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Key Technologies and Implementation Paths for Automation Transformation of Old Production Lines

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Abstract: The automation transformation of old production lines is of great significance for enhancing the competitiveness of enterprises. The transformation needs to first identify core requirements, attach importance to data collection and equipment interconnection, accurately consider technology selection, conduct process simulation verification, adopt a progressive implementation mode, design data connectivity solutions and implementation paths. The practice of transforming automobile and electronic assembly lines has verified its effectiveness, constructed a calculation model to evaluate economic benefits, analyzed non-economic benefits from multiple dimensions, and provided comprehensive solutions for the transformation.

Keywords: Old production line; Automation transformation; Technology selection

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1. Introduction

Made in China 2025 was promulgated in 2015 with the aim of promoting the transformation and upgrading of China's manufacturing industry. Against this policy background, the automation renovation of old production lines is of great significance for enhancing enterprise production efficiency and competitiveness. Currently, old production lines suffer from issues such as high energy consumption, frequent equipment failures, and poor production process continuity, which severely constrain enterprise development. During renovation, core needs must be identified from dimensions such as production take time matching, equipment compatibility, and human-machine collaboration requirements. Key technologies like data acquisition and equipment interconnection should be employed, with precise consideration of technology selection, validation through process simulation, implementation via progressive renovation paths, and analysis of both economic and non-economic benefits. This series of measures forms a comprehensive and systematic solution, helping enterprises achieve transformation and upgrading.

2. Current status and technical requirements of automation renovation for old production lines

2.1. Analysis of existing problems in old production lines

By comparing energy consumption data and equipment OEE indicators, numerous problems in old production lines can be clearly identified. From the perspective of energy consumption data, aging equipment in old production lines results in low energy utilization rates. The high-energy-consumption operating mode not only increases production costs but also exerts significant pressure on the environment [1]. In terms of equipment OEE indicators, frequent failures severely impact overall production efficiency. Due to long-term use, severe wear on mechanical components leads to high failure rates and prolonged maintenance times, reducing effective equipment operating time. Additionally, poor continuity in production processes results in unsmooth connections between various production links, with delays or blockages in material transfer and other stages creating production bottlenecks. These existing problems in old production lines severely restrict improvements in enterprise production efficiency and competitiveness, urgently requiring automation renovation to optimize production processes, increase efficiency, and reduce energy consumption and failure rates.

2.2. Identification of core requirements for automation renovation

When renovating old production lines for automation, core requirements can be identified from three dimensions: production take time matching, equipment compatibility, and human-machine collaboration requirements. In terms of production take time matching, the take time of old production lines may not adapt to new production scales and efficiency demands; precise calculation of time for each link is needed to ensure smooth take time after automation renovation and avoid bottleneck processes slowing the overall rhythm [2]. Regarding equipment compatibility, old equipment varies in brands and models, with non-unified interfaces and communication protocols; renovation must ensure effective docking and collaborative operation between new automated equipment and existing equipment, achieving data interaction and sharing. Human-machine collaboration requirements focus on the coordination between automated equipment and operators, leveraging the high-efficiency and accuracy advantages of automation while facilitating monitoring, maintenance, and intervention by operators through rational layout of operation interfaces and optimized workflows, thereby enhancing overall operational safety and efficiency.

3. Research on key technology systems for automation renovation

3.1. Data acquisition and equipment interconnection technologies

In the automation renovation of old production lines, data acquisition and equipment interconnection technologies are crucial. Based on an industrial IoT architecture, in-depth analysis of equipment data acquisition protocols is required. The OPC-UA protocol is key among them, offering advantages such as platform independence and high security, effectively enabling data interaction between different devices. Application examples of the OPC-UA protocol show that it can break data barriers between heterogeneous systems, achieving efficient data acquisition and transmission [3]. At the same time, for various heterogeneous systems in old production lines, integration schemes must be developed to enable interconnection among equipment of different brands and eras. Through rational selection of equipment data acquisition protocols and scientific design of heterogeneous system integration schemes, precise data acquisition and smooth interconnection of old production line equipment can be realized, providing a solid data foundation and equipment connection guarantee for subsequent automation renovation and promoting the intelligent upgrading of old production lines.

3.2. Technology selection for intelligent upgrading

In the intelligent upgrading process of old production lines, precise consideration of technology selection is necessary. For industrial robot applications, robot types and quantities should be selected based on factors such as operational complexity, repetition, and load requirements of the production line. For example, in an automotive parts assembly line requiring handling of multiple parts with high assembly precision, multi-joint high-precision robots are preferable. When selecting AGV scheduling systems, AGV load capacity, operating speed, and scheduling algorithms should be determined according to material transport volume, path layout, and transport frequency on the production line. For visual inspection devices, selection should be based on inspection precision, speed, and target features. For instance, in electronic chip inspection requiring extremely high precision, high-resolution and high-precision visual inspection equipment is needed. By comparing and analyzing adaptation standards for these technology combinations, scientific technology selection schemes can be provided for the intelligent upgrading of old production lines, ensuring efficient and stable operation after renovation [4].

4. Design of implementation paths for automation renovation

4.1. Phased implementation strategy for renovation projects

4.1.1. Preliminary process simulation validation

In the automation renovation of old production lines, preliminary process simulation validation is crucial. Using digital twin technology to build a virtual debugging environment for the production line enables feasibility verification of renovation schemes before actual implementation. By establishing digital models of production line equipment and process links, simulating their operating states and interactions, performance under different conditions can be precisely analyzed. For example, virtual testing of material transfer paths, equipment operating take times, and production process connections can identify potential issues such as collision interference or take time mismatches in advance [5]. This allows optimization of renovation schemes based on simulation results, avoiding delays, cost increases, and other issues due to unreasonable schemes during actual implementation, effectively improving the success rate and efficiency of renovation projects and laying a solid foundation for subsequent practical work.

4.1.2. Progressive renovation implementation mode

The automation renovation of old production lines adopts a progressive implementation mode to minimize the impact on production and steadily enhance automation levels. At the first step, conduct detailed assessments of each production line link and, based on results, select relatively independent modules with minimal impact for replacement. For example, start with the material conveying module by adopting new automated conveying equipment while ensuring transitional capacity through personnel adjustments and optimized production scheduling. After the material conveying module is renovated and operates stably, progressively advance automation in other modules such as processing and inspection. This mode makes the renovation process gradual, allowing employees to adapt to new equipment and processes step by step, while transitional capacity assurance measures effectively reduce negative impacts on overall production, laying a solid foundation for successful implementation of old production line automation renovation [6].

4.2. System integration and debugging schemes

4.2.1. Multi-level system docking architecture

A three-level data penetration scheme should be designed for ERP-MES-equipment control layers to build a multi-level system docking architecture. The ERP system focuses on enterprise resource planning and management, storing overall operational data such as orders and material plans. The MES system, as a production execution system, plays a bridging role at the workshop level, receiving production tasks from ERP and feeding back equipment status and production progress to ERP. The equipment control layer directly handles specific equipment operations and control. By establishing standardized data interfaces and communication protocols, smooth data interaction between levels is achieved, ensuring accurate delivery of production instructions to equipment and timely feedback of real-time equipment data to MES and ERP, providing an accurate basis for production decisions [7]. This multi-level system docking architecture effectively integrates data and functions across levels in old production lines, facilitating efficient advancement of automation renovation.

4.2.2. Whole-line joint debugging standards and acceptance

The design of automation renovation implementation paths must fully consider the current status of old production lines. Comprehensive assessments should be conducted to analyze efficiency and issues in each link. Based on identified problems, formulate detailed renovation schemes in combination with automation technologies, selecting suitable automated equipment and control systems. For system integration and debugging, ensure effective docking of automated equipment using modular integration approaches and progressively integrating parts. Debugging starts from single-machine, proceeds to unit debugging, and finally whole-line joint debugging. Whole-line joint debugging standards and acceptance are based on an established 22-item acceptance indicator system, covering production take time testing, fault simulation testing, etc., strictly checking production line stability, efficiency improvements, and fault response capabilities to ensure that renovated old production lines meet high-quality automated production requirements [8].

5. Engineering practice and benefit verification

5.1. Automotive parts production line renovation case

5.1.1. Specific implementation of renovation scheme

In the renovation of welding robot workstations on an automotive parts production line, process parameters were first optimized. Through extensive experiments and simulation analysis, welding current, voltage, speed, and angle were precisely adjusted to ensure stable welding quality and good weld formation, raising the welding yield rate from 85% to over 95% [9]. At the same time, emphasis was placed on upgrading the safety protection system. High-precision infrared sensing devices were installed to form sensing zones around the robot's operating radius, triggering alarms and pausing robot operation upon personnel entry. Additional protective barriers and light curtain sensors further ensured operator safety. Furthermore, the robot teach pendant interface was optimized to reduce mis-operation risks. After renovation, the production line's automation level significantly increased, boosting production efficiency by over 30%, markedly reducing labor costs and safety incident rates, and achieving excellent engineering practice outcomes and economic benefits.

5.1.2. Quantitative analysis of renovation effects

In this engineering practice of automotive parts production line renovation, quantitative analysis of effects is crucial. Taking a certain old automotive parts production line as an example, pre-renovation equipment comprehensive efficiency was low, with high product defect rates severely affecting production benefits and quality. Through automation renovation, applying key technologies and reasonable implementation paths, significant results were achieved. From key indicators, equipment comprehensive efficiency increased by 37%, meaning more qualified products could be produced per unit time, greatly enhancing production efficiency [10]. Meanwhile, the product defect rate dropped by 62%, effectively reducing costs from defective items and improving overall product quality. These quantitative data fully validate the success of this old production line automation renovation in improving production benefits and product quality, providing strong data support and practical reference for subsequent similar line renovations.

5.2. Electronic assembly line renovation practice

5.2.1. Experience in automated equipment selection

In the electronic assembly line renovation practice for old production line automation, technical-economic analysis is crucial for parallel robot selection in precision assembly links. Technically, focus on repeat positioning accuracy, which directly affects assembly precision, generally requiring ± 0.05 mm or higher to meet precision component needs. Motion speed is also critical, enabling completion of assembly actions within specified take times, such as a certain number of products per hour. Load capacity must adapt to different component specifications. Economically, calculate equipment procurement costs by comparing prices of different brands and models. Additionally, consider operating costs like energy consumption and maintenance, which differ significantly long-term. Comprehensively balancing technical and economic factors enables precise selection, meeting production needs while maximizing cost benefits.

5.2.2. Breakthrough in system integration difficulties

In the system integration process of electronic assembly line renovation practice, old production line automation faces many difficulties. Timing coordination between SMT equipment and AGV systems is one key issue. In practice, in-depth study of their operating logic and take times is needed. Precise analysis of SMT equipment mounting processes and time parameters in each link, along with detailed understanding of AGV transport path planning and start-stop time control. By building a simulation test environment and continuously adjusting parameters using advanced sensors and control algorithms, AGV can arrive at designated positions for material pickup and transport at precise times after SMT mounting completion. Through repeated testing and optimization, this timing coordination challenge was successfully resolved, significantly improving electronic assembly line operating efficiency and substantially shortening product production cycles, effectively validating the renovation scheme's feasibility and effectiveness in enhancing production benefits.

5.3. Comprehensive evaluation of renovation project benefits

5.3.1. Economic benefit calculation model

In constructing an economic benefit calculation model for old production line automation renovation projects, the payback period intuitively reflects the time needed to recover initial investment. By calculating renovation investment and subsequent annual net benefits, the payback period is derived, the shorter, the faster the recovery and better the project economics. Net present value discounts future net cash flows to present value at a certain rate and subtracts initial investment. If greater than zero, the project creates additional value considering time value of money, indicating economic feasibility. These parameters combined provide a comprehensive economic-level benefit assessment for old production line automation renovation, offering quantitative basis for decisions on project implementation viability.

5.3.2. Non-economic benefit analysis framework

In the non-economic benefit analysis framework for old production line automation renovation projects, production efficiency elasticity is an important dimension. Automation renovation enhances production's ability to respond to market demand changes. For instance, when orders suddenly increase, automated equipment can quickly boost capacity through flexible parameter adjustments, significant for adapting to volatile markets. In terms of technical reserve value, introduced advanced automation technologies lay the foundation for future product upgrades and business expansion. For example, application of intelligent control technologies enables mastery of key domain technologies, facilitating the launch of more competitive products and enhancing enterprise industry status and influence, yielding profound long-term non-economic benefits.

6. Conclusion

Automation renovation of old production lines is of great significance for enhancing enterprise production efficiency and competitiveness. During the process, technology selection decision trees enable more scientific and reasonable choices of suitable automation technologies, ensuring accurate renovation direction. Risk control checklists safeguard the entire project, identifying and mitigating potential risks in advance to reduce uncertainties. Renovation technology iteration directions proposed based on Industry 4.0 development requirements provide guidance for continuous upgrading of old production lines, maintaining adaptability and advancement in future production environments. These key technologies and implementation paths form an organic whole, offering a comprehensive, systematic, and forward-looking solution for old production line automation renovation, helping enterprises achieve transformation and upgrading in the automation wave and embark on a path of high-quality development.

Disclosure statement

The author declares no conflict of interest.

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