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
miguelsilvavillalva@gmail.com
Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
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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. 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.

Index Terms* – Industry 4.0*, automation, customization, industrialization, Volkswagen T-Roc.

INTRODUCTION

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. 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.

Particularly, 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.

The objective of this research is to study 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. To do so, the release process of the 2017 Volkswagen T-Roc in Volkswagen Autoeuropa was analyzed.

STATE OF THE ART

I. Historic Contextualization

Throughout the history of mankind there have been some significant improvements on manufacturing process that led to the evolution of industry and production processes. 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 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 third revolution happened in 1969 when Modicon presented the first programmable logic controller (PLC) that enabled digital programming of automation systems (Drath & Horch, 2014). At the present day, manufacturing is on the brink of the Fourth Industrial revolution, also called *Industry 4.0.*

II. *Need for Change*

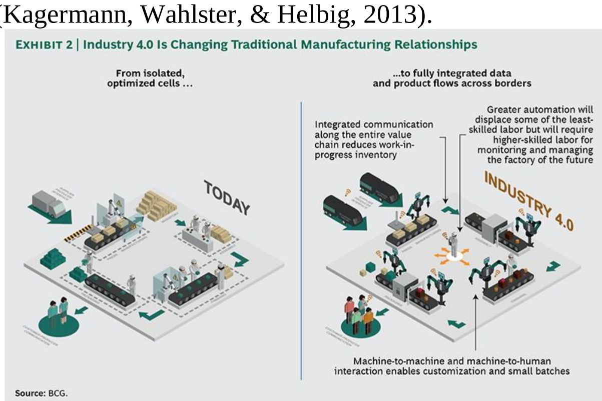
Up until now, manufacturing has firstly turned from craft production to mass production where producers focused on simply increase outputs and productivity without paying attention to the consumer needs fluctuations. However, this production vision is becoming completely outdated and is underway a paradigm 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.

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.

III. *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.

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).



Source: (Rüβman, et al., 2015)

FIGURE 1 - FROM 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).

CASE STUDY DESCRIPTION

I. Volkswagen Autoeuropa

Volkswagen is a car brand that belongs to the Volkswagen Group and has its headquarters in Wolfsburg, Germany. 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.

II. Current New Model Launching Process – 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 for each department and division 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 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).

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. 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.

III. T-Roc Release

In the process of launching to the market the new Volkswagen T-Roc, there are 4 factors that have been determined to be relevant for the characterization of the process and to evaluate it, and to do so some Key Performance Indexes (KPI) were created in order to measure how the release of the new model was accomplished:

- *Pre-series cars produced* – The number of cars that were produced in the factory in the pre-series stages until SOP;

$$KPI\ (number\ of\ cars) = \sum_{i=1}^{n} c_i, \quad \text{where } c_i \text{ is the number of cars produced by stage } i \qquad (1)$$

- *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;

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

- *Waste* – Amount of waste produced in the same pre-series stages just for the production of the pre-series vehicles;

$$KPI\ (waste) = \frac{w}{\sum_{i=1}^{n} c_i}, \quad \text{where } w \text{ is the total waste produced and } n \text{ is the number of stages} \qquad (3)$$

- *Operators Training* – training of the line operators for the production of the new model.

$$KPI\ (op.training) = \sum WS_j \quad \text{where } WS_j \text{ is the number of Workshops per area } j \qquad (4)$$

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.

This number 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
- Number of powertrains available
- Countries where the model is commercialized
- Number of paintjobs
- Novelty for the brand
- Maturity of the factory

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 1. The values for the number of vehicles produced are relative to the VFF phase of the T-Roc release and the duration of each stage is in terms of *t* periods of time in order to preserve some confidentiality in the values.

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. Also, stress tests begin to be carried out where the conditions and sequence of production in the SOP are tried to be replicated in order to evaluate the production system, conditions of the operators, manipulators and their availability for the new model, quality and logistics.

TABLE 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%

Furthermore, this growth is also defined taking into account the scheme of vehicles that will be produced after the SOP, called Ramp-Up Schedule (FIGURE 2), that approximates the number of vehicles produced over time to the value that needs to be produced when mass production is achieved.

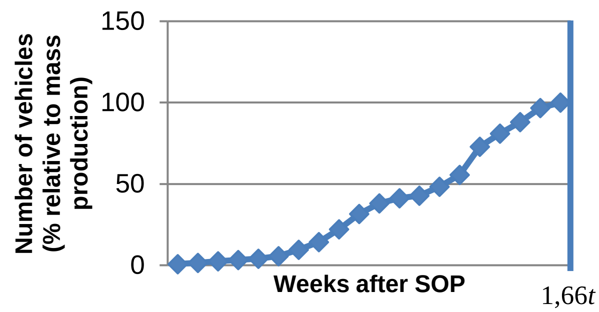


FIGURE 2 - RAMP-UP SCHEDULE FOR VOLKSWAGEN T-ROC IN PERCENTAGE RELATIVE TO SERIES PRODUCTION

The total number of cars produced in the 3 stages of pre-series represents one KPI for the launching process and its value corresponds to a total of 8.33 times the number of cars produced in the VFF phase.

$$KPI\ (number\ of\ cars) = 8.33 \quad (5)$$

TABLE 3 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). 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 this launch, and 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 – COMPARISON OF NUMBER OF CARS RELEASED IN PREVIOUS LAUNCHING PROCESSES (PROPORTION RELATIVE TO THE VFF OF THE T-ROC LAUNCH)

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

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 2.

$$KPI\ (time) = 4.33t \quad (6)$$

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.

The launch of this new model was a much cleaner and more efficient process 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:

$$KPI\ (waste) = SC \quad (7)$$

The greatest difficulties encountered during this whole process 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.

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:

$$KPI(op.training) = 60\ workshops \quad (8)$$

MODEL LAUNCHING 4.0

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.

I. 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.

In a controlling point of view, this simulation process can be visualized as depicted FIGURE 3*Error! Reference source not found.*.

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.

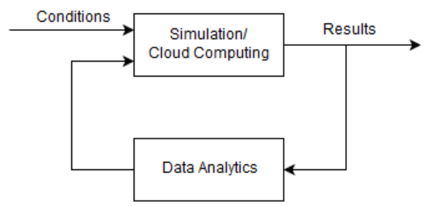


FIGURE 3 - FEEDBACK LOOP IDEA OF THE SIMULATION PHASE

The result of this idea is represented in FIGURE 4 where the first phase of the Series Preparation can be practically eliminated and substituted by a much smaller phase called Advance Predictive Simulation Phase.

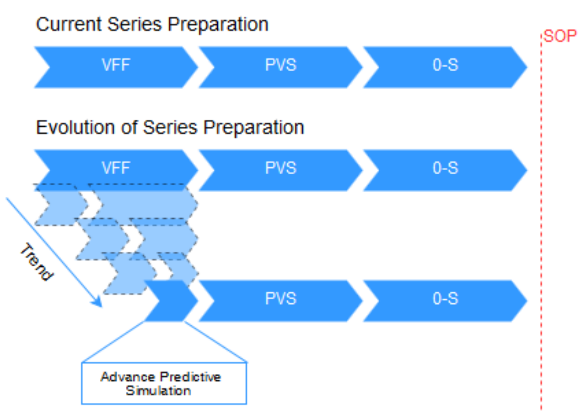


FIGURE 4 - EVOLUTION OF THE VFF TO ADVANCE PREDICTIVE SIMULATION

II. *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. 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.

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.

III. *Intelligent Automation*

The automation and digitalization of the production line is a process that is already being implemented in today's automotive industry. 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.

The next step in the evolution of production lines, as already mentioned, is the implementation of CPS's, systems that constitute intelligent collaborative robots allied with connectivity that make production fully automatic, connected, efficient and productive. 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.

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. An architecture that fulfill all the requirements for CPS is proposed in 5.

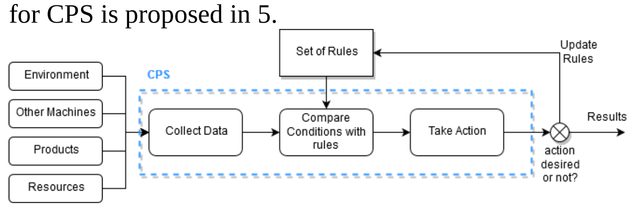


FIGURE 5 - CPS FRAMEWORK FOR THE FACTORY OF THE FUTURE

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 6.

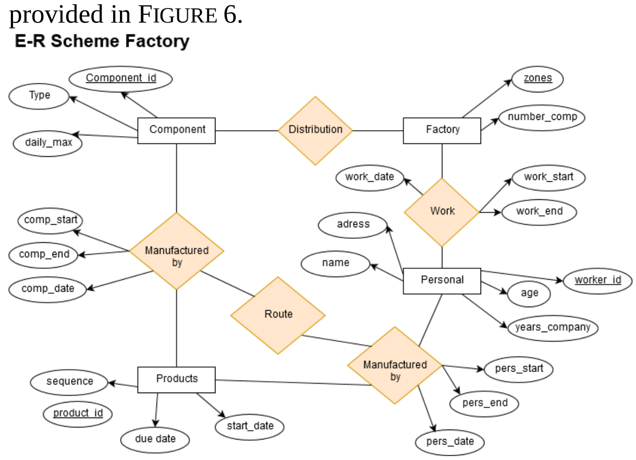


FIGURE 6 - E-R SCHEME PROPOSAL

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.

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 an 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. FIGURE 7 provides an example of the structure of this connection scheme.

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.

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. Eventually, production line will become so reliable that the phase of verification, that 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 suffers a drastic reduction. It will not completely disappear once the need for verification will always exists, however its duration will reduce from *t* months to no more than 1/3 *t* as shown in FIGURE 8.

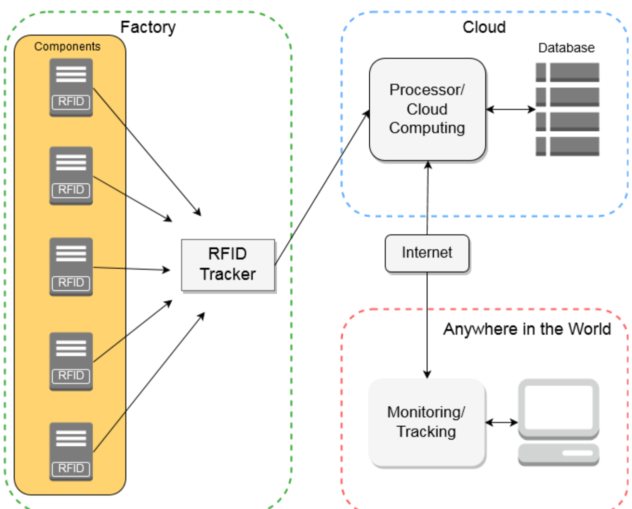


FIGURE 7 - COMMUNICATION STRUCTURE WITH RFID TAGS

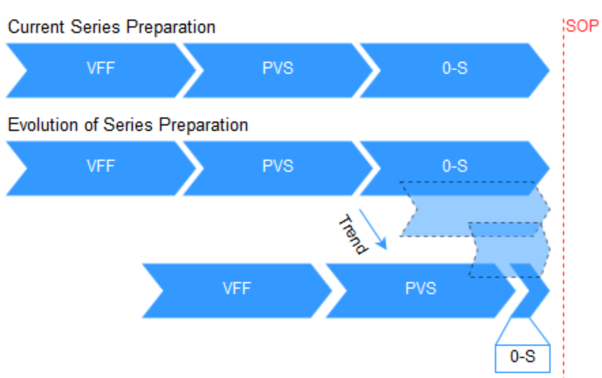


FIGURE 8 - EVOLUTION OF THE 0S WITH THE DIGITIZATION AND INTELLIGENT AUTOMATION OF THE PRODUCTION LINE

IV. Virtual and 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. 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.

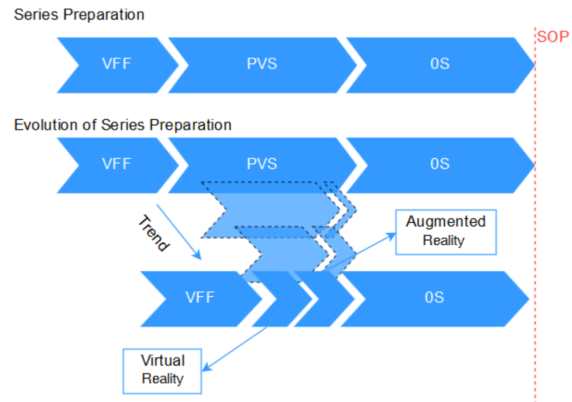


FIGURE 9 - EVOLUTION OF THE PVS WITH THE IMPLEMENTATION OF VIRTUAL AND AUGMENTED REALITY

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. This evolution is represented in FIGURE 9.

V. Future Model Launching Process

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. According to this progression, 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.

Relative to the ramp-up schedule this process will reduce its duration from the current 1,66*t* months to just a few weeks. A forecast for the evolution of this scheme is shown in FIGURE 10.

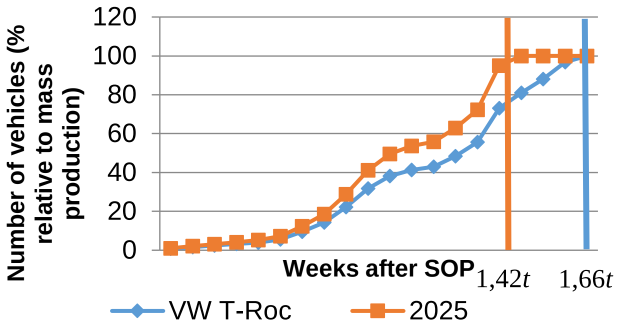


FIGURE 10 - FORECAST FOR THE RAMP-UP SCHEDULE BY 2025

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:

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

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, and new concepts in operator training. The value of the KPI related to the number of cars produced emerges then:

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

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.

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.

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

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.

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. The launching process will thus suffer a reduction in its duration, and also the number of workshops. The number of workshops will then result in about 90% of the Volkswagen T-Roc launching:

$$KPI(op.training) = 54\ workshops \quad (12)$$

The evolution of both the duration of the whole process and the scope of each phase of the Series Preparation is represented in FIGURE 11. 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.

TABLE 1 - 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%**

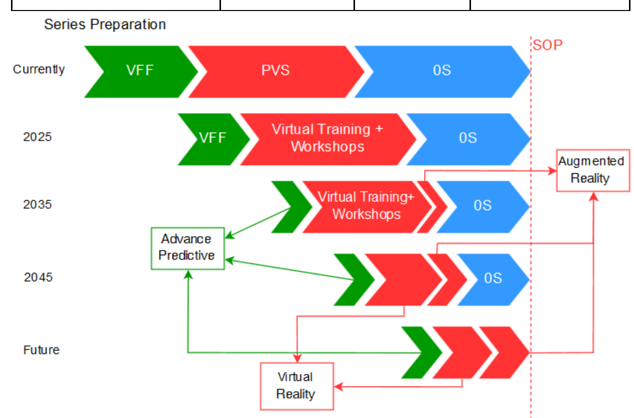


FIGURE 11 – EVOLUTION OF SERIES PREPARATION

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.

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.

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.

References

Anderl, R. (2014). Industrie 4 .0 - Advanced Engineering of Smart Products and Smart Production. *International Seminar on High Technology*.

Armbrust, M., Stoica, I., Zaharia, M., Fox, A., Griffith, R., Joseph, A. D., . . . Rabkin, A. (2010). A view of cloud computing. *Communications of the ACM, 53*(4), 50-58.

Audi AG. (2016). *Smart Factory illustrated - Modular Assembly Line*. Retrieved from Audi website: https://audi-illustrated.com/en/smart-factory/Die-Modulare-Montage

Azuma, R. T. (1997). A Survey of Augmented Reality. *Presence, 6*(4), 355-385.

Bak, D. (2003). Rapid prototyping of rapid production? 3D printing processes move industry towards the latter. *Assembly Automation, 23*(4), 340-345.

Baldwin, R. (2015, April 04). *Ferrari's AR showroom app delves inside your next supercar*. Retrieved from Engadget: https://www.engadget.com/2015/04/15/ferrari-ar-app/

Bartos, B. (2016, April 06). *What is the Internet of Things*. Retrieved from Misumi Mech Lab: http://blog.misumiusa.com/what-is-the-internet-of-things/

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2014). How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, 8*(1), 37-44.

Campbell, I., Bourell, D., & Gibson, I. (2012). Additive manufacturing: rapid prototyping comes of age. *Rapid Prototyping Jornal, 18*(4), 255-258.

Carimbo, I., Guerreiro, V., & Pedaço, P. (2017). Balanço primeiro trimestre - marca Volkswagen. Ofensiva SUV. *jornal Volkswagen*.

Critical Manufacturing. (2016, April 07). *CRITICAL MANUFACTURING RELEASES VERSION 4.3 MES WITH NEW VISUAL KPI WIDGETS, SHIFT PLANNING AND MAPPING*. Retrieved from Critical Manufacturing: http://www.criticalmanufacturing.com/en/newsroom/press-releases/posts/press-releases/critical-manufacturing-releases-version-4-3-mes-software-with-new-visual-kpi-widgets-plus-shift-planning-and-mapping#.WeT_aWiPJPY

Davies, R. (2015). *Briefing - Industry 4.0: Digitalisation for Productivity and Growth.* European Parliamentary Research Service.

Drath, R., & Horch, A. (2014). Industrie 4.0: Hit or Hype? *IEEE Industrial Electronics Magazine*.

European Parliament. (2015). *Briefing Industry 4.0 Digitalisation for productivity and growth.* Briefing European Parliamentary Research Service.

Fast-Berglund, A., Palmkvist, F., Nyqvist, P., Ekered, S., & Akerman, M. (2016). Evaluating Cobots for Final Assembly. *6th CIRP Conference on Assembly Technologies and Systems (CATS)*, (pp. 175 - 180).

Fennani, B., Hamam, H., & Dahmane, A. (2011). RFID overview. *2011 International Conference on Microelectronics (ICM)*, 1-5.

Friedemann, M., & Floerkemeir, C. (2011). From the Internet to the Internet of Things. *From Active Data Management to Event-Based Systems and More*, 242-259.

Gao, P., Hensley, R., & Zielke, A. (2014, October). *A road map to the future for the auto industry*. Retrieved from McKinsey & Company: http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/a-road-map-to-the-future-for-the-auto-industry

Gehrke, L., Kühn, A. T., Rule, D., Moore, P., Bellmann, C., Siemes, S., . . . Standley, M. (2015). *Industry 4.0 - A Discussion of Qualifications and Skills in the Factory of the Future: A German and American Perspective.*

Giusot, D., Iera, A., Morabito, G., & Atzori, L. (2010). *The Internet of Things.* New York: Springer.

Group History. (n.d.). Retrieved from Volkswagen Autoeuropa Website: https://www.volkswagenautoeuropa.pt/grupo-volkswagen/historia-do-grupo

Hagel III, J., Seely B., J., Kulasooriya, D., Giffi, C., & Chen, M. (2015). *The Future of Manufacturing - Making things in a changing world.* Deloitte University Press.

Heng, S. (2014). Upgrading of Germany's industrial capabilities on the horizon. *Deutsche Bank*.

Hermann, M., Pentek, T., & Otto, B. (2015). Design Principles for Industrie 4.0 Scenarios. *49th Hawaii International Conference on System Sciences.*

Kagermann, H., Wahlster, W., & Helbig, J. (2013). *Recommendations for implementing the strategic initiative INDUSTRIE 4.0.*

Kang, H. S., Lee, J. Y., Choi, S., Kim, H., Park, J. H., Son, J. Y., . . . Noh, S. D. (2016). Smart manufacturing: Past research, present findings, and future directions. *International Journal of Precision Engineering and Manufacturing - Green Technology*, 111-128.

Lasi, H., Fettke, P., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering, 6(4)*, p. 239.

Lee, J., Bagheri, B., & Kao, H.-A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters, 3*, pp. 18-23.

Leech, J., Whelan, G., Bhaiji, M., Hawes, M., & Scharring, K. (2015). *Connected and Autonomous Vehicles – The UK Economic Opportunity.* KPMG.

Leitão, P., Colombo, A. W., & Karnouskos, S. (2016). Industrial automation based on cyber-physical systems technologies: Prototype implementations and challenges. *Computers in Industry, 81*, 11-25.

MacDougall, W. (2014). *Industrie 4.0 - Smart Manufacturing for the Future.* German Trade & Invest.

Monostori, L. (2014). Cyber-Physical Production Systems: Roots, expectations and R&D challenges. *Procedia CIRP, 17*, pp. 9-13.

Mourtzis, D., Doukas, M., & Bernidaki, D. (2014). Simulation in Manufacturing: Review and Challenges. *Procedia CIRP, 25*, pp. 213-229.

Paelke, V. (2014). Augmented Reality in the Smart Factory. *2014 IEEE Emerging Technology and Factory Automation (ETFA)*, (pp. 1-4).

Peasley, S., Waslo, R., Lewis, T., Hajj, R., & Carton, R. (2017). Industry 4.0 and cybersecurity: Managing risk in an age of connected production. *Deloitte University Press*.

Pomerantz, D. (2015, December 11). *From Gigabytes To Gigawatts: The Power Plant Of The Future Will Look Like Like This*. Retrieved from GE Reports: https://www.ge.com/reports/from-gigawatts-to-gigabytes-the-power-plant-of-the-future-will-look-like-like-this/

Qin, J., Liu, Y., & Grosvenor, R. (2016). A Categorical Framework of Manufacturing for Industry 4.0 and Beyond. *6th CIRP Conference on Learning Factories.* Elsevier B.V:.

Rohling, G. (n.d.). *Facts and Forecasts: Billions of Things, Trillions of Dollars*. Retrieved from Siemens Digitalization & Software: Internet of Things: www.siemens.com/innovation/en/home/pictures-of-the-future/digitalization-and-software/internet-of-things-facts-and-forecasts.html

Rosen, R., von Wichert, G., Lo, G., & Bettenhausen, K. D. (2015). About the Importance of Autonomy and Digital Twins for the Future of Manufacturing. *IFAC-PapersOnLine, 48*(3), 567-572.

Rüβman, M. L., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries.*

Schlaepfer, R. C., & Koch, M. (2015). *Industry 4.0: Challenges and solutions for the digital transformation and use of exponential technologies.* Deloitte University Press.

Segura-Velandia, D., Neal, A., Goodall, P., Conway, P., & West, A. (2016). Industrie 4.0 implementations in the Automotive Industry. *Advances in Manufacturing Technology XXX Proceedings of the 14th International Conference on Manufacturing Research, Incorporating the 31st National Conference on Manufacturing Research*, (pp. 6-8). doi:10.3233/978-1-61499-668-2-319

Sherman, D., & Detwiler, T. (2015, November 18). *How a Car is Made: Every Step from Invention to Launch*. Retrieved June 07, 2017, from Blog Car and Driver: http://blog.caranddriver.com/how-a-car-is-made-every-step-from-invention-to-launch/

Shrouf, F., Ordieres, J., & Miragliotta, G. (2014). *Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm.* IEEE.

Sniderman, B., Mahto, M., & Cotteleer, M. J. (2016). *Industry 4.0 and manufacturing ecosystems.* Deloitte University Press.

Statista. (2017). *Number of Cars Sold Worldwide From 1990 to 2017 (In Million Units)*. Retrieved from The Statistics Portal: https://www.statista.com/statistics/200005/international-car-sales-by-region-since-1990/

Stock, T., & Seliger, G. (2016). Opportunities of Sustainable Manufacturing in Industry 4.0. *Procedia CIRP*, *40*, 536-541.

Sundmaeker, H., Guillemin, P., Friess, P., & Woelfflé, S. (2010). *Vision and Challenges for Realising the Internet of Things.* CERP-IoT – Cluster of European Research Projects on the Internet of Things .

Volkswagen AG. (2016, 11 22). *TRANSFORM 2025+ Volkswagen presents its strategy for the next decade*. Retrieved 07 18, 2017, from Volkswagen AG: www.volkswagenag.com/en/news/2016/11/transform-2025.html

Volkswagen Group Academy. (2015). *The PEP 2012 in vehicle projects of Volkswagen.* Briefing, Wolfsburg.

Volkswagen Group MQB platform. (2017, 06 06). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Volkswagen_Group_MQB_platform

Wan, J., Cai, H., & Zhou, K. (2015). *Industrie 4.0: enabling technologies.* IEEE.

Wang, S., Wan, J., Li, D., & Zhang, C. (2016). Implementing Smart Factory of Industrie 4.0: an Outlook. *International Journal of Distributed Sensor Network*.

Webel, S. (n.d.). *Industrie 4.0: Seven Facts to know about the Future of Manufacturing*. Retrieved from Siemens - Digital Factory: https://www.siemens.com/innovation/en/home/pictures-of-the-future/industry-and-automation/digtial-factory-trends-industrie-4-0.html

Weyer, S., Schmitt, M., Ohmer, M., & Gorecky, D. (2015). Towards Industry 4.0 - Standardization as the crucial challenge for highly modular, multi-vendor production systems. *IFAC - International Federation of Automatic Control.* Elsevier B.V.

Zhang, Q., Cheng, L., & Boutaba, R. (2010). Cloud computing: State-of-the-art and research challenges. *Journal of Internet Services and Applications*, *1*(1), 7-18.

Zhou, K., Liu, T., & Zhou, L. (2015). Industry 4.0: Towards Future Industrial Opportunities and Challenges. *International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)* (pp. 2147-2152). IEEE.