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The Role of Artificial Intelligence and Cloud Computing in Transforming Automotive Manufacturing: Enhancing Production Intelligence, Supply Chain Agility, and Financial Transactions in the Digital Economy

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Abstract

Despite having a sluggish first half of the last decade, the automotive industry is undergoing a major transition with the emergence of autonomous vehicles, electric vehicles, and connected vehicles. Consequently, the companies that manufacture automotive vehicles are reshaping current production methods and workflows to accommodate and facilitate this industry transition. Automotive manufacturing is traditionally very capital and labor-intensive. In recent years, however, breakthroughs in Artificial Intelligence and Cloud Computing have acted as important catalysts of change, as they have ameliorated technology accessibility, alleviating one of the main hurdles restricting their adoption. These technologies are already being used to facilitate or automate many activities at automotive manufacturing companies, such as vehicle design, supply chain and logistics operations, factory setup and operation, workforce management, quality control, marketing, sales, and after-market service management. Consequently, the efficiency of many key workflows is being dramatically improved, while costs, timing, and risks are comminuted. AI and CC are enabling the centralization and synchronization of previously discrete activities, thereby enhancing cross-functional decision-making. In this essay, we provide a detailed analysis of the role of these two technologies in enabling and supporting this transformation. We then examine the impact of their adoption on specific activities within these automotive manufacturing workflows. By highlighting key lessons and challenges, our analysis will serve both as a roadmap for automotive manufacturers to implement AI- and CC-centric transformations and as a guide for policymakers seeking to engineer similar transformations in other industries. Our essay will also identify important gaps in existing research and highlight opportunities for future academic work.

Keywords : Artificial Intelligence in Automotive Manufacturing,Cloud Computing in Industry 4.0,Smart Manufacturing,AI-Driven Production Optimization,Digital Transformation in Automotive Industry,Supply Chain Agility,Intelligent Supply Chain Management,AI-Powered Quality Control,Predictive Maintenance,Cloud-Based Manufacturing Solutions,Digital Economy in Automotive Sector,Automotive Financial Transactions,Real-Time Data Analytics,Cyber-Physical Systems in Manufacturing,Industrial IoT and AI Integration

1. Introduction

The modern-day automobile manufacturing industry has seen an outpouring of challenges brought on by the adoption of digital technologies and of growing user expectations. Eventual profit margins have been shrinking; product life cycles have become daily affairs, lengthening product development cycles; and demand for lower costs, enhanced safety, improved quality, and erosion of customer loyalty are forcing automobile manufacturers to devise new innovative offerings. These roadblocks, influencing all phases of demand, design, manufacture, and customer service, have grown complex and multi-dimensional. Their effect is constantly felt at the interface between the phase of responsibility and the consumer. The need is for a demand-pull strategy, quickly and efficiently executing the order of the customer, and offering a product that is affordable, with timely delivery. Along with the above, the automobile manufacturers are required to explore innovative ways of recruiting and retaining the best and the brightest. These new recruits need to be armed with more competencies and knowledge than ever before.

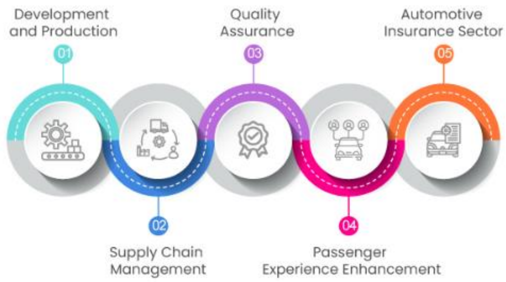

Fig 1: AI in Automotive Industry

Digital technologies are impacting and reshaping numerous facets of how today's companies operate. Through a unique convergence of enabling technologies, expanded interconnectivity is allowing business areas that were traditionally separate to come together to form an end-to-end value chain that is highly responsive to customer inputs. All this while creating mechanisms that enable companies to extend their reach across industry boundaries and into new markets. At its heart, this expansion is the cloud computing revolution, enabling innovative business models that leverage shared assets. These trends are leading to concerns over sensitive data that is central to any organization. The cloud is making it possible for anyone with an Internet connection to access any bits of information, share it, or manipulate it without authorization. The automotive industry is undergoing significant changes. Customers demand automobiles which satisfy their need for quality, safety, cost, and performance. Companies have to meet these demands with least or no impact on their existing capital resource.

1.1. Background and significance

The automotive industry ranks amongst the world's largest and most important industries, consisting of the manufacture of motor vehicles, their components, and their systems and the manufacturing processes and equipment that make them possible. It is a highly competitive and regulated industry, characterized by the globalization of markets and production, radical technological innovations, and product cycle management. Automotive manufacturing is also highly complex, requiring state-of-the-art technology and information systems to manage the design and manufacture of the vehicle, the network of suppliers, and the supply of parts and components. To sustain their profitability in a capital-intensive, low margin industry, automakers are turning to information technology (IT)-related investments and cloud computing-based technology and services. There has been an increasing concern that business investment in IT is not maximizing its potential to enhance productivity and promote innovation in the economy. Automotive manufacturers are increasing their investments in artificial intelligence (AI) and developing their own, or engaging in partnerships and collaboration with outside firms. They are also looking at implementing AI and other advanced information technologies in their supply chains. AI technology harnesses increasing digital sophistication and convergence on a number of individual technological fronts in information technologies and has the potential to become even more integral to the automobile of the future.

Artificial intelligence (AI) as a key technology of the Fourth Industrial Revolution aims at increasing productivity as the principal driver of economic development and has the potential to remedy the labor shortage in industry. Cloud computing is another key technology of Industry 4.0 that can provide a common platform for the new industrial and global value chain to improve productivity. AI Cloud is a potentially game-changing element in this mix of digitally connected technologies. AI and cloud computing represent a digital technology link that can enhance forecasting and information-sharing capability, allow the integration of supply chain processes, and therefore improve supply chain planning systems. AI extends the capability of traditional cloud-based supply services through the development of deeper insights and higher quality forecasts, involved in optimizing inventory and resource allocation decisions across increasingly complex global supply networks.

2. Overview of Automotive Manufacturing

The automobile industry is a pillar of the global economy, with an annual turnover of approximately 2 trillion Euros in Europe alone. Founded in the late 19th century, this industry has undergone significant changes over the course of 125 years. From production in small workshops with few workers constructing each vehicle by hand, the industry transformed into large-scale assembly production. With the aid of assembly line approaches, over 100 cars could be produced daily in the 1920s, then - 1000 units from the 1950s. In the 1980s, an additional transition took place with the introduction of mass customization and the associated flow production related to it: Creating unique, build-to-order vehicles still in high volumes, e.g., 1000 daily through so-called JIT supply chains. Presently, over 90 million cars are produced every year, generating a GDP share of above 10% in countries where these are manufactured.

The extensive integration of IT in the manufacturing and distribution processes has led to substantial progress in the efficiency of the industry. Cost pressure is high, due to global competition and increasing expectations of customers. In the face of nearing driving bans or higher taxes on CO2 emissions, automobile manufacturers have increasingly focused on foreign markets during the past decade. For the emerging markets of BRIC countries, the Western Original Equipment Manufacturers often establish joint ventures with local players, augmenting their existing export activities. While the practical development and application of automobile manufacturing have matured, both research and practice are again facing important changes. Recent forecasts for the industry predict a new phase of further innovations, focusing on electric engines and the integration of IT into the entire vehicle.

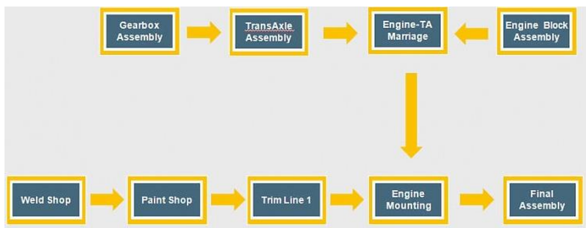

Fig 2: Automotive Manufacturing - An Overview

2.1. Research Design

This work is structured: first, an overview of the automotive manufacturing is presented, then, a brief literature review focused on AI and Cloud Computing is, afterwards, the methodological procedures adopted in the development of the work and the results obtained are detailed and, finally, the conclusions and the contributions are presented. The works, developed with a scientific approach, were based on a structured search in the databases, considering research articles published in English. In this sense, keywords related to AI, Cloud Computing, and automotive were used, and after a careful selection of the search results, a data template was used for each of the works selected for the final sample.

Afterwards, the papers selected for the final sample were analyzed and organized according to the contributions and the technological pillars. For the outline of the literature review, the structure was adopted, allowing for the synthesis of the characteristics of published research, allowing for a broader view of artificial intelligence and Cloud Computing. Furthermore, publicly available data sources were used to identify the Association of Original Equipment Manufacturers, which is formed by vehicle manufacturers that produce finished vehicles. The contribution comes from policymakers who are fighting to keep up with technological developments not only in hard technologies but also in soft technologies and how the two combine to create new service offerings.

Equ 1: Digital Financial Transactions (FT) Optimization

$$FT = f(CC_{ledger}, AI_{fraud}, SmartContracts\,Contracts, Blockchain, TransSpeed)$$

Where:

- FT: Financial Transaction efficiency in the digital economy
- CC_{ledger}: Cloud-based ledger systems
- AI_{fraud}: AI-based fraud detection
- $SmartContracts$: Use of programmable contracts (via blockchain)
- $Blockchain$: Decentralized, secure transaction processing
- $TransSpeed$: Transaction speed and throughput

3. The Digital Economy

As shown in the previous sections, technologies such as Artificial Intelligence and Cloud Computing are changing the traditional industrial environment. Their increasing ubiquity owes, among other things, to the intensity of use of digital services. This is supported by the massive generation, processing, and circulation of data in digital format, by the advancements in Information and Communication Technologies, by the global connectivity, and by the fast-growing demand for digital technologies and services by consumers and industries. The broader phenomenon of the digital economy increasingly reshapes traditional business models, boosts economic restructuring toward a new type of productive specialization where technology is increasingly integrated with human labor and knowhow, accelerates productivity growth and the pace of innovation, and provides businesses and consumers with new products and services which contribute to improving well-being.

All of these factors have contributed to the fourth industrial revolution we are experiencing. According to market surveys more than 90% of companies are either in the process of adopting AI or are planning to do so in the near future. Cloud technology is the backbone of businesses' digital transformation strategies, feeding and accelerating the development of Artificial Intelligence. Companies spent significantly on cloud infrastructure in 2021. In manufacturing, there is a growing intent to invest in Cloud Computing as it would provide AI tools able to develop solutions for automating and optimizing processes. Data is traditionally seen in economic theory as a factor of production, alongside land, labor, and capital. However, due to its characteristics, it is a very special kind of factor. Technologies like Cloud Computing allow companies to massively collect and store data.

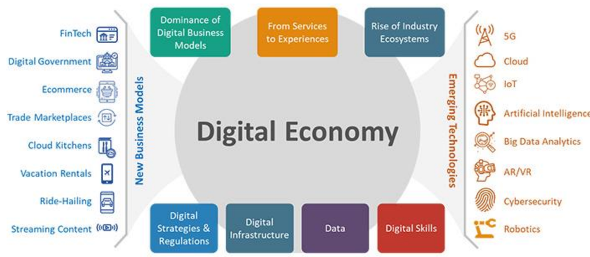

Fig 3: Accelerating the Digital Economy

3.1. Data Collection

Digital economy is a new economy formed through using modern information technologies, which recent research shows it is primarily focused on data, the foundation of artificial intelligence and cloud computing. Apparently, data has become the primary production factor of the digital economy. With large amounts of data revealed via the emergence of various technologies, they increasingly focus on the processes or flows to create more and better data, the key task of data collection. Current data collection technologies have been drastically matured and developed. Mass data collection moves from GPS, social media, and digital traces, such as footprints, contacts, photos, microblogs, to Internet of Things, which connect the real-world objects and digital world, converting the data collection from virtual or electronic approaches to physical channels and sources. Techniques and tools bridge the physical objects to the interactive digital world, allowing more interactive connections between data and producers.

With the support of cable, wireless, and mobile Internet transmission, mobile cloud and edge computing, mobile payment, mobile augmented reality, mobile robots and drones, mobile Big- and Little-Data, mobile sensors and devices, mobile user-generated content, data collection moves from spying-based passive surveillance to human-centered active sensing or crowd sensing. Data gathering not only requires innovative tools and techniques, but also user-friendly interfaces between devices, apps, cloud platforms and users, using massive Big Little Data analytics to improve the experience and privacy of data-producing users.

4. Artificial Intelligence in Manufacturing

Artificial intelligence (AI) technologies permit humans to design and develop super-smart systems capable of emulating human sensory perception, decision-making, and problem-solving. Furthermore, advanced sensing technologies for vision, touch, hearing, motion, and navigation are rapidly evolving as miniaturized, low-cost sensors become widely available. At the same time, advanced computer algorithms for reasoning, learning, and control are boosting the capabilities of these smart systems. Elbowed by the exponential growth in transcendent computing power, these additional capabilities are further fueling the progression of super-smart systems and their emerging applications. These capabilities will create innumerable novel and distinctive applications in the automotive and manufacturing domains where robots and super-smart systems will embed, augment, and augment the human workforce, while also digitally connecting and integrating suppliers, manufacturers, and consumers in the global supply chain, thereby revolutionizing automotive manufacturing.

Broadly, the current AI technologies used in manufacturing can be grouped into tools for machine learning, natural language processing, and pattern recognition, in addition to expert systems and heuristics. AI tools used in conjunction with manufacturing are listed in a subsequent section, and each is briefly explained. In a nutshell, machine learning tools and algorithms permit computers to learn from examples and improve performance, using different representations of the problem. Machine learning could be viewed as heavily relying on the pillar of inductive inference. The practitioners can leverage the plethora of machine learning libraries readily available. A knowledgeable user can often plug and play with suitable codes in some of the higher-level programming languages and realize very complex forms of machine learning without needing to delve deeply into mathematics.

4.1. AI Technologies and Tools

A large number of tools for programming AI agents and systems are available today. These tools help us to develop and maintain intelligent systems quickly and manageably. The programming tools take many forms: languages, libraries, and extensions for existing languages, and graphical programming environments that help us manage the inherent complexity of creating intelligent agents. These include environments for developing symbolic systems, symbolic-statistical systems, and statistical systems. In addition to the more traditional tools for reasoning, planning, and case-based reasoning, we now have statistical tools for pattern recognition and classification. These enable us to create systems that can perform tasks like handwriting recognition, sentiment analysis, and product defect classification.

Currently, the most advanced form of AI uses a hybrid or ensemble approach—using different methods for different parts of the task. However, there are many more specific tools with longer histories. For example, while NLP gained an enormous amount of attention, Classic-NLP still is the "engine under the hood" for many NLP products that companies use. While many AI applications focus on making predictions of some kind, AEG and AI Planning are more about taking the next best action to solve the world's problems today or in the near future and thus should be key in the toolkit of any AI engineer.

Fig 4: Artificial Intelligence Technologies

4.2. Machine Learning Applications

Since machine learning techniques are gaining a lot of attention due to their accessibility from cloud-based platforms, we mainly focus our discussion on applications for production manufacturing in this section. As we move more toward smart manufacturing, machine learning has become a popular avenue for advancing various innovative applications in this field. Some of the advantages of rising artificial intelligence (AI) and machine learning (ML) applications for production systems are the following: (1) hardware and software infrastructures could be supported from cloud computing; (2) advanced ML tooling, ML models, cloud-ready data lakes, and libraries are readily available from cloud service providers; (3) ever-increasing compute capabilities thanks to hybrid edge, on-premise, and cloud-supported servers and high-performance systems; and (4) data generation and acquisition from sensors are getting more standardized, thanks to various standard organizations. Following are some of the typical, revolutionary applications of ML for production in the modern world.

Data analytics for production systems – simple statistical tools are no longer sufficient to analyze production systems with more complicated interactions and noise in the data. For example, analyze the efficiency and productivity of the shop floor and overall equipment for better decision-making automation. Optimization of production parameters – search-and-find the optimal combination of parameters of complicated production functions and processes. For example, the best combination of parameters of a hot forging function for high-quality forging with less cost and less rejected parts. Predictive maintenance and disaster prevention for production systems – find and signal error and failure of machines and production functions and parameters to predict when breakdowns may happen in the future. With the combination of Internet of Things (IoT) sensors and advanced machine learning methods, predictive maintenance has become a very popular area with many successful implementations.

Quality and risk management for products – high-dimensional product characteristics, features for complicated products in applications cannot be accurately studied with advance but rather be more quantitative, such as six-sigma or Tolerance Design Theory. Compared to them, machine learning-based quality and risk prediction and assurance can be more effective.

Equ 2: Supply Chain Agility (SCA)

$$SCA = f(AI_{forecast}, CC_{collab}, VR, Supplier_{visibility}, Risk_{mgmt})$$

Where:

- SCA: Supply Chain Agility
- $AI_{forecast}$: AI-powered demand forecasting
- CC_{collab}: Cloud-based collaboration platforms
- VR: Vendor responsiveness (adaptive capacity)
- $Supplier_{visibility}$: Real-time supplier data access
- $Risk_{mgmt}$: Risk analytics and mitigation tools

5. Cloud Computing in Automotive Manufacturing

Selecting a cloud computing service for an automotive manufacturing company is usually a multi-step process. First, the manufacturer must select the type of service it wants: specified local cloud computer services based on high performance computing, general local services based on cloud bursting, or near real time access to a public cloud. Second, the manufacturer must understand cloud construction in terms of capabilities, costs, reliability and service. This analysis may be broken into several sub-studies. These sub-studies pertain to data center locations for those cloud services which use global data centers; networks, including dedicated lines; cloud construction option comparisons; and cloud pricing, especially the public cloud pricing and the hidden costs involved. Finally, the manufacturer must address security issues and the service level agreements associated with the use of the cloud. This requires understanding pre-completed cloud SLAs in addition to cloud cost structure and key SLA parameters.

Cloud services have had a significant impact on the operations of automotive manufacturers. The impact can be characterized as follows: first, reduced infrastructure costs are usually associated with the cloud's pay-per-use scale, causing most manufacturers to plan to take advantage of general commercial computing using the public cloud; second, the computational capabilities of the cloud allow for the performance of functions that were previously too expensive to consider; finally, cloud services allow the automotive manufacturer to consider outsourcing more applications than in the past.

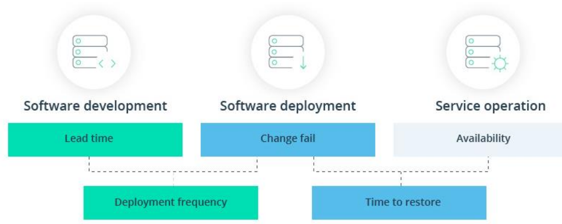

Fig 5: Cloud Computing in Automotive Industry

5.1. Cloud Infrastructure and Services

Cloud infrastructures are essential for creating specific services that enable the automotive domain to take advantage of the increasing availability of data concerning vehicles and their users. Moreover, they are charged for providing the necessary energy, security, and quality of service to handle the increased complexity of hosting high-demand sessions while operating around the city. They also help to lower redundant infrastructures by providing a shared resource to speed up the initial development of soft-mobile vehicular applications. To lessen the burden of providing data storage that can self-adapt to performance/delete/read costs in a sensible way, the automotive cloud can expose tools that support the development of applications that might use this evolving service.

Important cloud infrastructures are provided by the strong players of today. Each offers a different kind of service, but none is automotive specific. For instance, one infrastructure is stronger for both processing and data storage; another provides a sophisticated set of tools to design and code web applications, chatbots, and IoT back-ends. One is specialized in enterprise solutions and proposes some automotive-case proprietary frameworks and programs. Another is the leader in the IaaS domain and has implemented cloud offerings designed to prototype the infrastructure needed for the M2M/M2V circuits.

5.2. Data Storage Solutions

The enterprise must provide its users high-performance data storage systems with access at low latency. For frequently accessed data, the unit providing the lowest response time and best throughputs is indeed the device most commonly referred to as cache, usually a few dynamic random access memory chips that can reach speeds of several gigabits per second or up to a few hundred gigabytes per second. Where bulk, cost-effective storage is needed, non-volatile flash memories are widely adopted although they are also used in cache hierarchies, while hard disk drives are still used for the least active data for which cost per bit counts significantly. While in many sectors the trend is to migrate entirely to flash storage, in automotive manufacturing the inflection point will be achieved later, as budgets are tighter for unlocking potential value in data that is infrequently queried and data density is still paramount.

Furthermore, most automotive manufacturers and suppliers are increasingly using a hybrid approach in this area, with actively used data sets, or portions of larger datasets, stored in flash storage in front of hard disk drives actually carrying the datasets' bulk for cost considerations. This architecture is often referred to as Tiered Storage. Additionally, it is likely that embedded flash NAND storage in the form of storage class memory may disrupt the storage market and the automotive market in particular in both edge and core in the near future. An increasing array of storage appliances built with either technology are now offered.

6. Enhancing Production Intelligence

Artificial intelligence (AI) and cloud computing are not only critical enablers for automotive manufacturing but also on-going catalysts for development and transformation. They enable many complex changes in automotive manufacturing ranging from the way design operates to the actual assembly production. However, these transformations are limited to how effective AI and cloud compute are designed along with human factor considerations of advanced manufacturing work. To achieve this we propose an architected development for enhancing the manufacturing production intelligence exercise.

Advanced AI capabilities and access to cloud computing have enabled many manufacturing production systems to be modeled and implemented as smart manufacturing systems. These smart manufacturing systems can harness all of the product, process, and sustainability data to develop an embedded intelligence for variability and capability management for process control, and decision management for facilities and equipment scheduling, product sequencing, human resources, and transportation and delivery. The smart manufacturing systems are architected to harness the data by developing models for both product and process development that guide the capabilities and decisions for the manufacturing, assembly, and logistics systems. The smart manufacturing system capabilities include production advance capability planning, enabling capability element design for design failure mode effects analysis and concurrent vehicle design, as well as process advance capability planning that can optimize production ramp up as part of program management.

Cloud computing enables real-time data analytics capabilities for surfacing advanced modelling and simulation tools by developing unique observation and decision driven models for smart manufacturing systems that support advanced product attribution, capability specification, capacity analysis, work content analysis, and process improvement. As a result, advanced product attribution powered by product data management and product lifecycle management become decision and observational multimodular with respect to capability specification each decision – design for assembly, design for autonomation, design for logistics, design for manufacturing, and design for sustainability – embeds a complex set of fulfilment attributes that product decision makers must observe, prioritize, and optimize for their constraints to ensure production success.

6.1. Smart Manufacturing Systems

The expansion of new tools and techniques that are necessary for the implementation of smart manufacturing solutions allow for the utilization of multiple cutting-edge ICTs on an entrepreneurial level, which comprise among others Industrial Cloud Computing Platforms, big data analytics, edge computing, IoT infrastructures, sensor-based cyber-physical systems, industrial satellites and satellites-related infrastructures, cybersecurity-specific solutions, digital twins, industrial robotics, artificial intelligence and machine learning. Smart Manufacturing 4.0 refers to these kinds of Industry 4.0 solutions. It revolves around the development of a unique kind of smart manufacturing system made possible by advanced ICTs and economic incentives. The core of smart manufacturing systems includes a specific level of smart manufacturing 4.0 technological advancement and a specific keenness of labor-based productivity and financial performance that is better than what is needed to just afford an enhanced usage of advanced ICTs in some of the entrepreneurial processes and functions within the firm. The benefits that smart manufacturing systems entail is the possibility to offer customers a one-to-one production service, virtualization, toolkits for customized special service, distributed design, dynamic and decentralized production, internalization of core competencies, and machine-related service innovation. The particularities of smart manufacturing systems encompass capability, network, scalability, and flexibility. Such systems should have a distinctive role in the effort to both overcome current macroeconomic stagnation linked to the pandemic and face the difficulties coming from generational transition towards younger and more qualified entrepreneurs and companies.

6.2. Real-time Data Analytics

Real-time data analytics employs streaming data or time-series data to automatically detect sub-optimal smart manufacturing operations through self-learning pattern recognition without requiring any limits on the production rule parameters, and is able to accurately predict production trends, dynamics, statistics and distributions at different time scales from seconds to days ahead, without needing large training datasets. Real-time data analytics can serve as the major enabler of digital twins and digital threads for smart manufacturing by closing the loop between the factory floor and the cyber world to allow for verification and validation of physics-based models using real-world sensor data and rapid simulations of production schedules. Real-time data analytics can help close the loop for data-informed analytics and simulation, and realize active learning, by continuously utilizing real-time sensor data to improve prediction performance on the given objectives and evolve the models of the underlying systems. Real-time data analytics can also efficiently compute the digital twin and digital thread outputs of system configurations to allow efficient optimization of production operation steps directly on the outputs, if needed, without performing lengthy simulations. This data-enabled, digital thread-based active learning will accelerate training and tuning of the physics-based models, thanks to the minimal simulations for production schedule optimization. It is possible to realize non-linear statistical inference and multi-stage model training for production systems with components at all scales of time via real-time data analytics across the whole manufacturing system to achieve the goal of Production Intelligence 4.0, with input, process, output and outcome.

Equ 3: Production Intelligence (PI) Enhancement

$$PI = f(AI_{ops}, CC_{infra}, DT, IoT, Data_{quality})$$

Where:

- PI: Production Intelligence
- AI_{ops}: AI-driven operations (predictive maintenance, robotic automation)
- CC_{infra}: Cloud infrastructure scalability and computing power
- DT: Digital Twin integration
- IoT: Internet of Things devices for real-time data
- $Data_{quality}$: Volume × Velocity × Variety × Veracity of data

7. Supply Chain Agility

Global connectedness keeps rising to streamline a merchant’s distribution and logistics process. From suppliers of raw materials to producers and warehouses to retailers, manufacturers become highly dependent on one another, enabling global supply chain connectivity. As a result, automatically optimized operations in the manufacturer’s supply chain fuel the manufacturing era of adaptation, advanced supplier collaboration, and accelerated product deployment. AI and cloud extend manufacturers’ supply chain agility. Enabling applications reside at many places in the AI and cloud ecosystem—including on-premises software systems to cloud-enabled AI services. They include lettering manufacturers from silly spots, rapid market scoops and fast services provided to global end-consumer customers. Digital traceability—assigning the right digital fingerprints to physical goods—enables manufacturers and logistics companies to continuously optimize products in motion. Driverless cars improve the safety and efficiency of cargo delivery. In another example, a company produces and automates an entirely digital relationship that stores and their customers serve. Still other cloud players generate extreme efficiencies by automating routine B2B transactions.

The manufacturing of modular assemblies relies on entire factories being uniquely identified—allowed to build just the subassemblies desired at the right times. A major assembler exemplifies supplier market capabilities. Automating the reassembly of physical goods creates data tied to its creation, its delivery, and its final consumption. Cloud providers help manufacturers manage these evolving businesses. Three manufacturers now captivate end-consumer audiences while outsourcing large parts of their product creation. Today’s cloud manufacturers focus on higher-level integration and innovation, while delegating efficiency to factories with advanced organization for the machine tool and other automation suppliers.

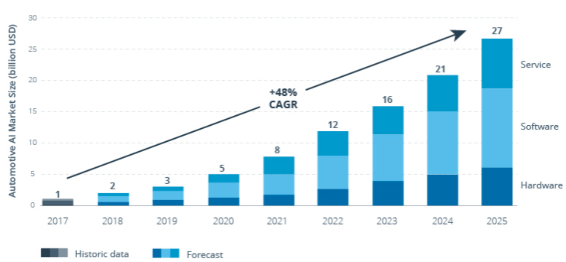

Fig 6: Adoption of AI in the Automotive Industry

7.1. Supply Chain Optimization

While the challenges of Automotive Supply Chains have long been addressed using Lean or Just-in-Time solutions, the Digital Supply Chain is evolving along different dimensions that require greater agile capabilities. These additional capabilities expose the weaknesses in Lean Supply Chain Thinking, because some variability in Supply Chain Execution Plans is usually inevitable. Programmatic, hierarchically-managed, document-heavy control of people, materials, information, money and assets, supported by Lean thinking and Six Sigma improvement programs, still serve the Supply Chain well for delivering quality products on time and at the lowest cost possible. However, as Auto Makers add more products and provide user-customization, even these traditional metrics are calling improvement into question.

Tightening Supply Chain risks and increasing product and environmental complexity exert a downward pressure on profitability and Corporate Governance for both the OEMs and their Tier 1-3 Suppliers. Lean principles of waste-minimization still hold, but other methods besides old-fashioned vertical integrations need to be deployed if Firms are to report increasing annual revenues and profits. The Segment-of-One trend has added hundreds of variants to traditional product lines, with each major Upgrade typically co-creating several new product variations that utilize existing Core Competency components. Major coatings, shaped metal and glass panels, and dye-sublimation products built on Business methods add enormous additional risk of ups and downs to Auto Makers, Foreign and Domestic Brand distributors, and Fleet Marketeers. Plug-in hybrid electric FV-EVs, fuel cell Hybrids, and battery electric BEVs add substantial additional Capital Expenditure requirements to the OEM, at a time of high volatility of stock prices and major investor demands for Visibility into the future profitability and growth portfolios of their Firms. Major Infotainment manufacturers currently located outside of Silicon Valley are stretching their competencies as they are dragged into this growing product complexity, as are Fast-Followers who hope to catch the largest additional profits. Potential future mega-disruptions from company-like-startups add Supply Chain Complexity that must be factored into the Supply Chain Optimization process.

7.2. Inventory Management Solutions

The automotive supply chain is crisis sensitive because of the economic downturn and the supply-demand imbalance. The automotive supply chain needs enormous capital investment to manage the supply chain effectively as the automotive products have high capital requirements and low-profit margins. The supply chain for the automotive industry consists of players, such as tier 1, tier 2, and tier 3 suppliers and original equipment manufacturers. Each player in the supply chain has specialization. The automotive product supply chain network is not linear but complex. The automotive product requires many parameters, such as quality, price, aesthetics, and technology, which have created increasing scheduling and inventory control issues. Optimization of the automotive supply chain is important to face unpredictable changes in supply and price inflation and to reduce waste during automotive production.

Automation driven by changes in regulations, emission standards, and demand for mass customization has been the mantra for growth in the automotive industry. The semiconductor fiasco of 2021 that cascaded into production shutdowns is an example of a supply crisis. The need for a synchronized, responsive, and connected automotive supply chain network has gained ground. Effective inventory management systems have become crucial to implementing an agile supply chain and to providing the companies with flexibility to respond to various types of customer demand in an uncertain environment. Effective inventory management systems therefore also help to balance demand and supply and thereby stabilize the supply chain and design network. Thus, the problem of formulating an optimal inventory decision integrated with other supply chain decisions with the objective of minimizing total cost and maximizing total profit in a multi-stage operation is a complex task and needs effective business intelligence and optimization solutions.

Traditional inventory control systems are not effective due to the increasing amount of information, product diversity, unreliable suppliers, uncertain demand, and sourcing complexity. Intelligent inventory control systems are also required to solve the problem of deciding the number of stocking points in an incompletely observed stochastic environment. AI and cloud technologies can thus ensure that the networks are smart and connected.

8. Conclusion

In this paper, the influence of AI and CC in automotive manufacturing is examined. While the role of Artificial Intelligence is shown to grow increasingly important in all phases of the manufacturing process, cloud computing is instead envisaged to overcome IT structure problems, in order to provide the right level of computational power requested and the possibility of exploiting novel and innovative AI solutions. The paper shows how these technologies are already very helpful in the context of manufacturing, but more is to be done ahead. For these reasons, many future trends in that direction are envisaged, such as developing novel AI techniques to easily manage unstructured or partially structured data; introducing innovative business models, such as design on demand; and the integration in the manufacturing process of changes introduced with the CC and AI solutions.

These last years of digital manufacturing have shown that it is no longer enough only to serve the physical world and that Data is really at the center of the value chain of newly conceived smart factories. New design philosophies are already being implemented that aim to convert production into a digital service linked to in-field monitoring and maintenance activities. Future solutions will likely be based on both AI and CC to reconstruct digital twins of products, machines, and factories. Data-driven architecture will be built to provide easily accessible services such as average predictive maintenance. The vision of a physical object, such as a machine or a facility, that interacts with the plant manager through artificial intelligence, such as a friendly chatbot technology coupled with a device, such as an augmented reality device, will be, in a few decades, the new smart factory.

8.1. Future Trends

The automotive industry is one of the most crucial industries across the globe and has been a crucial contributor to the evolution of modern civilization. The automobile industry is currently undergoing a massive transformation driven by the advancement of new technologies, changing consumer demands, the need for greater productivity, and more collaborative relationships within the supply chain and with suppliers. These transformations are complicated by globalization and by new competitive pressures.

The acceleration in electric and battery technologies is of major importance as is the development of new sustainable mobility offerings. Artificial intelligence is being applied across the entire automotive manufacturing value chain driving improvements in process performance, production efficiency, customer satisfaction, and cost savings. Cloud computing is seen as the technology that will provide and implement new data native solutions for the complete transformation of automotive manufacturing in areas such as autonomous vehicles, software-defined vehicles, and engineering and business transformation. Edge cloud technology is allowing companies to perform advanced AI/ML workloads on their manufacturing production floors. New generation cloud technology is enabling automotive OEMs to drive and implement bold engineering and business transformations in their organizations. Future centralized cloud-based business models will significantly lower the costs of vehicle ownership allowing consumers to choose from a wider offering of vehicles such as vehicle subscriptions, ride and mobility services, transportation as a service, and long-term leases.

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