operator by a specialized team of the Pilot Plant, the section of the factory responsible for the implementation of the new vehicle.

The training begins with several launch specific workshops in order to teach the operators on their operations, changes in the processes for the new model, and some other relevant information. These workshops are complemented with “in loco” learning with the help of the Pilot Plant team. The production of some vehicles of the new model is weekly scheduled so that these operators can learn all the new processes that have to be carried out in each workstation. To add to this, the mass recruitment of operators carried on by the factory was also a difficulty that the trainers had to deal with.

Many workshops were made across all the areas of the factory in order to prepare the production of the Volkswagen T-Roc. This value represents one KPI related to the operators training:

$$KPI(op.training) = 60\ workshops \tag{8}$$

# 4. MODEL LAUNCHING 4.0

## 4.1. The Road to 4.0

The process of launching a new car model in a certain factory is a far from optimal process. When the factory starts to interact with the new model, many of the procedures are already too long and time-consuming for the actuality where consumers have instantaneous need for products. A reduced Time-to-Market for new products is one of the main drivers for the evolution of this process. Furthermore, waste is still a very important characteristic of this process, once it is produced in excess in testing phases.

The trend of the launching of a new car model can be set as trying to achieve **Model Launching 4.0** where there is no waste and the new product is produced with the quality desired at first try and with a much reduced planning phase. It is a very progressive and futuristic idea, however this new concept is expected to increase both the profits of the company that save in waste, and customer's loyalty that receive their product much sooner and with the quality desired.

In this chapter is made an analysis of the evolution of the pre-series phase of the launching of a new vehicle, using as basis the launch of the Volkswagen T-Roc, and focusing only in the Series Preparation phase of the PEP where the factory has a direct contact with the new model. This analysis is divided in several main areas of optimization of the launching process taking into account some technologies and its implementation in the process. At the end of each phase is made a prediction of the evolution of the process with the implementation of the new technologies and the use of the changes proposed.

### 4.1.1. Advance Predictive Simulation

Production planning and scheduling activities are some of the most important tasks that may reduce costs, waste and time-to-market of a new product. For this, digitization and simulation of various planning processes for the implementation of the vehicle is a huge step towards a launching process optimized by *Industry 4.0*.

Combining sophisticated simulation processes with Big Data and Data Analytics it is possible to carry out detailed planning of the implementation of a new model in a production line in relation to the behavior of tools and implementation of new equipment, operator behavior and its progress, and logistics organization of the whole process. These simulation programs use previous data and the strong computational power in the cloud to predict possible errors in the implementation of the new model and to correct them even before the model itself is implemented in the production line.

In a controlling point of view, this simulation process can be visualized as depicted in ***Figure 4.1***. In this system, in the Simulation/Cloud Computing are introduced the conditions to be tested and information from other simulations and past experiences backed by data analytics that transformed the results in useful information to obtain results and, re-due simulations or arrive at a conclusion.

The main tasks that can be performed through simulation are:

- Simulation of tool behavior using specific simulations for each type of tool;
- Simulation of product behavior by analyzing it characteristics through the several processes;
- Simulation of production volumes and the feasibility of a specific product in the current production line through the use of a system similar to MES;
- Simulation of supplier organization, process and logistics.

Not all of these types of simulations are performed today, however the evolution of this technology indicates that exists the possibility that all these simulations may be performed and, furthermore, very quickly.

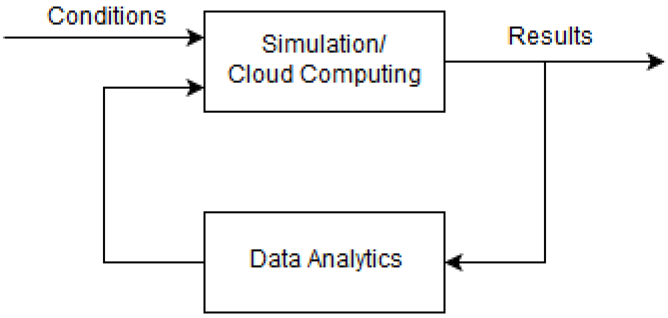


***Figure 4.1*** *- Feedback loop idea of the simulation phase*

This type of planning, despite requiring more resources in computational terms, prevents errors from occurring in the future, requiring a new phase of planning with the necessary changes. It becomes a unique, more dynamic and faster process that ensures that the implementation of the model on the production line will already be at a very advanced stage of the current PEP and with many fewer errors, fewer waste and much less need for changes and corrections.

Also, in addition to the increasingly powerful simulation tools that are being developed and investigated and to the growing power of computational entities, the increasing automation and digitization of production processes will make simulation easier once a fully automated production line is more predictable than humans, and results more and more reliable.

In the end, the “abusive” use of simulation processes will reduce the time it takes for a new model to reach a certain level of quality on the production line by means of a “by-pass” to certain test-and-error phases. The result of this idea is represented in ***Figure 4.2*** where the first phase of the Series Preparation can be practically eliminated and substituted by a much smaller phase called Advance Predictive Simulation Phase. The current first phase is used for optimization of the production line for the new model, identifying possible errors and corrections to be realized, and to test the fit and dimensional stability of some tools and equipment. All these procedures can be realized by simulation so that this phase can be gradually reduced and substituted by the new phase passing from the current *t* months to just a few weeks.

3

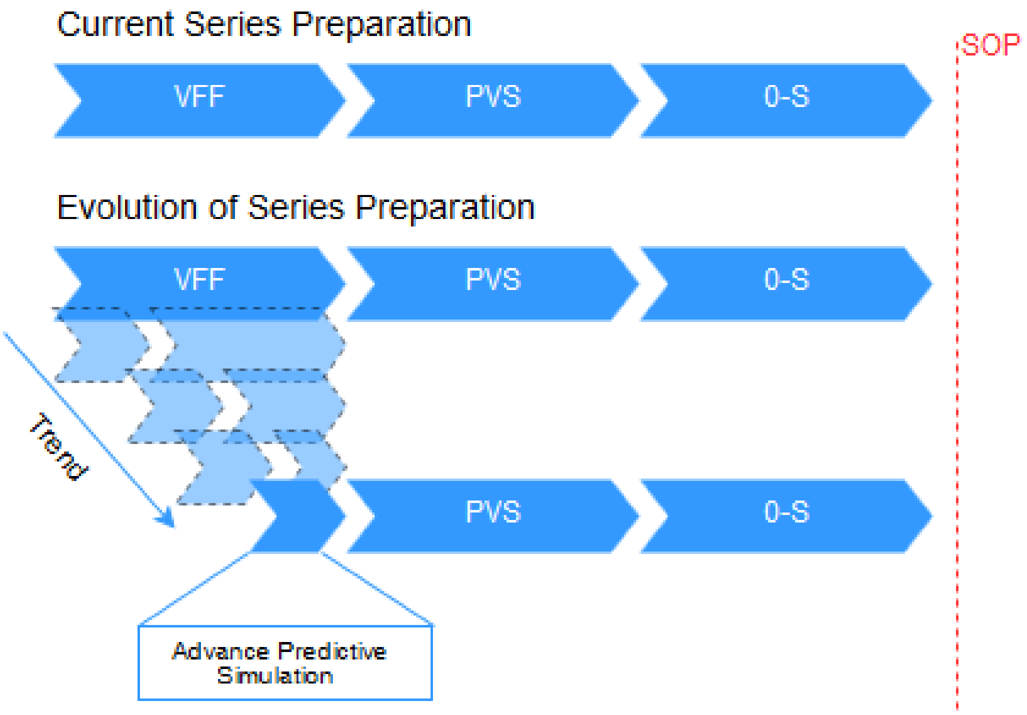


***Figure 4.2*** *- Evolution of the VFF to Advance Predictive Simulation*

### 4.1.2. 3D Printing

Currently, additive manufacturing processes are being used for the production of tools in the pre-series process, which corresponds to a great advance in this process. With 3D printing technology it is only necessary to convert the idea into a 3D file, send it to the printer, post-process after printing and the tool is able to be tested in order to evaluate concepts, dimensions and functionality, resulting in a faster implementation and greater efficiency.

Since the launch of the Volkswagen Sharan some test pieces and pre-series were produced by additive manufacturing. For the Volkswagen Sharan about 1% of the tools were produced by 3D printing, while in the launch of the Volkswagen Scirocco about 9% and in the Volkswagen T-Roc launch about 90% of all production support tools were produced internally to the factory and through this technology. In 2017 alone, 2361 prints were made corresponding to 48 kg of material, 365 CAD projects and approximately 2270 pieces produced with quality.

This growing use of additive manufacturing allows the expectation that all test tools will very soon be produced through this new technology at the next launch, and even expand this process for test parts in pre-series vehicles. With the current advances in 3D metal printing, that for example already allows to perform this process in stainless steel, this technology can be applied in the construction of cheaper prototype vehicles and in a faster way in order to test other equipment, tools, logistics or the training of operators, both in the factory and in other places such as in the development of tools in the suppliers.

### 4.1.3. Intelligent Automation

The automation and digitalization of the production line is a process that is already being implemented in today's automotive industry. In the view of *Industry 4.0*, processes that were previously performed manually are being replaced by highly efficient intelligent collaborative robots that can work along with humans or on their own.

This type of intelligent automation corresponds to a type of automation that incorporates artificial intelligence, through intelligent algorithms with learning ability, with collaborative robots in order to transform the current production line into a flexible, communicative and efficient production system. This type of production line allows the launch process in a car factory to become an extremely fast process as it will be fully automated and capable of extensive simulation but also much cleaner since the systems themselves are able to learn from the their errors and to avoid possible production of scrap by means of data analysis and communication with other components of the factory.

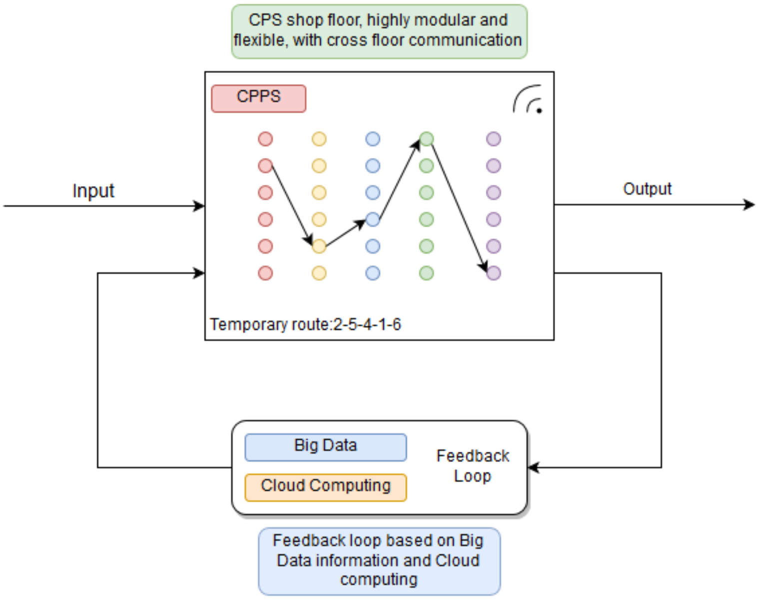
The areas of painting and press shop in the factory, for example, are areas with enormous potential for automation since the processes performed in these areas are quite repetitive and easily performed by a robot: in the press shop, production is organized by working cells that can become fully automated since currently the human interaction is merely for monitoring; in the other hand, in painting almost the whole sequence is automated with robots that change from color to color and can reach every spot of the vehicle that is necessary to be painted, both internally and externally, and this method can be expanded to the full length of the painting.

In the case of the assembly line the difficulty is increased in some processes that handle difficult components such as electrical cables, however in many other processes its introduction will make the overall process faster and more efficient, for example in the placement of wheels, doors, sealants and other solid components. In addition, with the automation of the production line, the number of errors and failures will reduce substantially and the need to verify the quality of the product will be reduced.

Inevitably, in the future the production lines will reach a point where there will be no direct functions of production occupied by humans. Production will become fully automated and where the most basic functions are fulfilled by robots. Humans will take more and more functions of equipment maintenance, which will become increasingly more predictive and programmed than corrective, and control of these intelligent systems.

The next step in the evolution of production lines, as already mentioned, is the implementation of CPS's. These systems constitute intelligent collaborative robots allied with connectivity that make production fully automatic, connected, efficient and productive. Its utilization in the production line will bring a great automation and digitalization to the process reducing errors, minimizing the waste that is produced, and reduce significantly the time it takes to adapt the manufacturing environment for a new product.

The implementation of these systems, in a controlling point of view, can be summarized by the ***Figure 4.3***, where the factory of the future can be reduced to a control loop with Big Data on the feedback branch. The machines, products and conveyors communicate between them, have self-awareness capabilities and control their own actions, taking into account both the data that they collect, and all the information that comes from the Big Data feedback loop that is analyzed and manipulated through CC (Wang, Wan, Li, & Zhang, 2016). Furthermore, all the components in the factory are connected through the IoT for instant, real-time access to all the data created in the physical world, so that performance indicators can be established and quantified for more accurate and effective decisions.

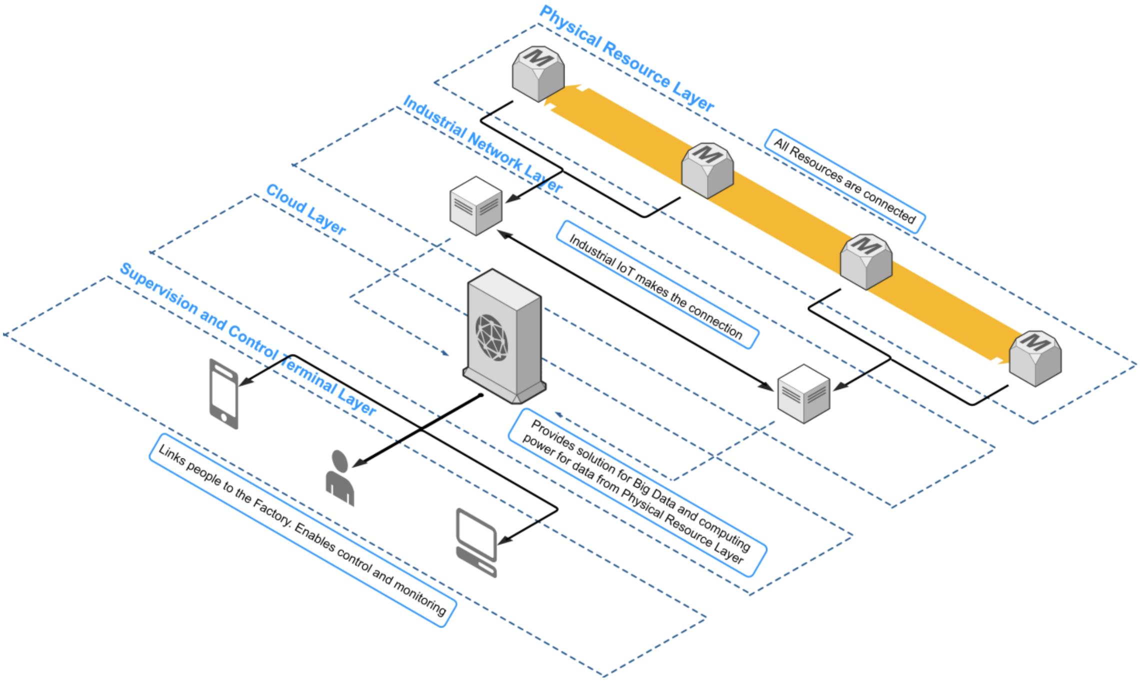


Source: adapted from (Wang, Wan, Li, & Zhang, 2016)

***Figure 4.3*** *- Controlling view of a Smart Factory*

Taking into account Big Data, CPS and the IoT, in the future, a factory can be divided into 4 different layers as represented in ***Figure 4.4***:

1. <u>Physical Resource layer</u> – physical objects such as smart products, smart machines, and smart conveyors that communicate with each other through the Industrial Network layer;
2. <u>Industrial Network layer</u> – forms the connection between artifact communication and links the Physical Resource layer to the Cloud layer;
3. <u>Cloud layer</u> – provides solution for Big Data analytics with storage space and computing power for data from the Physical Resource Layer through the Industrial Wireless Network (IWN);
4. <u>Supervision and Control Terminal layer</u> – links people to the smart factory.



Source: adapted from (Wang, Wan, Li, & Zhang, 2016)

***Figure 4.4*** *- 4 layers of the Factory of Future*

In a more technical way, each CPS will operate autonomously, making the best decision for each product according to a certain defined set of rules. These rules, which form the basis of decisions of these intelligent systems, are defined based on the history of the factory and previous knowledge, and a constant flow of information that is created during the factory operation and includes information about all the other CPS in the factory. This autonomous behavior of each CPS can be seen as a global behavior of the CPPS since each one takes into account the conditions of all other CPS relevant for its decision. To do so, these systems must have at their disposal a dynamic and real-time updated database that provides them with all necessary information for their decisions.

An architecture for each CPS is proposed in ***Figure 4.5*** where the system interacts with the database where obtains information about everything in the factory, with which it compares with the defined rules and makes decision for its actions. Subsequently, the actions are evaluated in order to check if it is necessary to update the rules or not.

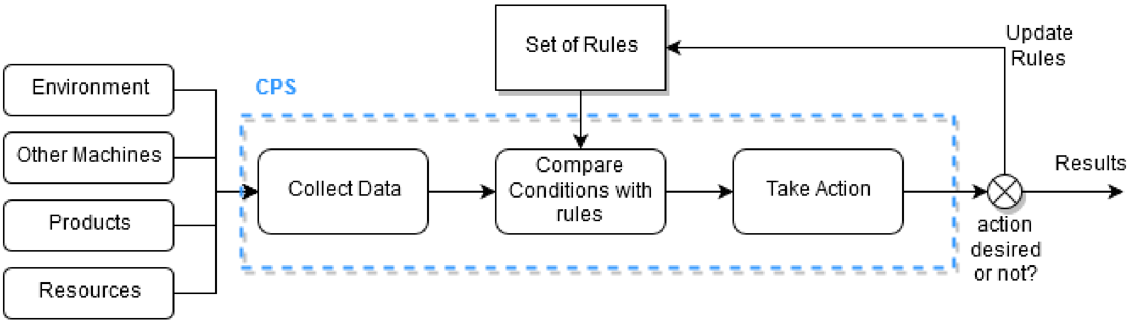


***Figure 4.5*** *- CPS framework for the Factory of the Future*

In this way, the first step should be the creation of a dynamic and robust database that will be a basis for the development of these systems. A database proposal is also provided in ***Figure 4.6***. It is organized as follows:

- Component represents all the equipment and machines in the factory:
    - Attributes: Component ID (Key attribute), Type of equipment, and daily maximum products to handle;
- Factory represents the entire factory as a whole:
    - Attributes: Zones of the factory (Key attribute) and number of components of each zone;
- Personal represents the information about all the workers in the factory:
    - Attributes: Worker ID (Key attribute), name, age, home address, and the number of years in the company;
- Products represents the information about all the products manufactured in this factory:
    - Attributes: Product ID (Key attribute), production start date, due date for delivery, and the necessary sequence for its production;
- Distribution represents the organization of each component in each zone;
- Manufactured by represents the sequence of components that handle a certain product;
- Manipulated by represents the sequence of worker that handles a certain product;
- Route represents the route performed by each product.

The route of each product is obtained by a combination of the tables Manufactured by and Manipulated by, represented by table Route, that has the structure of ***Table 4.1***.

Sequentially, the communication between machines, equipment and the products themselves is fundamental for the development of processes more efficient and fast, once each CPS need to gather as much information from its surroundings as possible.

Currently, in a production line still quite manual, the use of bar codes to identify products is the tool mainly chosen. These codes are specific to each vehicle and are read by operators through a bar code reader on almost every workstation.

In each station there is also a screen with some information relevant to the operators related to the bar code read by the personal and specific tool of each operator. This information includes bolt tightening procedures verification through the tool that communicates via Bluetooth and checks for the correct torque, vehicle information and steps to follow when possible. However not all workstations have this type of system since not all use tools that have the necessity to communicate with the system for verification of some procedure.

The use of a tag system that identifies each product, locates it and obtains information about it from a database is important in order to assign a dynamic identity to each component in a much faster and cleaner way. Using an RFID tag system assigned to each plant component with and updated real-time background information database allows monitoring and tracking product progression without the need to be constantly reading a barcode to keep the system informed. It becomes a much faster process and the operator doesn’t have to have the concern of constantly reading the bar code and can focus on its tasks. Furthermore, the information system that exists in some workstations can be maintained and even expanded to all workstations.

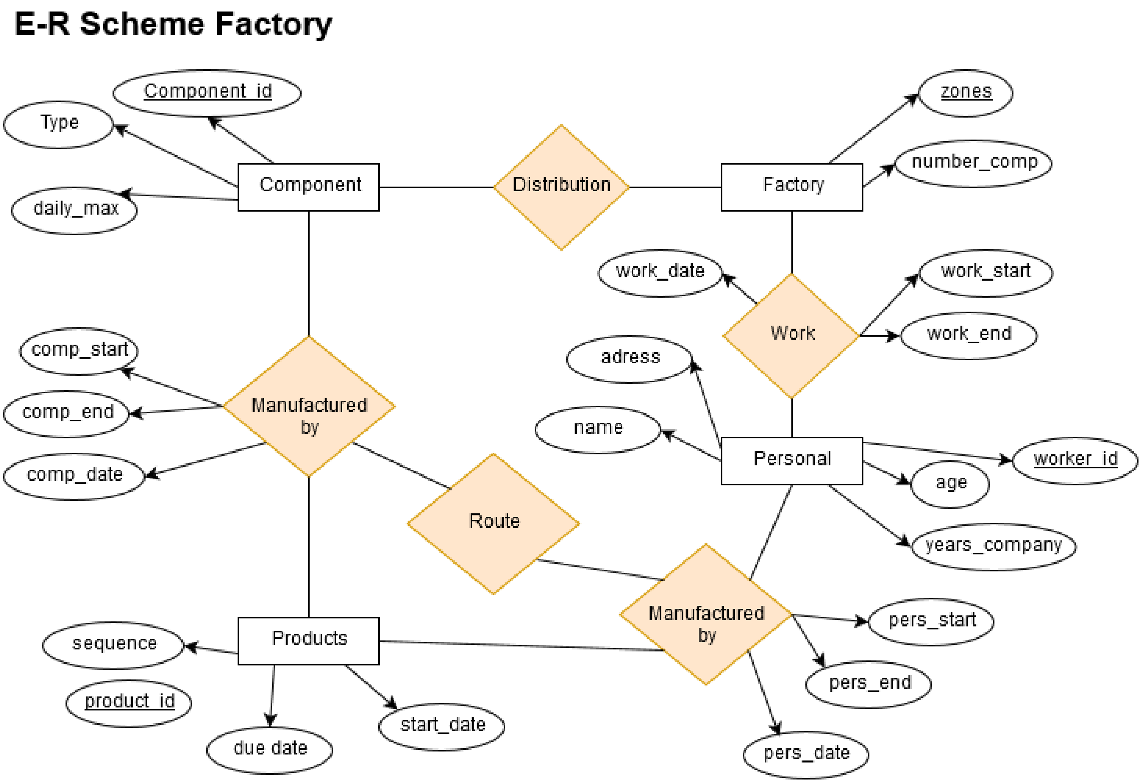


***Figure 4.6*** *- E-R scheme proposal*

***Table 4.1*** *- Route table scheme*

| product _id | comp _id | comp _start | comp _end | comp _date | worker _id | pers _start | pers _end | pers _date |
|---|---|---|---|---|---|---|---|---|
| ID445 | C05 | 08:55 | 09:01 | 10-08-17 | - | - | - | - |
| ID446 | C05 | 09:02 | 09:08 | 10-08-17 | | | | |
| ID445 | - | - | - | - | 42208 | 09:02 | 09:08 | 10-08-17 |
| ID446 | C03 | 09:08 | 09:14 | 10-08-17 | - | - | - | - |
| … | … | … | … | … | … | … | … | … |

In terms of equipment, it allows to identify the route the product went through the factory. The database information is updated by cloud computing power that uses RFID trackers as data input and real-time information. The user can access anywhere in the world to the information in the database about his “order” such as Time-in-System (TIS), manufacturing status, route, and expected completion time. ***Figure 4.7*** provides an example of the structure of this connection scheme.

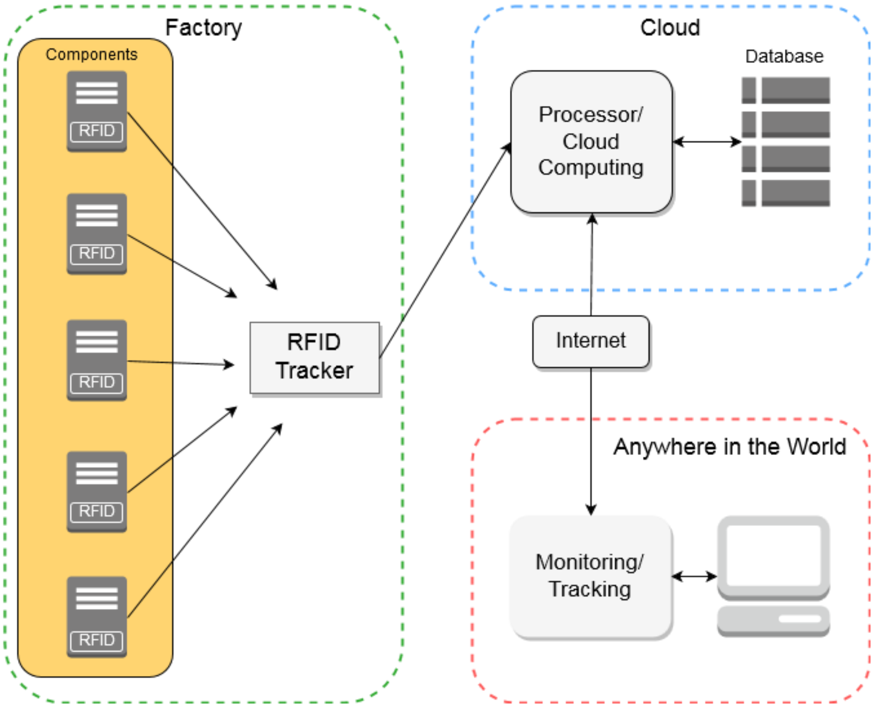


***Figure 4.7*** *- Communication structure with RFID tags*

In a next phase, in order to achieve a fully automated CPPS, the use of these tags will be replaced by communication systems incorporated in the equipment itself as their technologies evolve. It allows this communication to be even more dynamic and fast. The input of information in the cloud is now carried out through each of the components of the factory.

The use of this CPS architecture and database represents an organized and efficient way to establish an integrated communication network in the factory so that the automation applied is as productive as possible. Furthermore, and more importantly, reliability becomes a recurring term since one of the new objectives that will emerge will be not to get any kind or error or failure. ***Figure 4.8*** resumes the next stages in the way for Model Launching 4.0.

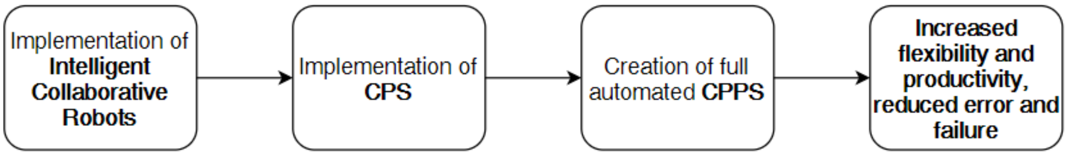


***Figure 4.8*** *- Evolution of the production line*

This evolution of the production line will bring a great advantage to the process of launching a new product: increasing the flexibility and reliability of the production line will reduce the verification and confirmation phases of the production in the PEP. A production line based on the idea of CPPS will allow a very high confidence that the product will be produced with the desired quality and flexibility to change the product in a short period of time.

Eventually, production line will become so reliable that this phase of verification suffers a drastic reduction. It will not completely disappear once the need for verification will always exists, however its duration will reduce to a few weeks.

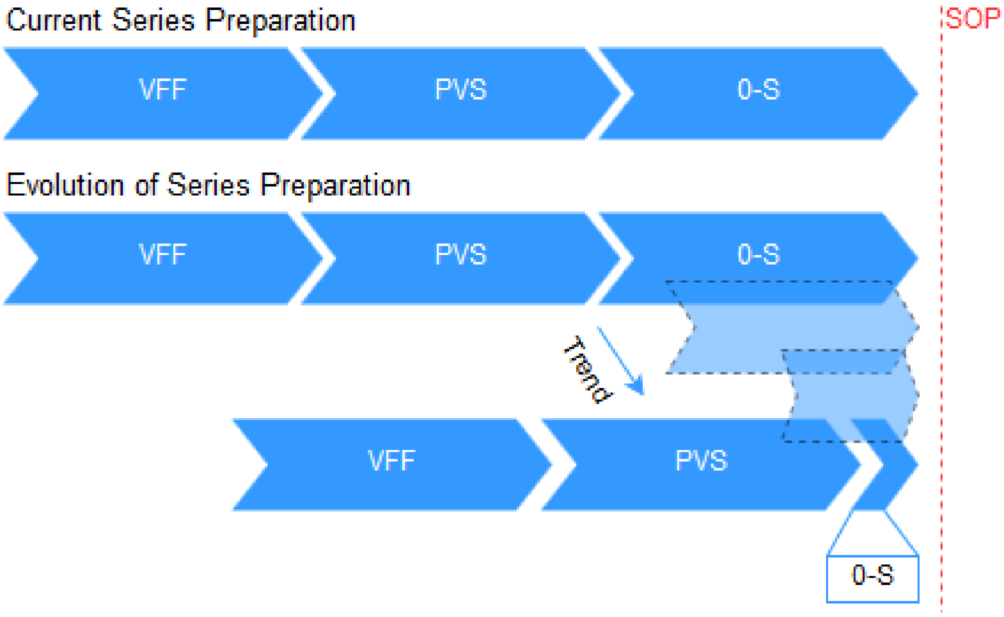


***Figure 4.9*** *- Evolution of the 0S with the digitization and intelligent automation of the production line*

This phase corresponds to 0-S where the production process is verified as well as all its equipment, operators, logistics and production system on conditions similar to those expected when production starts. With the evolution of automation the need for this phase will reduce as the product will almost automatically have the desired quality when is implemented in the production line. It will then go from the current *t* months to no more than 1/3 *t* as shown by ***Figure 4.9*** that represents the trend of this stage.

### 4.1.4. Virtual and Augmented Reality

The use of virtual and augmented reality technologies is one of the most promising solutions to accelerate this process and reduce the number of vehicles that are produced and wasted. The use of these systems allows the operators to learn to carry out the process in simulation at an early stage through virtual reality, and later, already at the production line, through the use of augmented reality.

As already mentioned, worker training is one of the most time-consuming and difficult stage in the entire process, and has been a critical issue in all vehicle launching processes in the factory. Currently the operator training is constituted by a number of workshops followed by training “in loco” where the operators receive training in the production line during the production of the pre-series vehicles.

The trend in this process is the implementation of virtual and augmented reality technologies in order to accelerate the entire process and prevent operators from feeling the need to train on real objects that have now high risk of becoming scrap due to the lack of experience of operators in the new procedures of production.

In the PEP, the phase where the training of the operators is most relevant is the PVS where all the equipment is tested individually. The use of augmented reality will reduce the duration of this phase from the current *t* months to about a few weeks where all the equipment verification tasks and operation training are carried out.

Initially, this process will change its premises and virtual reality technology will be implemented in the process to support the current forms of training. This implementation will reduce the number of workshops since with this technology they will become much more effective.

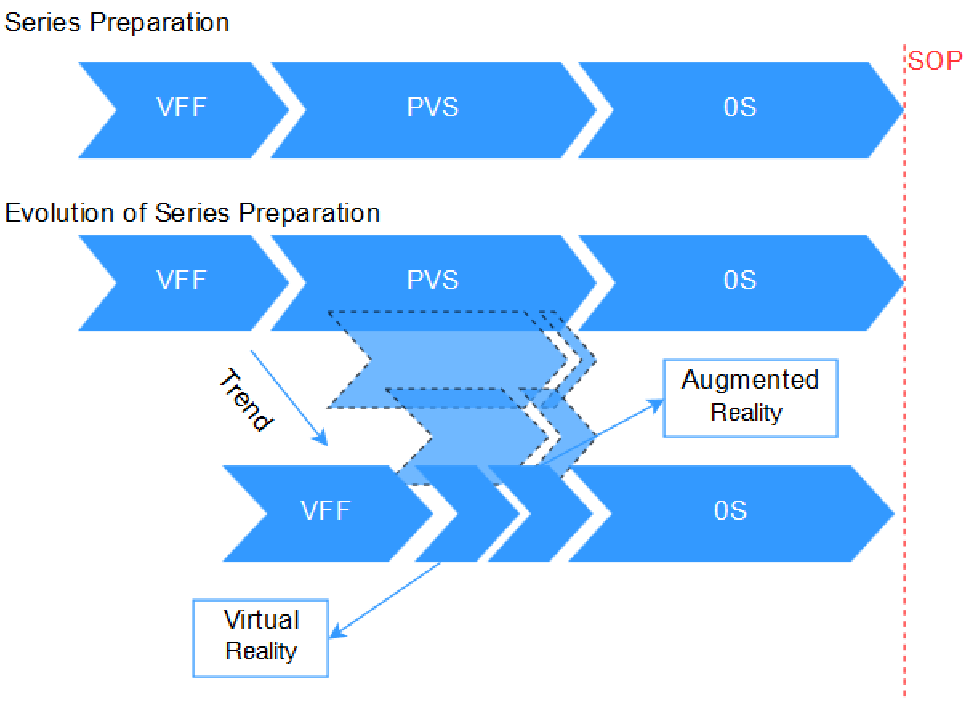


***Figure 4.10*** *- Evolution of the PVS with the implementation of Virtual and Augmented Reality*

Subsequently the implementation of augmented reality will correspond to the next phase in the evolution of this process. The use of this technology in the operators training will turn this process in to an even more effective one so that it will be increasingly implemented at this stage of the PEP. In the end, this intermediate phase of the Series Preparation will be resume to a set of Virtual Reality implementation followed by a set of Augmented Reality phase.

In addition to all the improvements mentioned above, this technology also has the potential to improve communication/connectivity between the factory and the product/process engineering. The use of virtual and augmented reality allows at an early stage to speed up the process of identifying and solving certain problems of product manufacturability and avoiding the existence of test phases and subsequent correction and scrap production. This allows phases such as VFF and 0S to have much less need to be used in their entirety so that they can subsequently be reduced in duration. Despite this, as already mentioned, the phase of PVS will be the phase most affected by the implementation of this type of technology.

## 4.2. Future Model Launching Process

Given the novelties that will be brought to the launch process in the future, which is here called **Model Launching 4.0** as it will correspond to the launching process related to *Industry 4.0*, it will suffer a reduction, or so it is expected, in terms of duration, number of cars produced, waste and duration of training of operators.

In all previous analyzes it was noted that in terms of duration the process would drastically reduce, however it is necessary to have in mind the progression of the technology and what still is necessary to be developed in order for the stages of the process to achieve the desired goals.

The intelligent automation of the production line is a theme where there are specialized teams totally dedicated to finding the opportunity to implement this kind of automatisms in the production line. In 8 years it is expected that intelligent automation has taken on greater proportions in the production line so that the reliability of the same increases among those responsible for the launch of the new model.

The evolution of the power of simulation predicts that by 2025 it will be possible to simulate to the smallest detail a manufacturing unit. More and more tools are emerging to complement the existing ones that already allow simulating, with some level of accuracy, the current processes. By that time the launch process will depend on this tool in the process of planning the implementation of the new model on the production line and will replace some stages of preparation and testing.

Regarding the training of operators, this topic will continue to be the most critical point in the whole process. Dealing with humans involves dealing with extremely random and very unpredictable systems where the power of simulation for these cases fails in terms of reliability. Operator training will reduce in duration as soon as virtual reality technologies are implemented in the training process, however, in the goal outlined, the virtual and augmented reality will not yet be profitable enough for mass implementation in a multinational such as Volkswagen.

Since 1997, Volkswagen reduced the duration of its launching process from 21$t$ months to 16$t$ months that represents a reduction of about 25% in the duration of the process. Aiming at the year of 2025 that coincides with the limit set for the objectives of the Volkswagen strategy, and assuming that the growth and innovation rate today can be much greater than it was before, it is expected that in 8 years this process has reduced at least 25% in terms of duration relative to today, corresponding to a reduction of about 0,66$t$ in the Series Preparation stage. At this stage the changes are measured in weeks since the goal is that in the limit, the total process is reduced to a few weeks.

Relative to the ramp-up schedule, with the evolution of automation it will be possible to implement a new product with much more safety and speed in the production line. This process will reduce its duration from the current 1,66*t* months to just a few weeks. In spite this, in the future is expected that this scheme will no longer be needed since, in a fully automated production line, the new product can be immediately produced in series from the moment the production order is issued. A forecast for the evolution of this scheme is shown in ***Figure 4.11*** where in each week is produced 1.3 times the production for Volkswagen T-Roc, in a way that Mass Production is reached 0,75*t* months earlier.

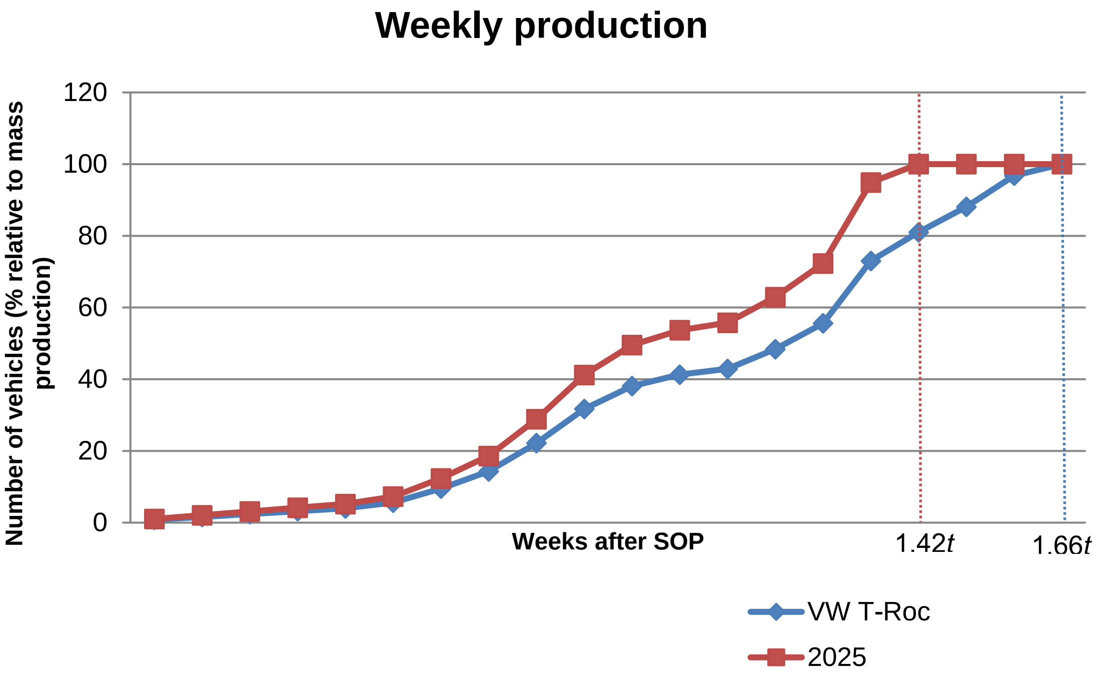


***Figure 4.11*** *- Forecast for the ramp-up schedule by 2025.*

Taking into account this evolution, by 2025, the launch process of a new vehicle will have a KPI related to the duration of the process as:

$$KPI\ (time) = 3{,}42t\ months \tag{9}$$

Allied to the reduction of the duration of the process, the number of vehicles produced will also suffer a decrease; however, in this case, this variation is expected to be even higher, reducing the number of vehicles produced to about 70% due to the decrease of the need of the production of cars for testing and evaluation of quality (intelligent automation of the production line and use of additive manufacturing processes provides reliability of quality at first try) and new concepts in operator training. The value of the KPI related to the number of cars produced emerges then:

$$KPI(number\ of\ cars) = \ 5{,}84 \tag{10}$$

The predicted distribution of these 5.84 vehicles (related to the VFF phase of the T-Roc launching process) along the stages of the Series Preparation is presented in ***Table 4.2*.**

***Table 4.2*** *- Number of pre-series cars produced in Model Launching 4.0 by 2025*

| **Pre-series phase** | **T-Roc (VW276)** | **VWxxx (after 2025)** | **% Reduction** |
|---|---|---|---|
| Advance Predictive Simulation/ VFF | 1 | 0.17 | ≈-80% |
| Virtual and Augmented Reality/ PVS | 3.33 | 3 | ≈-10% |
| 0-Series | 4 | 2.67 | ≈-30% |
| **Total** | **8.33** | **5.84** | **≈-30%** |

In one hand, the stage responsible for the operators training suffers the smallest reduction of around 10% due to the slow evolution that this process will suffer and the difficulty that is to fully implement virtual and augmented reality in 2025. In the other hand, the other two stages will suffer a massive reduction (around 80% in the first stage and 30% in the last stage), resulting in the production of half that was produced in the Volkswagen T-Roc. The first phase of this launching process in 2025 will suffer a greater reduction than the last phase, and consequently the greater reduction of the three phases, since the developments around simulation processes are very promising and, in spite that it is expected that automation will take great proportions in the future, simulation will be firstly implemented in full scale.

In **Figure 4.12** is represented this reduction. It is important to note that, in spite the first stage suffers the greatest reduction in percentage, it suffers the smallest reduction in terms of number of pre-series vehicles produced. Furthermore, in the next launch there will not exist the normal growth in the number of vehicles as SOP approaches, due to the small developments expected in the training phase relative to the other two phases.

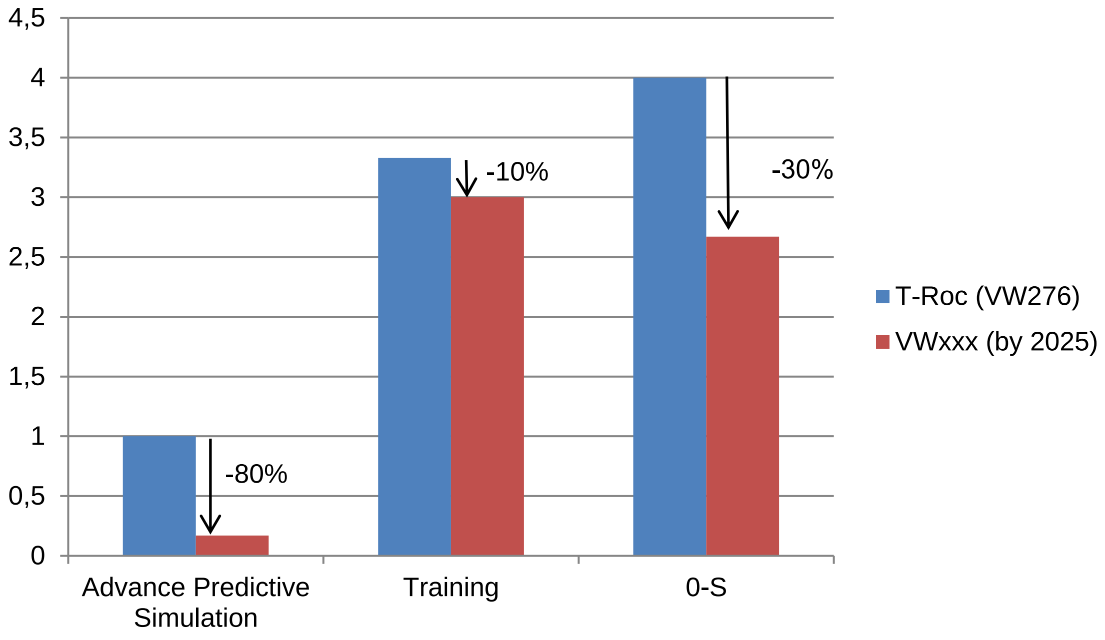


***Figure 4.12*** - ***Table 4.2*** *graphic representation of the prediction for the next launch*

Regarding waste, and taking into account that between the launch of the Volkswagen Sharan PA and the Seat Alhambra PA in 2015 and the Volkswagen T-Roc in 2017 there was a significant reduction in the production of scrap, so it is expected that, in 2025 this reduction will be even more pronounced.

Taking into account the evolution that is expected in automation of the production line and the massive evolution that additive manufacturing has been through in the last years it is possible to establish that, in 2025 the production of scrap will be about 75%, or even less, of the current value in a launching process:

$$KPI(waste) = 0{,}75SC \tag{11}$$

This value is set at 75% so that if on 8 years there is a 25% reduction in scrap production, then at this pace of progression in 32 years it is possible to launch a new model without producing scrap. However it is also expected that the evolution will gain new paces in the future and that it is possible to launch a new model without waste much sooner than 2049.

The training of the operators will undergo the biggest changes between all the major characteristics of the launching process. Initially, the use of virtual reality will allow operators to be prepared more consistently, quickly and effectively through simulations of their workspace and processes. In addition to being a much more dynamic and exciting process for the workers, it is a faster process that allows reducing the duration of this training period. The launching process will thus suffer a reduction in its duration, and also the number of workshops. With both these processes applied in the training of operators, the launching process will be reduced at this stage and the number of workshops may be in the range of a dozen or even less depending on the model to be launched.

By 2025, the augmented reality technologies won't be yet implemented so that the training of operators "in loco" won't be removed but will possible reduce their duration and scrap production due to the increased competency of the workers.

The number of workshops will then result in about 90% of the Volkswagen T-Roc launching that corresponds to about 54 workshops:

$$KPI(op.training) = 54\ workshops \tag{12}$$

The evolution of both the duration of the whole process and the scope of each phase of the Series Preparation is represented in **Figure 4.13**. In 2025 it is expected that the PVS phase will become a phase partially focused on training that combines virtual training with workshops and the usual "in loco" training in the production line. By 2035 the Advance Predictive phase will be fully implemented so that the former VFF phase will have a slightly different scope and also a much shorter duration. Also by this time the training with augmented reality will begin its implementation process complementing the previous training phase. The duration of all phases will continue to decline to a future where each will last for only a few weeks. In addition, the last verification phase will successively decrease its duration to a point where its existence will no longer be necessary, however this future is still a bit far from today's production reality.

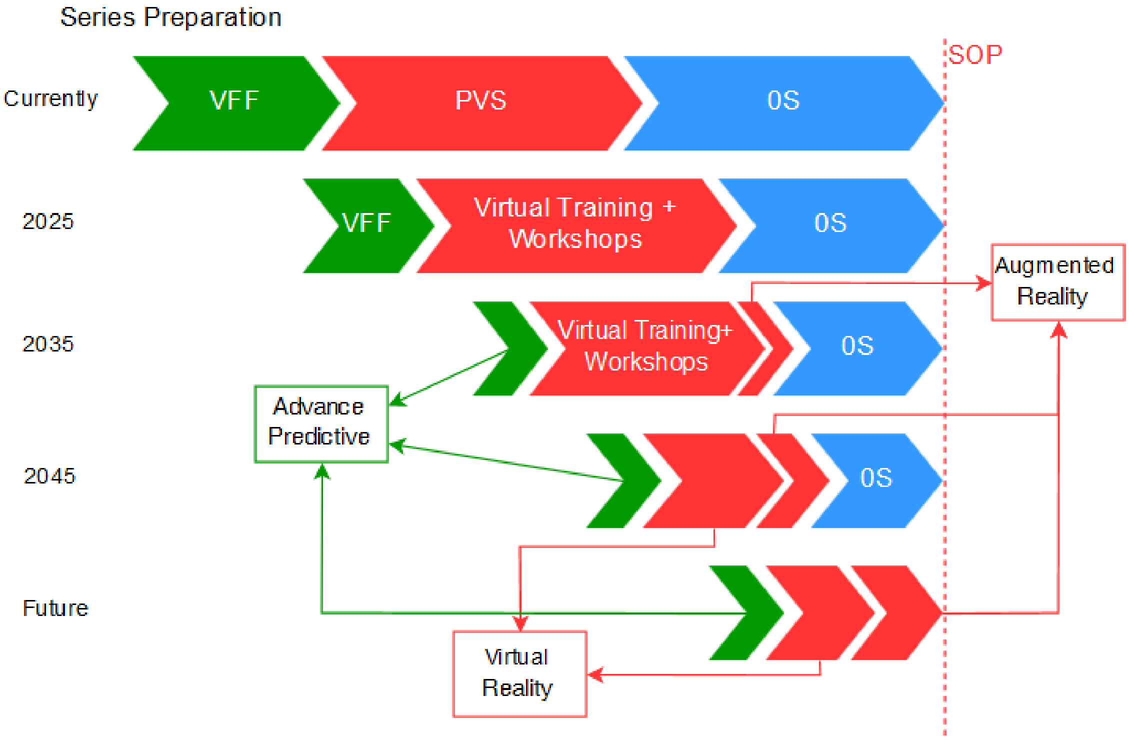


***Figure 4.13*** *- Evolution of Series Preparation*

**Table 4.3** and **Figure 4.14** represent the expected future evolution for the four KPI's established for the launch of a new car model.

Firstly, the amount of scrap produced in the pre-series phases will be the most rapidly eliminated feature from the four shown. Between the last launch and the launch of the Volkswagen T-Roc which, as already mentioned, differ between a FL and a completely new model, it was noticed a great reduction in the production of scrap, so it is completely valid to assume that around 2025 this amount reduces to about 75%. After this date, this progression will be even more accentuated by the increasingly growing automation of the production line that will bring reliability to the production process reducing the possibility of errors and misuse of resources. Furthermore, the evolution of data analytics and its implementation in the automotive industry will make possible to foresee possible errors even before they occur and to control more effectively all the constituents of the production process. In this way it is expected that by 2045 no more scrap will be produced at the launch of a new car model.

The number of workshops to be developed will be the feature that will more slowly evolve. Due to the great difficulties that exist in the training of the operators for the new processes and the expected slow implementation of augmented reality technologies in this process, by around 2035 this KPI will only have reduced around 15% of the current value. After this time, this technology will start its implementation path, the growth rate will greatly evolve, so that in 2055 this KPI will already be 30%.

The duration of the process and the number of vehicles produced therein maintain an evolutionary relationship over time. With the increasing implementation of automation and industrialization in the production line, it will be increasingly possible for these features to be successively reduced over time: as a primary measure in the evolution of this process, the number of pre-series vehicles is reduced in order to reduce the costs of implementing a new model; after validation that this reduction is sustainable for the launching process it is then possible to produce this same number of vehicles in a shorter time period, so the duration of the pre-series process also suffers a reduction. However, these changes in the process are out of phase since reducing the duration will require validating the reduction in the number of pre-series vehicles to be produced.

Taking into account this increasingly reduction, by 2025 the number of pre-series vehicles produced will be 70% of the current value. In turn, and consequently, the duration of this process may also suffer a small reduction to 90% of the current period.

At a later stage, this need for validation will be removed, so that the evolution of the duration will follow the number of vehicles produced. In spite of this rapid evolution, these two characteristics will continue to be relevant around 2055 since it will still be difficult to have a launching process without the production of pre-series vehicles and which has a production system so automated that it allows to produce a new model without any preparation and implementation phase.

However, by 2045 any launch of a new model in the factory will be a much more dynamic process due to the increasing experience that the factory will have in automotive launches, clean with scrap production very close to the null value, fast since the duration of the process will already be about 35% of the current value, and much cheaper and sustainable for the producer since the number of pre-series vehicles will be around 20% of the current production.

***Table 4.3*** *- Forecast of the evolution of the main characteristics of a launching process (% relative to the T-Roc launch)*

| | **Currently** | **2025** | **2035** | **2045** | **+2055** |
|---|---|---|---|---|---|
| Series Preparation duration (weeks) | 100 | 90 | 65 | 35 | 25 |
| Number of pre-series vehicles (% relative to the T-Roc Launch) | 100 | 70 | 40 | 20 | 10 |
| Number of workshops for operators training | 100 | 90 | 85 | 55 | 30 |
| Waste (scrap) produced in Series Preparation (% relative to the T-Roc Launch) | 100 | 75 | 45 | 0 | 0 |

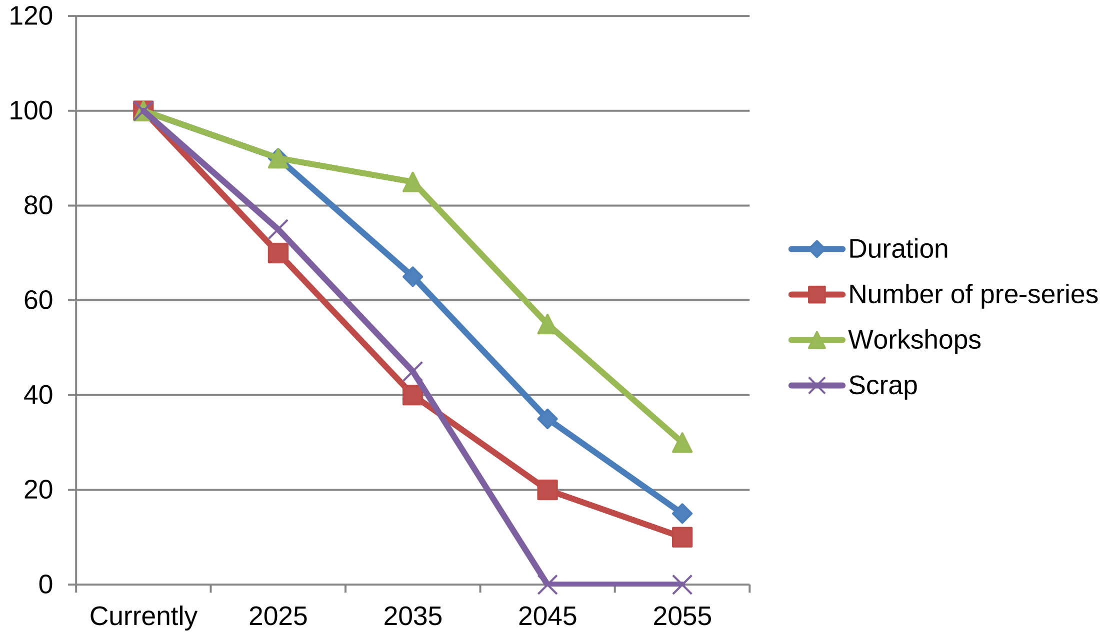


***Figure 4.14*** *- Evolution of the 4 KPI's*

# 5. Main fields of R&D in the automotive industry

As already mentioned, the launching process will have a progress of reduction of its duration, waste and scrap production, number of pre-series vehicles produced, and duration of the training of the operators. These developments will help create the future factory launch process where a new model is thought, developed and produced in series in a few weeks based on enormous versatility and flexibility in the process.

For the launch process to evolve in this direction to get a new model in a few weeks, the intelligent automation of the production line will have to be a major investment. Currently, in the production of a vehicle, many human operators are directly involved in its production, which reflects in a high possibility of scrap production and a very low flexibility. The trend of the production line is based on its total automation replacing the human operators and resulting in a flexible production line constituted by intelligent robots. This evolution is inevitable and must constitute a priority in future changes of the production line.

Technologies related to data analysis, computing and communication have undergone a huge evolution in the last years and its tendency and prospect of growth is enormous. Systems such as CPS that will become the basis in the achieving of *Industry 4.0* will be able to have its base increasingly strengthened so that its implementation is possible in an ever closer future.

The evolution of Virtual and Augmented Reality systems is a process that should be analyzed and followed very seriously and carefully since its implementation in the process of training operators will remove the need for much of the launch process, having a direct influence on the duration of the whole process, in the production of scrap, and in the duration of the training of the operators.

Research into these systems has been very intense currently and it is expected that in a very near future it will be possible to use these systems in a car factory in a cost-effective and sustainable way. The cost of its implementation is currently extremely high for its utilization; however it will eventually reach a level where large groups such as Volkswagen will be able to deploy it in series across its factories.

Finally, additive manufacturing is already a widely used process in automotive factories, especially in the production of pre-series tools. However, with the developments that this technology has undergone over the years it is possible that this type of production is expanded to the very production of pre-series vehicles and maybe one day be included in the production line itself. It is a technology with a huge growth prospect which is associated with great savings in terms of costs, time and also maintenance.

In the analysis carried out, the issue of cyber security was not addressed, despite the fact that this issue is extremely important in the development of *Industry 4.0*. In the automotive industry, a breach of security can lead to the passage of information and se to the competition, which can lead to branding to bankruptcy. Despite the importance of this concept, an analysis in this theme would have to be carried out with some depth, which would escape the theme of this dissertation.

# 6. Conclusion

## 6.1. Major Challenges

In the development of a thesis in collaboration with a company as well-known as Volkswagen Autoeuropa, the biggest challenge faced is the fact that there is a huge need for confidentiality in any information inside the company. Much information that was developed in the dissertation has an especially confidential aspect so that it was necessary to change the way the information is divulged in order to protect the company interests.

## 6.2. Conclusions

The development of *Industry 4.0* within the automotive industry is only just beginning, however, it is already possible to predict that this implementation will revolutionize automotive production from its core. In the case of the process of launching a new car model, this whole process will undergo an enormous revolution with reductions in its duration and production of waste, and in improving its effectiveness and productivity. It is necessary to follow the needs of the consumer who already bets on the customization and speed of manufacture.

Several features will influence how the launch process will evolve over time. The use of simulations will become a fundamental process in an automotive factory since it will allow for prediction and preparation of a new implementation in a much more in-depth and much more diverse way in terms of possible scenarios. Test and error phases will become totally obsolete.

Automation of the production line is already a concern of the automotive industry, however, it is expected that this process will continue in order to integrate communication systems that allow the creation of integrated, communicative and connected production systems, where the consumer becomes part both in the design phase and then in the follow-up of the production of his product. These systems will carry on decision-making and make these production lines more and more efficient, clean and productive.

Currently this process is still too time consuming, however it is expected that in the next launching process it will be possible to identify significant improvements, and later on this development will be further accentuated in posterior launches. Specifically for the implementation of the new model in the production factory this process will become much faster where new car models will be thought, designed, prepared, planned for production and implemented in a much shorter period than the current one.

This significant reduction in the duration of the process is also coupled with an expected reduction in the production of scrap which by 2045 is expected to be null or very close to that value, and the number of pre-series vehicles which are not expected to be eliminated, however will suffer a significant reduction to a very low and sustainable value.

The training of operators will continue to be a critical phase throughout this process and it is expected that it will not undergo many changes at an early stage, however, as technologies develop such as virtual and augmented reality, this process will take different proportions in a way that it is possible to get the most out of every training action in the most effective and dynamic way.

In particular, Volkswagen Autoeuropa already has a development policy which, if well exploited and with a clear initiative and a strong investment in innovation and the development of this process, can take major and important steps towards *Industry 4.0*. This development is still at an embryonic stage however it is expected that by 2025 it will suffer its great explosion and that its growth will increase dramatically. Investment and research around this theme must remain extremely active in order to drive the growth of the concept and its inevitable implementation across the industry.

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