PREDICTIVE MAINTENANCE MODEL BASED ON INDUSTRIAL IoT IN THE AUTOMOTIVE INDUSTRY

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Abstract. *The increasing complexity of production systems in the automotive industry makes ensuring equipment reliability a strategic technological challenge. This article is aimed at developing a Predictive Maintenance (PM) model based on Industrial Internet of Things (IIoT) technologies and machine learning algorithms. The integration of sensor data and real-time monitoring systems enables optimization of production processes and improves the efficiency of maintenance management. In the context of global industrial transformation, digital manufacturing technologies play an important role in increasing production efficiency. According to the World Economic Forum, the implementation of Industry 4.0 technologies significantly increases global industrial productivity [1].*

Keywords: *industrial IoT, Predictive Maintenance (PM), Machine Learning, Smart Manufacturing.*

Introduction

The introduction of digital technologies is considered an important strategic factor in the development of modern industrial systems. Within the framework of the concept of the Fourth Industrial Revolution, Industrial IoT (IIoT), artificial intelligence, big data analytics and Digital Twin technologies are transferring production systems to a cyber-physical architecture. Based on IIoT, it is possible to collect, transmit and analyze data from equipment in real time, which increases the transparency and accuracy of management of production processes. The concept of Predictive Maintenance (PM) is an important component of this transformation, which involves forecasting the technical condition of equipment based on sensor data and proactively managing maintenance. Unlike traditional reactive or strictly planned maintenance, PM predicts the probability of failure in advance through data-based predictive models and reduces the number of unplanned downtime. As a result, the OEE (Overall Equipment Effectiveness) indicator increases, operating costs are optimized and production stability is ensured.

The automotive industry is a complex production system based on high precision, tact and synchronized operations. Sudden equipment failure on welding, body assembly, painting and final assembly lines can lead to the shutdown of the entire conveyor system. Equipment degradation (vibration fatigue, thermal overload, mechanical wear) directly affects production efficiency. Therefore, the introduction of Predictive Maintenance (PM) systems is of strategic importance in the automotive industry. The issue of modernization and digitalization of the Uzbek industry has risen to the level of state policy. Shavkat Mirziyoyev, in his Address to the Oliy Majlis, emphasized the need to digitize economic sectors, introduce modern management systems in production and increase efficiency based on innovative technologies [2]. Also, the "Digital Uzbekistan – 2030" strategy sets the widespread implementation of digital technologies in industrial enterprises and

automation of production processes as a priority task [3]. The Development Strategy for 2022–2026 notes the need to expand the production of high-value-added industrial products and introduce innovative management technologies [4].

In this regard, the development of a Predictive Maintenance (PM) model based on Industrial IoT in the automotive industry and its integration into the production system is of not only technological but also strategic and economic importance. This direction will serve to ensure the stability of production, increase global competitiveness, and promote the innovative development of the national industry..

Practical experiences on the topic

The effectiveness of Industrial IoT and predictive maintenance technologies is confirmed by the experience of leading industrial enterprises in the world. In particular, automotive and high-tech manufacturing enterprises are achieving optimization of technical maintenance, increasing equipment reliability, and ensuring the continuity of production processes based on digital technologies. For example, BMW Group has implemented virtual modeling systems for production processes as part of the digital factory concept. This system allows for pre-simulation of production processes and optimization of planning processes. According to the company: “The virtual factory planning tool integrates a range of planning data and applications and allows real-time collaboration with unrestricted compatibility” [5].

Also, the Amberg Electronics Plant of Siemens AG is one of the successful examples of digital production technologies. Industrial IoT, automated monitoring, and production data analysis systems are widely used at this enterprise. As a result, product quality has been brought to a very high level. The company’s representatives state: “We have a defect rate of just 11 defects per million. That’s 99.9989 percent perfection” [6].

General Motors also has experience in using predictive maintenance technologies in the automotive industry. The company is developing systems for real-time monitoring of equipment status and early detection of technical failures by implementing IoT sensor networks on production lines. Studies note: “Predictive maintenance uses connected sensors and advanced analytics to detect anomalies and predict equipment failures before they occur” [7]. Bosch’s Bosch Connected Industry platform is also expanding the possibilities of forecasting technical maintenance based on IoT in the industry. Studies note: “The intelligent use of vast condition data enables not only preventive but also predictive maintenance and changes the strategy from troubleshooting to error prevention” [8].

Predictive maintenance technologies based on Industrial IoT are also being actively used in the aviation industry. In particular, Airbus has implemented a system for early detection of technical failures based on real-time data and analytical systems. Studies have noted: “Predictive maintenance uses real-time data and advanced analytics to anticipate failures before they occur and optimize maintenance operations” [9]. These experiences show that the implementation of predictive maintenance technologies based on Industrial IoT is of great importance in increasing the reliability of equipment operation, reducing production downtime, and optimizing maintenance costs.

Implementation model at “UzAuto Motors” JSC

The implementation of a Predictive Maintenance (PM) system at UzAuto Motors is proposed to be carried out in accordance with the company’s digital transformation strategy of the automotive manufacturing system. The model is based on a three-stage technological paradigm.

First stage – pilot testing phase (Body Shop Lines). The pilot project will be implemented within the welding and body assembly technological processes (Body Shop). At this stage, Industrial Internet of Things (IIoT) sensor systems will be installed to monitor the operational condition of robotic welding equipment. Parameters such as vibration amplitude, temperature regime, electrical current load, and mechanical vibration frequency will be monitored in real time. Using feature extraction methods from sensor data, degradation trends will be identified, and the probability of equipment failure will be predicted using machine learning algorithms. Testing of the PM diagnostic model in Body Shop lines serves as a scientific and technical basis for assessing the technical effectiveness of the Industrial IoT platform, calibrating the accuracy of the model, and algorithmic optimization.

Second stage – technological expansion (Paint Shop Lines)

Based on the results of the pilot phase, the introduction of PM monitoring systems into the technological processes of the Paint Shop is planned. To ensure the stability of painting quality, the following technological parameters will be monitored:

- air temperature and humidity levels;
- pressure differential;
- concentration of chemical components;
- thermodynamic regime of drying chambers;
- dynamics of material viscosity.

At this stage, probabilistic forecasting algorithms and regression-based machine learning models will be applied to evaluate the risk of technological environment degradation in real time.

Third Stage – Enterprise-Level Integration Platform

It is recommended to expand the PM platform to the enterprise's core production systems.

At this stage, integration with the following industrial information systems will be implemented:

- Manufacturing Execution System (MES);
- Supervisory Control and Data Acquisition (SCADA);
- Industrial IoT data lake architecture;
- Machine Learning analytical module;
- Real-time decision support platform.

The integrated digital management architecture will increase the level of production process observability, reduce technological risks, and optimize operational efficiency. The proposed model will contribute to increasing the level of cyber-physical control integration within automotive production lines.

Discussion

Predictive Maintenance (PM) systems based on Industrial Internet of Things form an adaptive and data-driven model for managing production processes in modern industrial enterprises. These systems enable the collection and analysis of numerous technological indicators—such as equipment operating parameters, vibration, temperature, pressure, and electrical energy consumption—in real time through Internet of Things sensors. As a result, continuous monitoring of the technical condition of production systems becomes possible, allowing early detection of potential equipment failures.

In Predictive Maintenance systems, Machine Learning algorithms play a crucial role. In particular, classification models help identify potential malfunctions by categorizing equipment operating states into different conditions. At the same time, the Probabilistic Forecasting approach

makes it possible to estimate the probability of failures that may occur during equipment operation and to optimally schedule maintenance activities. This enables the transition of production systems from a reactive management model to a proactive management model. The implementation of PM systems based on Industrial IoT can lead to several significant technological and economic outcomes in industrial enterprises. In particular:

- the reliability of equipment operation increases and the stability of technological processes is ensured;
- unplanned downtime in production lines is significantly reduced;
- operational costs decrease due to the optimization of maintenance processes;
- efficiency in the use of energy resources improves;
- the overall efficiency and sustainability of production processes are strengthened.

At the same time, several important challenges arise in implementing Predictive Maintenance systems, including ensuring the quality of collected data, processing large volumes of sensor data, and integrating analytical models into existing production systems. Considering these factors, the comprehensive integration of Industrial IoT and Artificial Intelligence technologies can significantly accelerate the digital transformation of industrial enterprises.

Conclusion

In the automotive industry, the integration of Industrial Internet of Things, large-scale production data analytics, and Machine Learning technologies represents one of the key technological components of the Smart Manufacturing paradigm. These technologies enable digital monitoring of production processes, allowing real-time assessment of equipment conditions and early detection of potential failures. The Predictive Maintenance (PM) model developed on the basis of Industrial IoT contributes to increasing the level of digital transformation in production systems, optimizing maintenance processes, and ensuring the reliability of equipment operation. This approach enables the prediction of equipment failures in advance, which helps reduce unplanned downtime, increase production efficiency, and lower maintenance costs. At the same time, the large volume of data collected through Internet of Things sensors serves as an important source of information for deep analysis of production system conditions and for improving digital management mechanisms.

The research results indicate that the implementation of predictive maintenance technologies based on Industrial IoT plays a significant role in ensuring the stability of production processes in the automotive industry and in increasing the technological competitiveness of industrial enterprises. In future research, it is advisable to further develop Deep Learning-based fault prediction models, feature extraction methods aimed at deep analysis of signal data, and adaptive diagnostic algorithms operating in real time. In addition, integrating Industrial IoT platforms with Digital Twin technologies could enable virtual modeling of production systems and further improve predictive maintenance processes.

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