ISSN: 2688-8645

Research on the Application of Digital Twins Technology in the R and D Stage of Automobiles Enterprises

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Abstract

As a pillar industry of the country, the digital transformation of the automobile industry is of great significance to optimize the upgrading of the automobile industry structure, promote the long-term development of automobile enterprises, and accelerate the construction of smart cities and smart transportation. However, for all automobile enterprises to promote the digital transformation of automobile industry, it is necessary to formulate a complete set of digital transformation plan for the whole life cycle of automobile product development, among which Digital twins technology can be used as the first choice of digital transformation plan. Only by promoting digital transformation can enterprises be competitive in the future development.

Keywords

Vehicle Companies; Digital Twins; The Development Trend.

1. Preface

For traditional automotive companies, digital transformation is a technological revolution based on digitization, which will trigger profound organizational changes, management changes, business improvement, and model innovation. This is similar to the rapid development of China's railway system from traditional green trains to high-speed trains.

Digital Twins (DTs) can be traced back to the early 20th century. In 1991, Yale University's GELERNTER first proposed the basic concept of digital twins in Mirror Worlds[1]. Later, in 2002, Professor Michael Grieves of the University of Michigan introduced a conceptual model of product lifecycle management[2]. In 2010, the National Aeronautics and Space Administration (NASA) published the report "Modeling, Simulation, Information Technology & Processing Roadmap" (TA 11), which used the term Digital Twin for the first time[3].Then, in 2012, NASA and the U.S. Air Force Research Laboratory (AFRL) jointly built the Airframe Digital Twin of the F-15 fighter jet to comprehensively diagnose and predict flight systems through digital twin technology [4]. A digital twin is the digital modeling of a physical object, updated by receiving data from the actual object in real-time to ensure that the digital model is consistent with the actual object throughout its lifecycle. Digital twins can be used for a variety of analytical, predictive, diagnostic, and simulation operations, with real-time feedback for optimization and decision-making. In addition, the digital twin, physical objects, and simulation and feedback based on the digital twin form a cyber-physical system to form a digital device manufacturing twin. Since 2016, with the rise of Industry 4.0 intelligent manufacturing, Siemens has begun to try to apply digital twin technology and proposed the concept of "digital twin" to realize the digitalization of product design, manufacturing, and sales [5]. ANSYS introduced digital twins into its ANSYS Twin Builder product to assist users in troubleshooting, planning maintenance, and improving product performance [6].

In short, digitization is a force of the times that can bring tremendous changes to automotive enterprises. The Digital twins technology is the first to bear the brunt of digitization, and now Digital twins have made some progress in the automotive industry. However, currently, most

ISSN: 2688-8645

vehicle companies still encounter many difficulties in applying Digital twins technology to promote digital transformation. This may be due to the overall lack of unified and comprehensive understanding of digital transformation, as well as unreasonable digital transformation plans and incomplete diagnostic and evaluation plans. These issues seriously hinder the process of enterprise digital transformation. Therefore, in order for enterprises to complete digital transformation as soon as possible, it is necessary to develop detailed plans and strategies for each stage of the entire life cycle of automotive product development, so that enterprises have a clearer digital plan for each stage of manufacturing automotive products. The Digital twins technology is mainly reflected in the following five stages throughout the entire life cycle of automotive products, namely the automotive research and development design stage, automotive production planning stage, automotive production and manufacturing stage, automotive business management stage, and automotive after-sales service stage.

2. The Technological Roadmap of Digital Twins Technology in the Entire Life Cycle of Automotive Production

2.1. Technical Roadmap of Digital Twins Technology in the Automotive Research and Development Design Stage

The automotive research and development design stage includes the design and simulation of automotive components, as well as the process design of components. The technical roadmap of Digital twins technology in the research and development design stage is shown in Table 1.

Table 1. Technical roadmap for research and development design

<table>
<tr><td colspan="4">Technical roadmap for research and development design</td></tr>
<tr><td colspan="2">Time</td><td>2025</td><td>2030</td><td>2035</td></tr>
<tr><td colspan="2">Target</td><td colspan="3">Transforming real-world components into virtual twin bodies through Digital twins modeling technology, achieving virtual reality. And update the data in real-time according to changes in user needs and provide timely feedback to the product design department, in order to optimize the original model of automotive components.</td></tr>
<tr><td rowspan="2">Key sub businesses</td><td>Design and simulation of automotive component products</td><td colspan="3">(1) Establish a knowledge base for complex and typical parts and import it into the Digital twins platform to standardize CAD technology;
(2) Using digital modeling techniques based on traditional techniques, namely 3D annotation (MBD) technology;
(3) Building a cloud platform through Digital twins technologies such as the Internet of Things and big data enables parallel collaboration of information between modeling and simulation, while also allowing it to store data from previous modeling and simulation.</td></tr>
<tr><td>Automotive component process design</td><td colspan="3">(1) Design a process design management system to achieve intelligent guidance;
(2) Create a three-dimensional digital model based on Digital twins MBD technology to complete simulation analysis and iterative optimization of the process design process;
(3) Building a cloud platform based on Digital twins technology to achieve real-time information exchange and parallel collaboration between product design and process design.</td></tr>
</table>

2.1.1. Automotive Component Product Design and Simulation

In the design stage of automotive parts products, the main use is Digital twins modeling technology, namely CAD technology. For the design of typical and complex product components, enterprises can establish a typical knowledge base containing this information to standardize CAD technology. At present, enterprises generally use traditional modeling techniques in the production and manufacturing process. This technology generally uses two-dimensional

ISSN: 2688-8645

engineering drawings to represent the geometric information of parts, which is a technology mainly based on two-dimensional drawings and assisted by three-dimensional entities. Enterprises should adopt 3D annotation technology (MBD) that has more advantages than traditional technologies. This technology provides a detailed record of all information related to the 3D solid model, including dimensions, tolerance annotation rules, and expression methods of process information.

2.1.2. Automotive Component Process Design

The process design stage is similar to component design. Firstly, enterprises need to design a process design management system to achieve intelligent guidance. Secondly, enterprises should use the part information recorded in the 3D digital model created by MDB digital modeling technology to complete simulation analysis and iterative optimization of the process design process. In addition, based on the created cloud platform, real-time information exchange and parallel collaboration are achieved between product design and process design.

2.2. Technical Roadmap of Digital Twins in the Automotive Production Planning Stage

The stage of automobile production planning includes: production process planning, production equipment planning, resource allocation planning, logistics planning, etc. Table 2 shows the technical roadmap of Digital twins technology in production planning.

Table 2. Technical roadmap for production planning

Technical roadmap for production planning				
Time		2025	2030	2035
Target		Build a product data management platform and unify data management to support the development of Digital twins technology. Simultaneously modeling the production process of the physical world, pre planning the layout of required equipment, resources, configurations, etc., simulating according to project regulations, analyzing simulation results, and optimizing the original project according to evaluation rules to improve production capacity.		
Key sub businesses	Production process planning	(1) Building a PDM system to support the development of Digital twins technology; (2) Map the actual production line into a virtual production line through Digital twins modeling technology, achieving "virtual to real", and further optimize the production line design process using Digital twins simulation technology; (3) Utilizing Digital twins technology to achieve simulation optimization of logistics design.	(1) Standardize the PDM system information model to enable information exchange between different systems. At the same time, enterprises need to integrate new and old application systems with PDM systems; (2) Further utilizing Digital twins technology to develop a complete production line simulation design process; (3) Upgrade the enterprise logistics planning system using Digital twins technology.	(1) Develop independent workflow modules to continuously enhance their functionality, with configuration management as the core, integrating data management, workflow control, and change control to form a more powerful PDM system; (2) The use of Digital twins technology to design, simulate, and optimize the entire production line process is more mature.

2.2.1. Unified Management of Production Planning Data Information

Production planning, as a follow-up to product design and a prerequisite for production manufacturing, is what enterprises need to do in the production planning stage to build a bridge between product design and manufacturing, so that data and information can be shared between the two. The Product Data Management (PDM) system, as an integrated platform for modeling, simulation, and process design, can precisely solve this problem and become a bridge between the two. The PDM system is a digital management system that supports the

ISSN: 2688-8645

development of Digital twins technology. It is a digital system platform that centralizes and manages all relevant process data and product data information in the product manufacturing process, with the product as the center. This platform can standardize and standardize the management of all twin data, optimize various processes of product development, and share all data information throughout the entire research and development process, which is conducive to data management throughout the entire product life cycle. Therefore, the use of PDM systems by enterprises can not only reduce the investment cost of products, but also effectively shorten the research and development cycle of products, enabling enterprises to stand out in numerous competitions. The application of PDM technology is not only the current demand for enterprise informatization, but also the only way for enterprises to win competition in the future market based on the implementation of Digital twins technology.

2.2.2. Simulation Optimization of Production Line Design

The simulation optimization of production line design is based on data such as production line process equipment layout, rhythm, and faults. The physical world of production lines is mapped into corresponding virtual production lines using Digital twins modeling technology to achieve "virtual to real". Production and logistics processes are simulated on virtual production lines, and a series of simulation experiments are conducted using Digital twins simulation technology. At the same time, simulation data is calculated and analyzed to obtain efficiency indicators reflecting the workshop system, Identify and improve production bottlenecks in actual production lines, scientifically and quantitatively analyze workshop planning schemes, and search for better resource allocation and production strategies based on simulation experiments and optimization algorithms. However, currently, a complete and universal simulation process has not been formed for the production line simulation research of domestic enterprises. In the future, enterprises should continue to optimize their existing production line simulation processes to make their operations more mature and stable. In the near future, we will be able to develop a complete set of our own production line simulation processes.

2.3. Technical Roadmap of Digital Twins Technology in the Production and Manufacturing Stage of Automotive Enterprises

Table 3. Technical Route of Production and Manufacturing

<table>
<tr><td colspan="4">The technical route of production and manufacturing</td></tr>
<tr><td colspan="2">Time</td><td>2025</td><td>2030</td><td>2035</td></tr>
<tr><td colspan="2">Target</td><td colspan="3">Before actual production, enterprises use Digital twins technology to conduct extensive simulations of each stage of the production line, analyze simulation results, monitor and evaluate the simulation process in real time, record simulation data, and exchange this data with physical world data in real time through Digital twins technology to control the production process in the real world, ultimately achieving "virtual control over real".</td></tr>
<tr><td rowspan="2">Key sub businesses</td><td>Process Definition</td><td colspan="3">Enterprises need to finely manage all information related to their products and production lines.</td></tr>
<tr><td>Key indicator monitoring and evaluation</td><td colspan="3">(1) Simulate and debug the production line using Digital twins technology, and comprehensively evaluate the feasibility of the production line based on the debugging results and various factors;
(2) Before officially entering production, use Digital twins simulation technology to simulate the performance of the product through a series of simulations, and predict potential problems in advance;
(3) Real time recording and monitoring of data from twin production lines, timely discovering anomalies, and providing a basis for optimizing product performance in the future.</td></tr>
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ISSN: 2688-8645

The production and manufacturing stage is simply divided into three stages: process definition, simulation, key indicator monitoring, and evaluation. The technical roadmap of Digital twins technology in the production and manufacturing stage is shown in Table 3.

2.3.1. Process Definition

Enterprises need to adopt a structured way to organize and manage information such as products, processes, factory production, and production factors, so as to achieve accurate control of the product production process, and conduct virtual simulation according to the modeling information of the product process, so as to provide accurate output for the production of the production system.

2.3.2. Key Indicator Monitoring and Evaluation

Virtual manufacturing evaluation - production line debugging. The construction of automated production lines in enterprises requires large investment, long cycles, complex automation control logic, and difficult on-site debugging. According to the construction rules of the production line, the earlier the problem is discovered, the lower the repair cost. Therefore, before formal production, installation, and debugging, enterprises must use Digital twins simulation technology to simulate and debug the production line in a virtual manner, in order to detect and solve possible problems in the actual production process in advance, and comprehensively evaluate the feasibility of the production line by considering various influencing factors.

Virtual Manufacturing Evaluation - Production Process Simulation. Before product development, simulation can be conducted on the production process under different products, parameters, and external conditions to predict production capacity, efficiency, and potential bottlenecks, thereby accelerating the introduction of products.

Key indicator monitoring. By collecting real-time operational data of various equipment (such as sensors) on the production line, the entire production process is visually monitored. Using experience and machine learning methods, key equipment parameters and inspection indicators are monitored, and anomalies that violate rules are analyzed and corrected in a timely manner, in order to achieve a stable, continuous, and optimal production process.

2.4. Technical Roadmap of Digital Twins Technology in the Management Stage of Automotive Enterprises

Table 4. Technical Roadmap for Business Management

<table>
<tr><td colspan="4">The technical route of business management</td></tr>
<tr><td colspan="2">Time</td><td>2025 2030</td><td>2035</td></tr>
<tr><td colspan="2">Target</td><td colspan="2">Based on twin data models for market forecasting and generating sales plans. Simultaneously mining data, modeling analysis, and comprehensively analyzing customer characteristics, ultimately achieving precise marketing that meets customer needs. In addition, virtual simulation technology can be used to meet the virtual experience of customers for the product. Finally, achieve a collaborative supply chain system.</td></tr>
<tr><td rowspan="2">Key sub businesses</td><td>Marketing and E-commerce Management</td><td colspan="2">(1) Enterprises use models such as consumer psychology to construct consumer Digital twins, dividing consumers into different levels. By collecting and organizing consumer consumption habits, they establish twins that fully conform to consumer characteristics, predict consumption habits, and influence consumption behavior;
(2) The VR/AR technology using Digital twins technology achieves human-machine interaction, stimulates consumer purchasing desire, and ultimately achieves precision marketing.</td></tr>
<tr><td>Supply Chain Management</td><td colspan="2">Establish a Digital twins of the supply chain, receive real-time data from supply chain nodes, make real-time predictions, decisions, and feedback adjustments, and continuously optimize the supply chain grid.</td></tr>
</table>

ISSN: 2688-8645

In terms of the physical field of the automotive industry, the application of Digital twins technology in the management stage is mainly reflected in marketing, e-commerce management, and supply chain management. The technical roadmap of Digital twins technology in the management stage is shown in Table 4.

2.4.1. Marketing and E-commerce Management

With the increase of sensors, accessories (such as wearable devices) are becoming more and more abundant, and the intelligence of apps is also becoming more and more advanced. As mobile devices of the Internet of Things, more and more user data will be collected. At present, these data are widely scattered across different apps (companies). Enterprises need to integrate data, first of all, they need to be able to accurately establish Digital twins corresponding to consumer characteristics based on models such as consumer psychology. It is best to facilitate data exchange and sharing between different consumer twins to promote consumption and enhance the consumer experience. Finally, enterprises can involve consumers in the entire automated design process driven by creative design, allowing consumers to use VR and AR virtual technology to observe and design products that fully meet their own preferences online during the process. Enabling consumers to conduct performance simulation and interactive operations based on the Digital twins of the product to achieve "human-machine interaction" can greatly stimulate consumer purchasing desire .

2.4.2. Supply Chain

With the continuous progress of modern society, a large amount of data has been generated in the information flow, logistics, and funding of the supply chain, and traditional calculation methods are no longer able to effectively process and use this data. To solve the problems of traditional computing methods, enterprises need to build a supply chain Digital twins in order to build a continuous, fast, and sustainable fine-tuning supply chain network system. Using Digital twins technology to simulate the entire complex supply chain, and receiving real-time supply chain node data for real-time prediction, decision-making, and feedback adjustment.

2.5. Technical Roadmap of Digital Twins Technology in the After-sales Service Stage of Automotive Enterprises

Table 5. Technical roadmap for after-sales service

Technical roadmap for after-sales service				
Time		2025	2030	2035
Target		The enterprise collects customer needs, records data, and transmits the data to various departments at the business level through the digital twin information platform, and each department maintains and optimizes the product based on the data. Finally, we will realize "customer-centric" products and serve customers.		
Key sub businesses	After sales logistics service	(1) Upgrade logistics services using Digital twins technology, and further optimize logistics services by placing product components in appropriate locations for unified management; (2) When the product is about to be scrapped, reverse recycling logistics in the optimal way.		
	Customer service	(1) Develop customer service standards to achieve precise service; (2) Establish a database for unified management of customer requirements and transmit them to various departments through the Digital twins information platform, providing a basis for subsequent product maintenance.		
	Product Services	(1) Real time tracking and monitoring of product operation status, enabling timely detection of errors and early warning; (2) Use Digital twins technology to predict potential product failures, record data in real-time, and optimize product maintenance services.		

ISSN: 2688-8645

When the product manufacturing is completed and successfully delivered to the user, it officially enters the after-sales service stage of the product, which is divided into three stages: after-sales logistics service, customer service, and product service. The specific technical route of Digital twins' technology in the after-sales service stage is shown in Table 5.

2.5.1. After Sales Logistics Services

The application of Digital twins technology can provide more value-added services for automobile manufacturers. After the product is sold to customers, enterprises must track its current location and status, and conduct continuous data collection and analysis. Only in this way can customers receive better service. The matching work also includes: reasonable arrangement of inventory of sold parts, and continuous optimization of related logistics service models. This process will continue until the end of the product's lifespan. In addition, organizing reverse recycling logistics in the optimal way when products are about to be scrapped is also one of the categories of Digital twins.

2.5.2. Customer Service

After delivering the product to the user, the enterprise should establish a set of service standards that enable employees to accurately and efficiently serve the user. In addition, the information provided by customers is managed in a unified and standardized manner through an information management system. All customer requirements for the product are imported into the information management system database, and then transmitted to all relevant departments in the business field through the Digital twins platform, providing data for product maintenance and optimization, and achieving digital management of the entire business field.

2.5.3. Product Services

In the process of product service, enterprises should use Digital twins technology to track and monitor the condition of products in real time, and judge whether there are faults in the products through statistical analysis of product usage and maintenance, and predict and analyze their functions and performance. At the same time, in the event of a malfunction or quality issue, it is possible to quickly locate the faulty part of the product, analyze and record the malfunction and quality issue, and then replace the faulty parts to maintain and upgrade the product. This maintenance process will continue until the product is scrapped or retired. Finally, the fault and maintenance data will be unified and managed to establish a fault maintenance database, which will be imported into the Digital twins platform to provide guidance for on-site and remote operation and maintenance of after-sales service personnel. The maintenance of general products is mainly divided into two types: online fault analysis and predictive maintenance.

3. Conclusion

The digital transformation path developed by enterprises based on Digital twins technology is disruptive and will trigger profound changes in the automotive industry, product forms, business models, and service models. At present, digital transformation of enterprises is no longer a choice issue, but a survival issue. All enterprises must achieve digital transformation in order to sustain development, especially for traditional industries. In the future, enterprises will have a complete set of digital production lines with the help of Digital twins technology. For enterprises, their operating mechanisms, management models, and organizational forms will undergo significant changes. For users, digitization will bring them the ultimate "human-machine interaction" experience from all aspects of hearing, touch, and vision, with user centered products that enterprises are dedicated to creating.

ISSN: 2688-8645

Acknowledgments

Natural Science Foundation.

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