Digital Transformation of Manufacturing Processes in the Automotive Industry

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Abstract

The digitalization of the automotive industry involves key factors such as customer experience, product innovation, strategy, organizational structure, process digitalization, collaborative work, IT infrastructure, culture, expertise, and transformation management. This article highlights five emerging trends reshaping the sector: connected vehicles, shared mobility and connectivity services, digital automobile sales, data analytics, and the rise of electrified vehicles.

Our study outlines a six-step framework for digital transformation in the automotive industry. It begins with assessing a company's digital maturity, followed by creating an action plan, defining a digital strategy and objectives, developing a global roadmap, implementing changes, training teams, and launching a new operating model. A comprehensive model for the digital automotive industry is proposed, emphasizing the integration of technologies to digitize all processes. Key components include data management, connectivity, supply chain management, manufacturing execution, sales and marketing, customer relationship management, and analytics.

The proposed model streamlines operations enhance performance, and improves customer satisfaction through tools like virtual control centers, AI, RFID technology, and online quality control. Additionally, a table summarizes the 12 core processes within the model. The article concludes with a practical tool for measuring digital maturity in the automotive sector, based on IATF 16949, VDA 6.3, and AIAG standards.

Keywords: automotive industry 4.0, process, digitalization, model, digital maturity, challenges

1. Introduction:

Industry 4.0 originated as a strategic project of the German government to support the digital revolution of its industry. It is based on the ongoing digital revolution that we are currently experiencing. Industry 4.0 concerns all sectors of industry, the product life cycle, and especially their production. The most active players are ERP/EMS software publishers and equipment and automation providers. From a Lean point of view, Industry 4.0 offers interesting tools for automation and networking, but people remain at the heart of improvement processes (KAIZEN). We are only at the beginning of this revolution, which will accelerate with the development of AI. We must be wary of over-inversion, and implementation should be done gradually, in a modular and flexible manner.

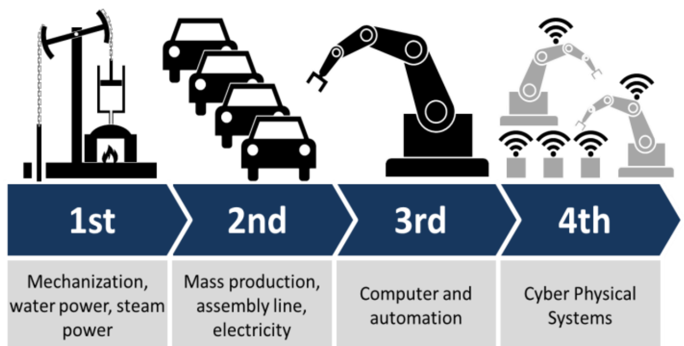

Figure 1. the evolution of industry 1.0 to 4.0

2. Digital maturity in the automotive industry

The advancement of a company in digital matters is measured by taking into account its technological knowledge combined with its motivation to enrich and deploy this know-how. Digital maturity questionnaires proposed by consulting experts generally focus on the following aspects:

- Customer experience: The company has implemented the ability to interact with the customer in order to collect useful data for adjusting marketing and communication strategies.
- Product innovation: The company has adapted its products and services to digital innovations.
- Strategy: The company prioritizes the development of digital projects and can clearly define the skills it needs to ensure the success of the company.
- Organization: The resources available are sufficient and the company is flexible enough to quickly respond to technological developments.
- Digitalization of processes: The company has integrated digital channels for communication, processes, and services.
- Collaborative work: Employee collaboration is done through digital platforms and internal experts are responsible for managing digital-related issues.

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- Information technology: The internal IT department is capable of quickly integrating new products and services.
- Culture and expertise: Digital expertise occupies a central place in the development of the company, and employees master digital products.
- Transformation management: Digital transformation follows a strategic plan and clearly defined objectives.

3. Five New Trends to Reshape the Automotive Sector in The Coming Year.

3.1. Penetration Of Connected Cars

Connected cars equipped with the Internet of Things (IoT) technology offer enhanced safety and comfort to passengers. This technology enables a convenient multimedia experience with on-demand features that enable drivers to access web-based services while operating their vehicles. Connected vehicles have the ability to communicate in both directions with a range of external systems and can share internet connectivity and data devices both inside and outside the car. These cars can share information and monitor services such as remote diagnostics and digital data, vehicle health reports, access to 4G LTE Wi-Fi hotspots, data-only telematics, turn-by-turn directions, and provide information on car health issues that allow users to take preventative measures and avoid breakdowns.

3.2 Shared Mobility, Connectivity Services, And Feature Upgrades

There is a significant shift underway in individual mobility behavior, driven by changing consumer preferences, stricter regulations, and advancements in technology. This shift is expected to result in a substantial increase and diversification of the automotive revenue pool, with a significant portion being derived from data-driven services and on-demand mobility solutions. This shift has the potential to generate up to $1.5 trillion in additional revenue by 2030, which represents a 30% increase from traditional car sales and aftermarket services/products. This is a significant increase from approximately $3.5 trillion in revenue generated in 2015, which is projected to rise to around $5.2 trillion by 2030.

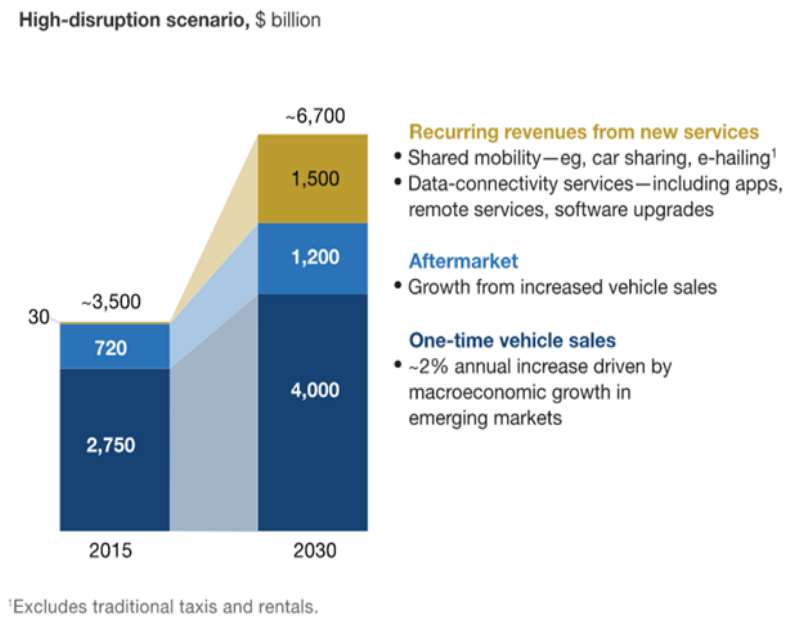

Figure 2. the turnover evolution till 2030 (Source: McKinsey & Company)

Connectivity, and later autonomous tech, will increasingly provide the car to become a platform for passengers and drivers to utilize their time in transit to devour novel services and media or dedicate the freed-up time to other personal activities. The accelerating speed of advancements, especially in software-based systems, will need cars to be upgradable. As shared mobility services with short life cycles will become more common, customers will be constantly aware of technological advancements, increasing demand for upgradability in privately used cars.

3.3. Digital Automobile Sales

Automotive companies are considering various ways to simplify the vehicle buying process for consumers by exploring the idea of virtual showrooms, making it possible to purchase cars online. The demand for virtual showrooms has surged due to the COVID-19 pandemic, which restricted physical movement. Even after the pandemic, consumers still prefer online shopping for cars, and automobile companies find virtual showrooms advantageous as they facilitate sales, reduce overhead and infrastructure costs, and enable retailers to offer attractive deals and competitive prices. In addition, online purchasing provides other benefits such as virtual car tours, online documentation, and secure payment options.

3.4. Leveraging Data Analytics

Data analytics provides a promising prospect for car dealerships that are eager to leverage technology to differentiate themselves from their rivals. By employing automotive retail analytics, dealerships can track customer movements within their showrooms. Additionally, analytics and behavior-sensing technology facilitate the creation of heat maps, as well as the installation of digital signage or cameras in high-traffic areas. By pairing these features with interactive displays, dealerships can tailor their marketing messages to appeal to millennial customers and cater to their preferences.

By utilizing behavior prediction technology, auto retail sales teams can enhance their effectiveness and provide the necessary resources and messaging to enable dealers to stay ahead of the industry curve.

3.5. Electrified Vehicles

Stricter emission regulations, widely available charging infrastructure, lower battery costs, and increasing consumer acceptance will create new and robust momentum for the penetration of electrified vehicles (plug-in, hybrid, fuel cell, and battery electric) in the coming times. The pace of adoption will be determined by the interaction of customer pull (partially driven by the total expense of ownership) and regulatory push, which will vary enormously at regional and local levels.

By 2030, the share of electrified vehicles could go up from 10% to 50% of new-vehicle sales. Adoption rates will be on top in densely developed cities with strict emission regulations and consumer incentives (special parking, tax breaks, driving privileges, discounted electricity pricing, and more). Sales penetration will be slow in rural areas and small towns with higher dependency on the driving range and low levels of charging infrastructure.

Through continuous improvements in battery technology and expense, the local differences will become less pronounced, and electric vehicles are expected to gain more market share from standard vehicles. With battery prices potentially decreasing to $150 to $200 per KW-hour over the next 10 years, electrified vehicles will achieve price competitiveness with traditional vehicles, creating the most crucial catalyst for market penetration. In the same manner, it is significant to note that electric vehicles involve a large portion of hybrid electrics, which means even beyond 2030, the internal-combustion engine will remain very pertinent.

4. Automotive Industry 4.0 challenges

Today, the automotive industry witnessed a massive transformation. The transformation is pervasive across the automotive manufacturing value chain and much of it is driven by the potential of industry 4.0. At the wake of leveraging the potentials and benefits of industry 4.0, automotive company stakeholders and executives are bound to face challenges.

- One of the biggest challenges is to have the right skilled people in place to effectively plan, execute, measure and optimize technologies and digital systems.
- Another challenge is to opt for a suitable approach. The transformation is viable provided the whole organization is aligned with a specific digital strategy rather than an individual isolated

strategy for each department. In other words, a holistic approach to digital transformation in the automotive industry witnesses greater success as opposed to an isolated approach.

- Another approach that has been adopted by auto manufacturers in the process of digital transformation is by starting to solve small problems. When small challenges are resolved right, it sets precedence for stakeholders, executives and technical expertise to delve into implementing industry 4.0 on the same page whilst focusing on the core value propositions of the company.
- Specific to the automotive industry, supply chain integration can seem challenging initiating a transformation to industry 4.0. Auto manufacturers rely on external partners and contractors for supplies and logistics which often becomes a challenge in integrating all stakeholders into one ecosystem. Initially, the process might seem daunting, but eventually with the right choice and use of industry 4.0 technologies, smart factories can be achieved.
- Vulnerable to cybersecurity threats with industry 4.0 in automotive manufacturing is another challenge. In order to eradicate this threat, stringent mechanisms and policies are to be put in place to ensure data security.

1. The connectivity of software and equipment, including existing equipment.
2. The standardization of norms and processes that facilitate data sharing.
3. The reengineering of work methods and processes.
4. The management of cybersecurity in order to protect sensitive information and know-how.
5. Access to digital technology specialists.
6. The development of new skills.

5. The six steps of digitalization in automotive industry:

This digital transformation is fundamentally characterized by automation and by integrating new technologies into the company's value chain. The exploitation and massive management of data, the interconnection of machines, the dematerialization of communication and distribution channels and restructuring of the company for a flexible and personalized production, in order to succeed we propose here an action plan with six main steps:

1. The company must take the first step towards digitalization: analyzing its level of digital maturity (like an audit).
2. The result of this analysis, audit or assessment should lead to an action plan that the company must follow to outline its digital strategy.
3. Once these elements are gathered, the company can define a digital strategy and the objectives of its digital transition.
4. These goals serve the company, in a fourth step, to create a global roadmap, parallel to the implementation of changes aimed at starting the digital transition.
5. After that, the company must focus on how these changes will be managed within the team of collaborators.
6. The final step is the launch of the new operating model.

6. Fist model of automotive Digital industry:

Digitizing the Automotive Industry, the majority of manufacturers currently working in the specialized automotive industry follow processes that are all customer-oriented, whether it's internal customers (process-to-process relationships) or external customers (relationships with partners). As we will see later on, these manufacturers are all IATF 16949 certified without exception. The most common model is as follows

6.1 digitalize all processes of the automotive industry

To digitalize all processes of the automotive industry, you will need a core model that encompasses several key elements, including:

1. Data management: A robust data management system that can store, process, and analyze vast amounts of data from multiple sources, such as production data, sales data, and customer data.
2. Connectivity: A system that can connect different parts of the automotive industry, such as suppliers, manufacturers, distributors, and dealers, to facilitate the flow of information and goods.
3. Supply chain management: A system that can optimize the flow of materials and products through the supply chain, from procurement to delivery, and track the status of orders, shipments, and inventory.
4. Manufacturing execution: A system that can manage the production process, from the scheduling of production runs to the tracking of production performance and quality control.
5. Sales and marketing: A system that can support the sales process, from lead generation to customer service, and track the performance of marketing campaigns and the customer experience.
6. Customer relationship management: A system that can manage interactions with customers, from lead generation to post-sale support, and track customer preferences, behavior, and satisfaction.
7. Analytics and reporting: A system that can analyze and report on key performance indicators (KPIs), such as sales, production efficiency, and customer satisfaction, to help organizations make informed decisions.

6.2 Total digital Management using industrial KPIs

This core model will provide the foundation for digitalizing all processes of the automotive industry, enabling organizations to streamline their operations, improve their performance, and enhance them.

- The flow throughout the supply chain (and the supply chains of suppliers and subcontractors) are planned via the internet (portal) to satisfy these customers in Quality, Cost and Delay.
- Each order placed triggers the production order of the vehicle (or component in case of supply from the supplier Tier1 and Tier2
- The simulation made at the control center (calculation of the total supplay chain) will notify the customer by the date and place of delivery of his vehicle (component in case of supplier Tier 1 or Tier 2)

- Control centers are virtual platforms (AI) that simulate scheduling the various tasks of production, material supply to satisfy the customer order before sending a confirmation to the customer.
- The routing of parts is fully automated thanks to robot operators and perfectly fluid and flexible RFID technology.
- Workspaces are cleared, heavy tasks are programmed via robots, otherwise witnesses (laser sensors) managed by programmable logic controllers.
- Quality control is carried out online, the values entered on the system make it possible to validate or block the product is validated by the operator.
- It is in the production control center that decisions are made and correction to any drifts are taken in real time, thanks to ultra-connected processes technology Quality controls are done automatically on the ERP, or even in case of parts received from a supplier
- At the design level, the evolution of models is optimized by the visualization of 3D models on production lines.

  The 12 processes known and used in any company operating in the automotive industry are grouped in the following table:

Table 1. the 12 processes known and used in the automotive industry

Process	Target TDM (Total Digital Management)	Mean digital KPI
1. maagement processes		
2. purchasing processes		QCD: Quality, Cost, Delay
3. Supply chain & logistique management proceess	Coordination of the flow of materials, components, and finished goods between suppliers, manufacturers, and customers Movement of finished vehicles and components from the manufacturing plant to dealerships and	OTIF, Lead time, delivery accuracy, inventory levels, supplier performance Delivery speed, delivery accuracy, transportation costs, customer satisfaction

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	other final destinations	
4. Research and developement process	Development of new automotive products and components using advanced technologies such as 3D printing, computer-aided design (CAD), and virtual reality (VR)	Time-to-market, design accuracy, number of product recalls, customer satisfaction
5. Human research process		
6. Continus improuvement process		
7. Manufacturing process	Automated assembly and production of automotive components and vehicles using robotics and other advanced technologies	Production speed, product quality, inventory levels, machine utilization, TRS, Scrap Rate
8. Maintenance process		MTBF ; MTTR ;
9. Finance process		EBITDA
10. Sales & marketing process		Turnover
11. After sales service precess	Provision of maintenance, repair, and other services to customers after the sale of a vehicle	Repair time, customer satisfaction, repeat service visits, warranty costs
12. Information technology process		

Table 2. The level of digital maturity according to the digital tools

Level of digital maturity	**Recearch & developement process**	**Adminitrative & Information technology process**	**Supply chain & logistics management process**	**Manufacturing process**	**Services**
8	FAO Advanced	Big Data			Intégration
7	CAO 3D Paramétrique	Commerce Electronique	RFID		IOT
6	PDM -PLM	Configurateur of product		Additive manufacturing	Prédictive maintenance
5		Business Intelligence		Cobotique	Cybersécurité
4		GED	APS	FMS	Mobility
3	CAO 3D	WMS	MES	Robotique	Connectivity
2	FAO	CRM	Barre code	PLC	Maintenance préventive
1	CAO 2D	ERP	ERP	CNC	Networking

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Table 3. Automotive industry and Lean manufacturing

IATF	Industrie 4.0	Lean Manufacturing
Customer focus	Autonomie	Value
Leadership	Inter opérabilité	The value chain
Engagement of people	Durabilité	The Flow
Process approach		Traction
Improvement	Cyber Phyisical Security	Perfection
Evidence-based decision making	IOT/IOS	Elimination of waste:
Relationship management	Big Data	1- Overproduction
	Self maintenance	2- Overstock
Customer and stakeholder specific requirements (CSR)	Autonomous collaborative robots	3- Waiting time
PDCA	3d printing	4- Moving unuseful
DFMEA & PFMEA	Clourd computing	5- Unnecessary transport
APQP	Simulations	6- Defects
SPC & MSA		7- steps without VA
APAP		
Reduction of variability and losses in overall SC		

6.4 Future perspectives of the IATF 16949

IATF 16949 is an international standard for quality management systems in the automotive industry. It was developed by the International Automotive Task Force (IATF) and is based on the ISO 9001 standard. The standard specifies requirements for a quality management system that organizations in the automotive industry can use to ensure that their products and services meet customer and regulatory requirements.

The IATF 16949 standard is currently in its 2016 version, but a new version is expected to be released in 2023. This new version is expected to have a greater focus on sustainability and **the use of new technologies**, such as electric and hybrid vehicles, as well as connected and autonomous vehicles.

In terms of the future perspective, it's important to note that the automotive industry is constantly evolving and there are many factors that can affect the adoption and implementation of standards like IATF 16949. For example, the increasing focus on electric and **autonomous vehicles**, as well as the rise of connected and shared mobility solutions, may lead to changes in the way quality management systems are approached in the industry.

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One area where the new IATF 16949 standard may have an impact is in the production of batteries for electric and hybrid vehicles. The standard is expected to specify requirements for the design, development, and production of these batteries to ensure that they meet safety and performance standards.

The CAN (Controller Area Network) protocol is a widely used communication protocol in the automotive industry. It is used to allow different electronic systems in a vehicle to communicate with each other. The new IATF 16949 standard is expected to specify requirements for the use of the CAN protocol in the design and development of automotive systems, including requirements for the testing and validation of these systems.

In summary, the new IATF 16949 standard is expected to have a strong focus on sustainability and the use of new technologies in the automotive industry, with implications for the production of batteries for electric and hybrid vehicles, as well as the use of the CAN protocol in automotive systems.

7. How to measure digital maturity in the automotive industry?

We must answer a questionnaire according to our status at the time of the audit. To calculate the maturity level of each item, we need to multiply the three key factors: technology, mastery, and integration of this technology within the process. The result is a radar graph. Each axis should be placed in one of the five levels of digital maturity obtained.

Table 4. Maturity level rating

1	Traditionalist	It's time to set foot in digital transformation
2	Aspirant	Very good start
3	Evolutionary	Bravo, we must continue on this beautiful momentum
4	Modernist	Open to change, still some small efforts
5	Futuristic	The ultimate level: has developed remarkable digital ingenuity

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Table 5. Seven Chapters to assess the maturity of the company

CHAPTER 1	**STRATEGY & IMPROVEMENT**	Note /10
	• Vision & Strategy	
	• Objectives	
	• Measurement, Analysis and Action Plans	
	• Continuous improvement	
	• Supply Chain Development	
CHAPTER 2	**WORK ORGANIZATION**	
	• Organizational processes	
	• Organizational processes	
	• Resource planning	
	• Factory Environment and Human Resources	
CHAPTER 3	**PRODUCTION CAPACITY & PLANNING**	
	• Product Development	
	• Capacity planning	
	• Production planning	
	• Systems Integration	
	• Production operations	
CHAPTER 4	**COSTUMER INTERFACE**	
	• Communication	
	• Packaging & Labelling	
	• Shipping	
	• Transport	
	• Customer satisfaction & Feedback	
CHAPTER 5	**PRODUCT / PROCESS MASTERY**	
	• Product identification	
	• Inventory management	
	• Change management	
	• Traceability	
CHAPTER 6	**SUPPLIER INTERFACE**	
	• Selection of suppliers	
	• Logistics Protocol	
	• Communication	

	• Packaging and labelling	
	• Transport	
	• Reception	
	• Performance measurement	
CHAPTER 7	**MAINTENACE**	
	• preventive maintenance	
	• predictive maintenance	
	• self maintenance	
	• MMAO	

Table 6. Example of questionnaire audit « digital level » :

	Item	**Technology**	**mastery**	**Intégration**	**Level of digital maturity = somme (technology x mastery x intégration).**
1. 4. 25	Are the complete physical inventories PF, MP and WIP PR automated: using technologies that allow easy access to data such as RFID readers, barcodes, etc.	3	2	3	12
4. 1. 22	Delivery requests (DELJIT, shipping forecasts, synchronous shipments) from customers must be received electronically and integrated without human intervention.	3	3	3	27
1. 2. 26	The available tools make it easy to calculate the Costs of Non-Quality	1	2	3	6

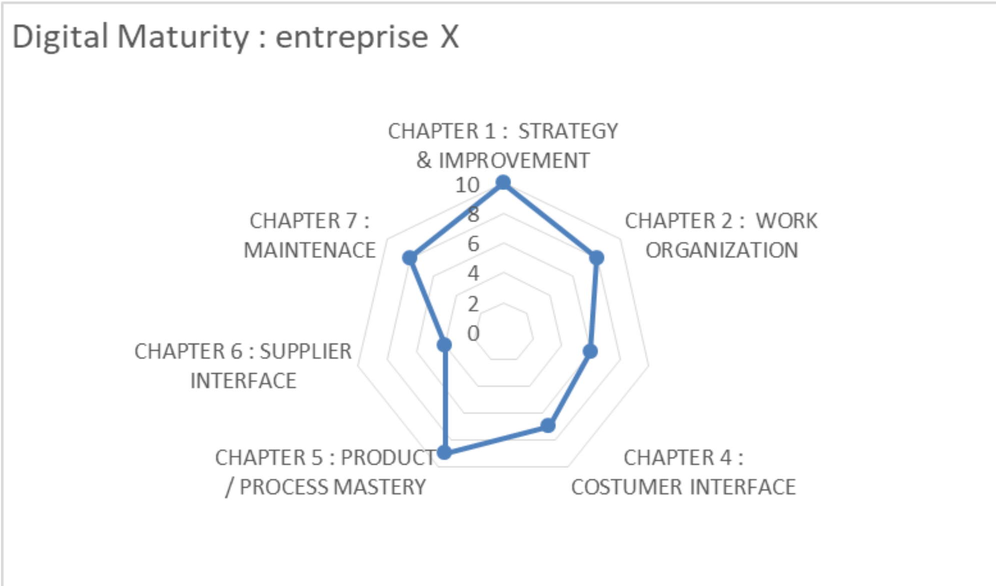

Figure 3. Radar graph of the seven-axis maturity level

Use case studies or examples from the automotive sector to illustrate maturity levels. For instance:

- A company at Level 3 might implement digital twins to simulate production processes.
- A Level 5 company might employ real-time adaptive manufacturing using AI and IoT.

8. literature review 2019-2024

The digital transformation of manufacturing processes in the automotive industry has been a focal point of research between 2019 and 2024. Key themes include the integration of advanced technologies, the development of digital capabilities, and the shift towards sustainable practices.

8.1 Integration of Advanced Technologies

The adoption of technologies such as 3D printing, advanced robotics, and the Industrial Internet of Things (IIoT); Wikipedia
Development of Digital Capabilities; ResearchGate
Transition to Sustainable Practices; ResearchGate & IEEE Xplore

8.2 In summary, the period from 2019 to 2024 has witnessed substantial advancements in the digital transformation of automotive manufacturing processes. The integration of advanced technologies, development of digital capabilities, and commitment to sustainable practices have collectively contributed to the industry's evolution.

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Recent Developments in Automotive Digital Transformation
The Auto sector scrambles to retool workforce for electric and automated future; Reuters

Toyota and Volkswagen fall further behind in the software race; Financial Times

Conclusion

The automotive industry is rapidly transitioning toward Industry 4.0, marked by the adoption of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and machine learning. These innovations enable highly automated, data-driven, and interconnected manufacturing processes, leading to significant gains in efficiency, flexibility, and production speed.

Achieving digital transformation in the automotive sector requires assessing and advancing a company's maturity level. This maturity is evaluated based on several critical criteria, including technology infrastructure, business processes, workforce competencies, performance measurement, and strategic alignment. Organizations progress through maturity levels, starting with isolated digital initiatives and advancing toward fully integrated, self-optimizing smart factories characterized by Industry 4.0.

The first proposed model for the automotive Industry 4.0 emphasizes the integration of these criteria and outlines key performance indicators (KPIs) for evaluating the success of each process. By adopting this model, organizations can streamline operations, enhance productivity, and improve customer satisfaction. Simulating and implementing the digital automotive model, however, is a complex endeavor involving well-defined steps, which will be detailed in our next publication.

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