

Article

Implementation Criteria for Intelligent Systems in Motor Production Line Process Management

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Abstract: In this study, the factors that affect the implementation of intelligent systems in motor production lines are analyzed. A motor production line located in Vietnam is used as the research object. The research methods include secondary data collection, field study, and interviews. This study demonstrates the following: firstly, the implementation of intelligent systems in motor production lines is heading toward Industry 4.0. Secondly, it is proposed that three functional systems—robot arm, image recognition, and big data analysis—can be introduced in the motor production line. This study analyzes the process involved in coil and motor production lines and attempts to combine intelligent system functions. It is expected that in the future, manpower will be reduced, production line productivity will increase, and intelligent production lines will be proposed. The factors that affect the introduction of intelligent systems in motor production lines are improved, and the importance of intelligent systems, which has been rarely considered in previous studies, is highlighted. In the implementation criteria of the intelligent system in the process management of the motor production line, this study provides some suggestions (to coil and motor assembly line) for the production process management. These suggestions can be provided as a reference for production lines that acquaint with intelligent systems.

Keywords: intelligent systems; motor production lines; process management

1. Introduction

This section elaborates on the research background related to this research, how to introduce the application of intelligent systems in the motor production line and analyze from the perspective of process management.

1.1. Research Background

In the past, as a result of underdeveloped technology, production was costly and consumed considerable resources including time; Also, the output was low, which caused failure in meeting customers' product demand on schedule. Moreover, there was no system capable of monitoring the production line to implement quality control in real time. The low quality of goods indirectly caused credit problems with customers. This led to the rise of the so-called industrial revolution, which gradually solved the problems related to resources, time, and output. In the last decade, Germany first proposed the concept of Industry 4.0, which integrates the current Internet of Things (IoT), IT, virtual reality, and other technologies for developing smart factories and smart grids to, in turn, achieve smart cities. For the English abbreviation of this study, please see Appendix A.

Similar to those in Germany and Japan, companies in Taiwan that are confronted with problems in production have gradually implemented intelligent production lines. In this study, the research object is Solen company, which is committed to the manufacture of specialized and automated motor

products as well as complex key electromagnetic components. The factories in operation are located in Taoyuan, Kaohsiung, Taiwan and Ho Chi Minh, Vietnam. The motor manufacturing plant in Ho Chi Minh City is an original design model manufacturer commissioned by the original factory of Japan's M company to manufacture and deliver motors. In this study, the motor assembly and coil assembly production lines are surveyed. It is found that the production line employs considerable manpower to inspect the motor appearance and test motor performance. A semi-automatic production mode, which uses both humans and machines, is employed in processes operated by personnel; hence, labor cost is substantial.

It has been reported in literature that artificial intelligence [1] can be utilized to collect and analyze the fault mechanism of motor insulation, and image recognition can assist in the inspection of the motor's rotor appearance [2]. Artificial intelligence can also collect vibration signals through machine learning-based techniques [3] to evaluate sound data and implement automatic fault detection functions. If cyber-physical systems (CPSs) used in the aviation, automotive, chemical process, and infrastructure manufacturing industries can be introduced into the production line, then costs may be reduced and production capacity may increase, thereby achieving a fully automated model. Moreover, the growth of the world's population has gradually changed in recent years; hence, if intelligent systems can be employed to reduce manpower in the production line, then the problem of insufficient manpower may also be resolved in the future.

1.2. Research Objectives

The purpose of this study is to explore the application of intelligent systems in motor and coil assembly production lines as well as to determine the available intelligent systems. The research questions are as follows.

- (1) What is the current status of "SM" (Solen Vietnam Motor Production Line) motor and coil assembly lines in Vietnam, and are there intelligent systems in place?

At present, there are seven employees in the motor assembly line. Each employee is assigned to a workbench to assemble the motor and test its operation on a machine. After completion, the motor is transferred to the next workbench for final visual inspection before shipment. All of these are manually implemented.

- (2) After understanding the current status of the "SM" motor and coil assembly lines in Vietnam, what intelligent system may be implemented in the future to support the motor and coil assembly lines?

In this study, secondary data collection, field survey, and interview are conducted to determine the intelligent system that may be utilized to support the production line.

1.3. Literature Review

In this study, we collected relevant literature on intelligent systems, Industry 4.0 and motor production lines; In particular, this paper analyzes the motor production process in nine steps.

1.3.1. Intelligent Systems and Industry 4.0

In an information-developed society, the use of intelligent systems is necessary to aid companies in resolving complex problems and facilitating the allocation of manpower. The interpretation of smart systems varies from industry to industry; the perspectives of experts also vary. Many people quote Prof. John McCarthy (recognized as the father of artificial intelligence) who said, "artificial intelligence is to make machines behave like intelligent behaviors shown by humans." It is akin to putting human wisdom on a system so that it can autonomously make reasonable evaluations and implement external changes. Simply put, an intelligent system must be able to aid people to perceive changes, analyze judgments, and perform tasks [4].

Currently, many intelligent systems can directly send and receive information, analyze received information, and perform tasks automatically. Moreover, with the development of 5G technology, these functions can be performed anytime and anywhere to rapidly process tasks and produce outputs for the enterprise or users.

1. According to some scholars [1], CPS is a network and engineering system that can integrate both cybernetic and physical worlds. That is, it can be combined with physical sensors and other integrated systems in the field of virtual computer control called “virtual-integrated systems.” Some embedded devices, such as the IoT and sensor networks, have systems similar to CPS. Embedded devices, however, emphasize device performance, whereas the CPS is a combined system of physical devices and network with emphasis on the relationship between their interaction [5].
2. The CPS is typically used in automation and sensor systems (e.g., robots, autonomous driving systems, monitoring systems, and process control systems) and in manufacturing [6]. This means that the physical devices in the manufacturing system can generate the same virtual model through the CPS. The data generated by the physical system are analyzed through the network and thereafter applied to the virtual model in real time in order to accurately present the current status of the physical system. The advantage of the virtual model is that it can be optimized through big data and artificial intelligence, which in turn can be used in manufacturing systems [7].

With the advent of globalization, the trade competition among countries has become increasingly intense. In this era, the Internet as well as science and technology have rapidly developed. Industry 4.0 was first proposed in the German Industry Fair in 2011 as a high-tech industrial plan. Thereafter, plans for the U.S. manufacturing partners, i.e., Japanese Industry 4.1J, Korean Manufacturing Innovation 3.0, and Made in China 2025, were made public.

In literature, it has been reported that [8] Industry 4.0 is the result of the fourth industrial revolution that has not been fully completed. Similar to other historical periods, the introduction of structural changes to production processes can lead to significant innovations and changes, which will also considerably impact production as well as influence and ultimately generate new business models. Industry 4.0 is comprised of technologies, equipment, and processes that allow a self-sufficient production model. This model can run the supply chain in an integrated manner at multiple stages and production process levels as well as operate with minimal human effort.

Industry 4.0 also represents the process of automating high-tech integration with manufacturing. Its contents include the integration of sales and products, and production and sales processes are customized. To obtain various data for the production process, an IoT framework that assists production is established. The big data information analysis technology is utilized for enabling operators to understand engineering and product-related data from the machine computer and identify the project and its stage of implementation. The objective is to improve the existing quality of the product and make appropriate decisions. The concept of Industry 4.0 includes the use of paradigms and technologies to support big data, augmented reality, robotics, CPSs, cloud computing, and the industrial Internet to promote the shift from traditional factories to intelligent production [9].

1.3.2. Intelligent Application for Motor Production Line

The motor production process involves approximately nine steps [10], and the research on this aspect can also utilize the concept of Industry 4.0, as follows.

1. Housing and Rotor Cage Production

Production starts from casing fabrication; however, no direct solution for the casting of motor casings has been found. During the casting process, the voltage or temperature can be collected and stored by sensors. Thereafter, machine learning technology in combination with artificial intelligence can be used to optimize the parameters in the casting process, predict the casting quality, and determine the appropriate casting material variables.

In addition, simulation methods can be employed to model the solidification of the liquid metal in the mold. The core can then be assembled by subordinate robotic arms, thereby reducing manpower and the probability of error. The asynchronous motor's rotor is manufactured by die-casting, which is also a method applicable to casing fabrication. Note that if the quantity of rotors to be manufactured is small, then it is necessary to prepare copper rods to be welded to the short-circuit ring.

2. Laminated Core Production

The data collected from the laminated core manufacturing process using machine learning algorithms can be utilized to predict the quality of raw materials required for production. In the case of electrical board production, machine learning algorithms can classify the materials for electrical steel plates based on the electromagnetic properties of microstructures. During the cutting of electrical boards, by monitoring the cutting force, audio signals, or vibration signals through sensors, machine learning algorithms can be employed to detect and predict errors and build models. Virtual reality smart devices can also be used to assist in the cutting and welding operations. Using different techniques to cut out electrical boards, sensors can be used to monitor the punching forces, audio signals, or vibration signals. For the laser-cutting process, data mining through the use of machine learning algorithms can afford the potential of detecting errors and predicting key events. The quality inspection of cuts and the entire laminated core can be performed through computer vision.

3. Insulation and Impregnation

In the motor manufacturing process, many of the steps involve providing insulation to motor parts. There are different alternatives for insulating the raw stator materials used in the slot, including the application of insulating paper powder coating or injection-molded polymers. Machine learning may be employed to aid in modeling this process and determining the best process parameters. Big data can also be combined to determine quality-related parameters and generate predictive models. After winding, the entire coil is insulated. In this aspect, machine learning can also identify the appropriate impregnation process simulation support.

4. Winding

The technology of Industry 4.0 may be employed to set the sensor in the winding machine and guide the machine in creating a precisely positioned coil. Rodriguez et al. [11] proposed that a machine learning system can be used to optimize the wire contour generated by an automatic winding machine so that the coil contour is wound as uniformly as possible. Apart from accurate and non-destructive winding, it is also important to maintain the required coil resistance during enameled winding. This can also be optimized by machine learning by simulating the winding parameters (e.g., wire tension and winding speed). Combined with the image recognition technology, the use of a robot to wind and install coils can facilitate production and detect the cause of failure at any time.

5. Contact technology

The existing method relative to contact technology directly solves the problem of crimping in motor production. It was reported in [12] that a standard OPC Unified Architecture condition monitoring system may be used to track the thermal crimping process (OPC Please See Table A1). In addition, Mayr et al. [13] studied the application of machine learning algorithms in the ultrasonic field for crimping. First, quality indicators (e.g., resistance and extraction force) can be estimated based on process parameters. Second, visual or auditory features can be used to classify joint quality.

In quality management, machine learning-based models are used as quality estimators, eliminating the necessity of quality management measures, such as random checks. For example, convolutional neural networks use visual features to predict joint quality. A comparison between deterministic models and machine learning methods shows that machine learning technology is more powerful, easier to automate, and more accurate. It can also detail the machine learning-based process control methods for the real-time measurement of parameters in the near future [14].

In addition to crimping, the potential of using machine learning in the laser welding of hairpin windings is studied. The application of laser welding contacts is particularly suitable for hairpin windings because of the large number of contact points. The use of machine learning can predict the quality of weld processing based on machine parameters. For the subsequent quality assessment, the combined image data can be used to detect and classify weld defects based on their severity. In the future, these applications will be incorporated into a quality monitoring system, which may also contain data from the upstream process. In particular, the burrs formed during the cutting process and residues resulting from peeling considerably influence the welding results [15].

6. Shaft Production

Al-Zub Ardi [16] indicated that machine learning can be employed for quality management, process control, and predictive maintenance in the cutting process. The proposed model focuses on the prediction of surface roughness and cutting forces as well as the estimation of tool life and wear. In addition, the application of machine learning technology combined with edge and cloud computing allows the analysis of large data streams. Computer vision can be used for process monitoring or quality inspection of machined parts through machine learning algorithms. Different methods have also demonstrated that the OPC Unified Architecture condition monitoring system can aid in optimizing machining processes [17,18]. Moreover, compared with traditional machining centers, robots are convenient for machining operations because of their flexibility and relatively low investment costs. Finally, weight reduction can be achieved through the AM (Additive Manufacturing) of the shaft [19].

7. Permanent Magnet Rotor Production

Various methods are employed in the production of motors, including permanent magnet synchronous motor rotors and those used in related fields. For example, image recognition can be employed for the visual inspection of magnetic surfaces after fabrication. In addition, sensors can be used for magnetic field measurements, which can be utilized to test a single magnet or the entire rotor. Magnetic field measurements also provide the basis for selective magnet assembly. Magnetic deviation has a critical influence on the operating characteristics of the motor, and it can be applied to optimize the deviation compensation magnet arrangement. Apart from traditional algorithms, machine learning techniques can be employed to develop optimal magnet assembly strategies. For each batch of magnets, a magnet or magnet stack is selected and installed according to an algorithm to minimize the deviation from the simulated magnetic field of an ideal rotor [20–22].

8. Final Assembly and Testing

In the final motor assembly, various connection processes are involved, including press-in operations, gluing, shrinking, tightening, and welding. Data mining methods can be utilized to study the relationship between force–displacement and current curves in a press operation. The testing process naturally generates a considerable amount of data; hence, data-driven methods, such as machine learning, can be used to check multiple areas. For stator testing, machine learning methods can be used to evaluate and classify the fault mechanisms in electrical insulation. The quality characteristics measured herein can also be used as labels for predictive models based on machine learning that utilize parameters from previous processes, such as winding, insulation, and contact. In addition, several methods directly solve the end-of-line test of the motor, e.g., image recognition technology can support stator inspection. Machine learning technology capabilities can also be utilized for evaluating vibration signals [3] as well as acoustic data to analyze motors [23] and produce automatic fault detection functions.

9. Overall Process

Apart from the application scenarios of Industry 4.0 technology in each sub-process, there are other methods related to the overall process that can include various steps in the value chain. For instance, with regard to the development of motors and related production systems, semantic technology can considerably improve the cross-domain information exchange. In addition to pure knowledge management, from the perspective of a configurator, knowledge-based systems can be used to automate simple engineering tasks. Thus far, it can only be found in motor design; however, it can also be employed in the engineering design of related production systems. For example, simulations can aid in analyzing the cost–benefit ratio of alternative production technologies.

With regard to production, knowledge-based systems can aid in optimizing individual jobs, and machine learning algorithms will be useful in processing big data and making fault predictions for the entire production line. Data mining can therefore facilitate the detection and rapid response to deviations within the assembly line. In this case, machine-to-machine communication technology performs an important function. For example, wireless communication technologies, such as Bluetooth 4.0 can be used to identify and locate tools and objects [24]. In the human–machine interface field, virtual reality-based auxiliary systems can support complex assembly processes [25]. In motor production, simple tasks can be handled with sensitive lightweight robots and automated guided vehicles. Another approach involves developing machine learning-based controllers for robots that can reduce the programming effort for assembly tasks [26]. In this case, machine or robot control can be transferred to the cloud and be provided as a service [27].

With the foregoing, the relationship between the motor production process and Industry 4.0 is established. Moreover, the application of the motor production process of the research object is summarized in Table 1.

In summary, the literature summarizes the intelligent systems that can be used in motor manufacturing, and also supplements the system that is lacking in existing literature. For the industry, it also provides a practical intelligent system model.

Table 1. Comparison table of motor production process and Industry 4.0.

STEP	INDUSTRY 4.0
1. Housing and Rotor Cage Production	Use sensors to monitor production data (specifications, quality, etc.) and store them on a computer. Then, use artificial intelligence to analyze and predict the required materials to avoid excessive waste. For example, if the specifications and quality can be predicted in advance, it is set at the time of production, and when the rotor of the production line is cut, the excess parts can be cut out to save raw material consumption.
2. Laminated Core Production	When cutting electrical boards, the sensors installed on the machine receive cutting force and sound and vibration frequency data. Then, use artificial intelligence and CPS virtual operation models to simulate and obtain more accurate data to aid in production. For example, when the rotor of the production line is cut, the above methods can be used to make the machine operate more accurately, and the accuracy of the finished product specifications can be improved.
3. Insulation and Impregnation	In the selection of washer (insulation parts) materials, artificial intelligence is used for simulation and analysis to find the most suitable materials and specifications. Then, production and assembly are performed to find the most suitable materials and specifications. To provide a better insulation effect, accurate installation position is necessary.
4. Winding	In the winding step, install the sensor to return data, and use artificial intelligence analysis to find the best winding data (number of turns and winding speed, etc.). The image recognition system can make production faster and more accurate and inspect the appearance at any time.
5. Contact	Part of the rotor spot welding is equipped with an intelligent system. In addition to returning production data (resistance, temperature, etc.) to monitor the entire welding process, it can also optimize the welding quality. If image recognition is added, weld defects can be found. The severity is classified for subsequent analysis and optimization.
6. Shaft Production	Use artificial intelligence to analyze and optimize shaft production data (quality, specifications, etc.) to find the best production method. It can also be used in the assembly of the bearing, installation of sensors, and monitoring of parameters (size, assembly force, shaft radius, etc.) for computer analysis and optimization to reduce the number of defective products.
7. Permanent Magnet Rotor Production	The permanent magnet assembly step uses image recognition to visually inspect the magnet surface after production. The machine is equipped with a sensor during the magnetization step of the permanent magnet. After magnetization, the position and magnetic field of positive and negative poles are automatically checked to avoid affecting the motor operation.
8. Final Assembly and Testing	In the motor assembly line, image recognition (e.g., brush appearance inspection and motor press-fit appearance inspection) is added to check the appearances. The data generated during the motor performance test can also be stored and analyzed using artificial intelligence in order to identify problems and aid the motor designer.
9. Overall Process	Using the machine-to-machine technology, the intelligent system installed on each machine is connected to exchange and upload data in real time. Data management is performed through knowledge-based systems to speed up the entire operation and management processes.

2. Materials and Methods

2.1. Research Architecture and Methods

In this study, secondary data collection, field study, and interviews are performed to explore the selection of intelligent systems to be applied to Solen company, which is Vietnam's motor production line. In terms of secondary data collection, this study has searched for related research papers, journals, and reports on existing smart manufacturing cases; production line standard operating procedure manuals are also obtained. From these, feasible methods for "SM" motor production line are initially evaluated.

The main author and coauthor of this study also visited the Solen company Ho Chi Minh City factory in Vietnam on 19–22 September 2019 to conduct a field survey. This allowed the authors to observe the actual operation of the motor production line staff and understand each step of the operations. Based on this field visit, the processes and systems that smart systems may import from the technology of Industry 4.0 are initially assessed. (See Table 2)

Table 2. Research methods and data types.

RESEARCH METHOD	DATE	DESCRIPTION	COLLECTED DATA
Secondary data collection	July 2019–February 2020	Information on research issues from existing papers, journals, cases, and company materials is obtained. After analysis, the feasible methods for “SM” motor production line are summarized, integrated, and initially evaluated.	Papers, journals, books: 28 Company production line operation process description SOP(Standard Operating Procedure): 1 copy Production line working time statistics
Field study	19–22 September 2019	Actual operation status of production line is monitored by observing motor production line and collecting data.	Production line photographs
Interview	27 November 2019, 13:00–14:00	Two practical experts were invited to laboratory for interview.	Record interviews, verbatim files, photographs
	31 January 2020, 14:00–15:15 On February	Visited Taiwan headquarters of Solen company, interviewed three practical experts, collected questions related to the implementation and design of production line. Questions raised by interviewees are asked to obtain helpful information for research. Two experts are responsible for the production line process and machine design. One expert is responsible for the actual production line execution.	Record interview files, verbatim files, photographs
	14 February 2020, from 14:00 to 14:30	Visited Solen company Taiwan Headquarters, and a practical expert was interviewed.	Record interview files, verbatim files, photographs

A three-stage interview is conducted to collect expert opinions. 1. On 27 November 2019, two practical experts were invited to the laboratory for interview. 2. In order to understand the current situation of the company’s production line automation, three persons in charge of the motor production line in the Taiwan headquarters of Solen company were interviewed on 31 January 2020 and from 14 February 2020. They were interviewed regarding feasible solutions for preliminary evaluation as well as the company’s views on the introduction of intelligent systems and future planning. To ensure the correctness of the information, the consent of the respondents to record and photograph the interviews was obtained. It is also treated anonymously after the interview to protect respondents.

In this research, secondary data collection, field study, and expert interviews are mainly conducted to study the “SM” motor production line in Vietnam. Based on the observations of researchers of the actual production line and personnel interviews to understand existing production process, the smart machine tools (smart systems) necessary for smart manufacturing are introduced. Finally, the intelligence of the motor and coil assembly processes of this production line is analyzed. The research architecture is shown in Figure 1. In this study, there are three stages of research steps, Step 1: Secondary data collection, to widely collect data on the “SM” production line. Step 2: Field study, go to the production line for research. Step 3: Interview, this study conducted a total of 3 interviews to obtain a prosperity of research data.

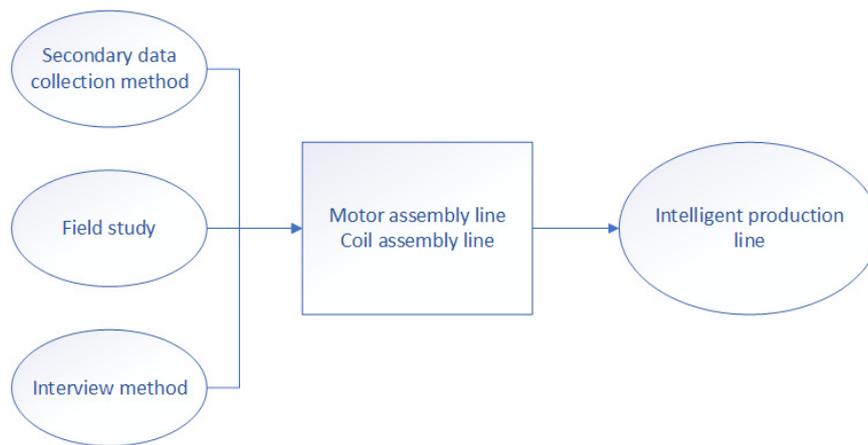


Figure 1. Research architecture diagram.

2.2. Research Objects

The “SM” motor production lines in Vietnam are mainly divided into engineering, coil, and motor assembly production lines. The engineering production line is mainly focused on the assembly of rotors, sleeves, bearings, and other components, as well as magnet production. The coil assembly line is primarily responsible for winding, spot welding, cutting of commutators, washer assembly, bearing assembly, and distance inspection as well as voltage, insulation, and impedance testing. The motor assembly line deals with coils, brushes, washer, and motor assembly, as well as visual inspection. The layout of the “SM” motor production line in Vietnam is shown in Figure 2. In total, there are three production lines and two assembly lines. Each rectangle represents one workbench, each person is assigned to a workbench and is responsible for handling 1–2 operating procedures.

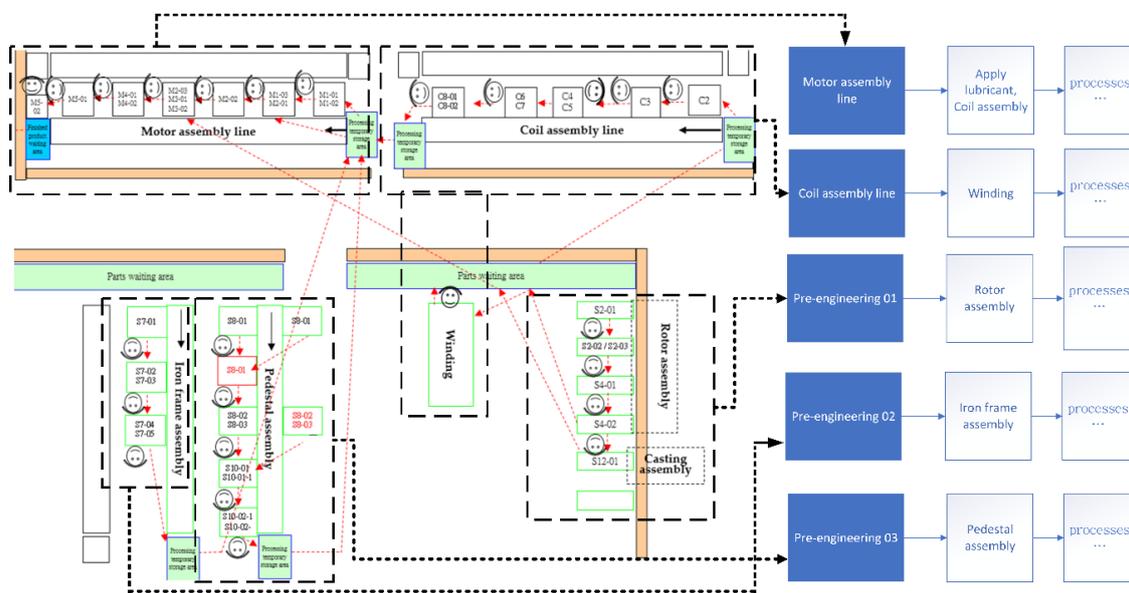


Figure 2. Production line layout.

The operation processes of the coil and motor assembly lines are shown in Figures 3 and 4, respectively.



Figure 3. Coil assembly line.

The coil assembly line in Figure 3 is composed of eight main operating procedures as follows.

1. Winding

- (1) Check if the rotor is rusty and there is a mounting sleeve; there must be five grooves. After confirmation, ensure that the machine is inserted according to the direction.
- (2) Press the button for the machine to start winding.
- (3) Use a wooden shaft to number the parts.
- (4) Ensure that the copper wire is not cracked. The diameter of the rotor should not exceed those of the casing and spot welding of the rotor.



Figure 4. Motor assembly line.

2. Commutator spot welding

- (1) Place the coil into the machine according to the direction.
- (2) Press the button to allow the machine to start the spot welding.
- (3) Check whether the appearance of parts is complete and if there are five grooves. The NG product is placed in the NG box, and good products proceed to the next step.
- (4) Photographs are taken and saved for every 1000 products.

3. Commutator cutting
 - (1) Place the parts of the machine according to the direction.
 - (2) Start the button to allow machine cutting.
 - (3) Check whether the appearance of parts is intact; put the NG product in the NG box.
 - (4) Install the bolt gauge tool to the commutator after cutting.
4. Pneumatic rectification
 - (1) Place the parts in the machine.
 - (2) Clean the parts with a brush.
 - (3) Use a magnifying glass to check the appearance of parts and for foreign objects. Put the NG product into the NG box; the good products proceed to the next step.
5. Air pressure removal
 - (1) The parts are placed into the machine and aligned with the air-jet holes for air-jet cleaning.
 - (2) Check the parts for foreign matter and whether the parts appear complete and bright. Place the NG product in the NG box; the good products proceed to the next step.
6. Washer group voltage withstand, absolute resistance, and impedance tests
 - (1) Place the washer into the machine.
 - (2) Press the switch to initiate the washer punch.
 - (3) Put the parts into the machine for voltage withstand, absolute resistance, and impedance tests. Put the NG products into the NG box; good products proceed to next step.
7. Bearing assembly
 - (1) Place the bearing and coil in the machine in the same direction.
 - (2) Press the switch to initiate punching.
 - (3) Check whether the parts are intact and correctly aligned. Place the NG product into the NG box; good products proceed to the next step.
8. Bearing distance check
 - (1) Place the parts of the inspection machine as directed.
 - (2) Press the button to initiate machine check.
 - (3) Check if the parameters are within range. Put the NG product into the NG box; good products proceed the next step.

The motor assembly line in Figure 4 is composed of nine main operating procedures as follows.

1. Lubricant application
 - (1) Align the iron frame with the coil cut groove and place it in the dispenser.
 - (2) Press the switch to dispense the machine.
 - (3) Check whether the parts have a sufficient amount of glue. The NG product is placed into the NG box, and the good products proceed to the next step.
2. Coil assembly
 - (1) Place the parts of the machine according to the direction.
 - (2) Clip the iron frame into the coil with the white assistive device and take it out.
 - (3) Check whether the parts are installed. Place the NG product into the NG box; good products proceed to the next step.

3. Brush assembly

- (1) Align the red part of the brush with the machine.
- (2) Press the switch to open the terminal.
- (3) Assemble the parts and coils into the finished product according to the working procedure.
- (4) To provide a gap in the iron frame, check the positioning point. The base assembly must be accurately positioned. The NG product is placed in the NG box; good products proceed to the next step.

4. Brush appearance inspection

- (1) Assemble the machine parts.
- (2) Inspect the parts for damage through closed-circuit television. The NG products are placed in the NG box, and the good products proceed to the next step.

5. Washer enrollment and inspection

- (1) Put the small and large washers on the machine and install the parts.
- (2) Press the button to connect the washer.
- (3) Put the parts into the machine according to the indicated direction, and capture image.
- (4) Ensure that no washer is missing based on the image. Put the NG product into the NG box, and good products proceed to the next step.

6. Motor press assembly

- (1) Check whether the size of the washer is correct, and the iron frame cover must fully fit the iron frame.
- (2) Align the machine parts.
- (3) Press the button to initiate pressing.
- (4) After installation, ensure that there are eight cut-outs in the parts. Place the NG product into the NG box; good products proceed to the next step.

7. Clearance confirmation

- (1) Place the parts of the inspection machine.
- (2) Press the button for the machine to detect the gap. Place the NG box out of the specification range; the good products proceed to the next step.

8. Motor performance check and lighting

- (1) Align the parts of the inspection machine.
- (2) Press the button for the machine to transport the parts until they touch the terminals.
- (3) Press the switch to start measurement and check the 88 items of motor performance data.
- (4) Check if the data are within range. Put the NG product into the NG box; good products will be automatically engraved with a number. Proceed to the next step.

9. Final visual inspection

- (1) Use a tool to check if the screw pattern is correct.
- (2) Use a tool to check whether the laser marking (seal) is sufficient.
- (3) Check if the motor rotation direction is correct.
- (4) Put the motor into the machine to check whether the terminal is defective. Put the NG product into the NG box and put the good product into the box according to its number. Finally, pack and ship.

2.3. Interview Outline

Interviews on the design and execution dimensions of the production line have been conducted.

1. Interview questions related to production line automation.
 - (1) Is each part numbered and recorded in the computer to manage all parts? If so, how does it work?
 - (2) Is there a sensor installed on the production unit to detect, for example, the current production quantity or whether the parts of the unit itself are faulty? If so, what is the current function of the sensor? If none, have you considered installing it?
 - (3) Will the photographs captured by the CCTV (Closed Circuit Television, is a photographic equipment and equipment for capturing images to improve quality, etc.) and machine-measured data be stored? If yes, are they classified and used for other applications?
 - (4) In the motor assembly line, how many photographs are taken by the CCTV brush appearance inspection, and which of these can provide basic information for image recognition in the future?
 - (5) Does the company currently have any expectations? To what extent has the production line been automated, such as the introduction of robotic arms? If so, can the reduced labor and machine costs after the introduction be maintained or increased to production capacity?
 - (6) In the previous interview, the two managers mentioned that the identification of imported images requires huge data to train the AI and generate a model. How much data are currently stored in the factory? Do the images identify the manufacturer of the device?
 - (7) In terms of data collection, it is evident that good data must be retained, but in order to introduce image recognition or other machine learning models, considerable NG data are also necessary. Are there any plans for retaining NG data?
2. Production line interview questions
 - (1) Will the photographs captured by the CCTV and machine-measured data be stored? If yes, are they classified and used for other applications?
 - (2) To what extent is the production line currently automated, and which parts are produced using both machinery and labor?
 - (3) The images captured by the CCTV are used for appearance inspection. How is it judged whether the product is OK or NG? Some products have missing corners but can still be used, what is the criterion for making this decision?
 - (4) Production line standard operating procedure.

3. Results

The research results based on field study, interviews, literature, and secondary data analysis are compiled.

3.1. Motor Production Line Analysis

Approximately three years ago, the cooperation with company M was implemented. The company went to Vietnam several times to review the motor production line and check problems related to failure mode, design, and equipment. Approximately 5–8 persons come from Japan every visit, which is approximately 1–2 weeks every two to three months. Starting September 2019, the products have been manufactured through small-scale production. Thus far, the total output is approximately 200,000 motors, and considerable performance test data are available. The failure mode verification along the production line involves checking the 200,000 motors. In the production, the selection of materials is gradually adjusted, and the testing process is improved. One example is the defect

reported by a customer that was not observed in the production line testing but was observed during use. The problem was traced in the assembly press-fitting.

Status of production lines at the “SM” Motor Plant in Vietnam: In the pre-production line, there are three production lines, each of which has 3–6 workbenches. Each workbench has 1–2 operating procedures; only one person is responsible for each workbench. Table 3 summarizes the status of the first production line.

Table 3. Status of coil assembly line production.

WORKBENCH	OPERATION STATUS
1	Responsible for winding. Check whether the rotor parts are fully installed, put the rotor into the machine (four rotors at a time), automatically wind and mark the number, and check the appearance of parts.
2	Responsible for spot welding of commutators. Place coils in the machine for spot welding, check the appearance of parts, take photographs for every 1000 pieces produced.
3	Responsible for commutator cutting. Put parts into the machine for cutting and check the cutting status of parts.
4	Responsible for air pressure rectification and air pressure removal. Clean the parts with a brush, check the foreign matter residue with a magnifying glass, put the parts into the air pressure cleaner for cleaning, and check the appearance of parts.
5	Responsible for washer group voltage resistance, absolute resistance, and impedance tests. Put the washer into the machine for punching, and then into the test machine for voltage resistance, absolute resistance, impedance tests.
6	Responsible for bearing assembly and bearing distance inspection. Put the bearings and coils into the machine for stamping, and then place the parts into the inspection machine to check the bearing distance.

There is one coil assembly production line in the “SM” Motor Plant in Vietnam. The production line has six workbenches. Each workbench has 1–2 working procedures, and only one person is responsible for each workbench.

The motor assembly line in the “SM” motor plant in Vietnam only has one production line. The production line has seven workbenches, each of which has 1–3 operating procedures and handled by one person. The status of the motor assembly line is summarized in Table 4.

3.2. Process Analysis of Smart Manufacturing Line

1. Smart manufacturing status of production lines at the “SM” Motor Plant in Vietnam.

Sensors have been installed in the machines of the production line of the “SM” Motor Plant in Vietnam. Apart from detecting machine failure, the sensors are mainly used to detect the operator’s negligence. When an operation error occurs, a warning is given, and the machine is automatically stopped to avoid operator injury and product damage. Sensors are installed to record the number of operations in the coil, commutator cutting, and spot welding. They can be used to push back the total production volume (e.g., finished products and defective products) so that the person in charge of the production line can record and check the output. In the motor performance test, the data after passing the test are supposed to be retained; however, these are not retained because of limited storage space, and those that have already been stored are not used.

Table 4. Status of motor assembly line production.

WORKBENCH	OPERATION STATUS
1	Responsible for dispensing and coil assembly. Align the iron frame with the coil and place it in the dispenser. Then, place the parts in the machine, use the auxiliary tools on the machine to snap the iron frame into the coil, and check whether the installation is complete.
2	Responsible for the assembly and appearance inspection of the brush assembly. Put the parts into the machine and assemble with the finished product of the previous workbench, then move the parts in front of the CCTV, and the personnel will check its appearance through CCTV.
3	Responsible for the assembly and inspection of the washer. Put the washer on the machine to join, move the parts to another machine to take pictures, and check whether the washer is missing according to the inspection.
4	Responsible for motor assembly press-fitting and clearance inspection. Put the parts into the machine and press the motor. Finally, check if there are eight gaps in the parts. Then, put the parts into the testing machine to check the gap.
5	Responsible for motor performance inspection and lightning engraving. Put the parts into the testing machine to check the motor performance. The machine automatically engraves the parts that passed the inspection and stores the test data.
6	Responsible for the final visual inspection. Use tools to check whether the screw pattern is sufficient. Check whether the laser marking (seal) is sufficient. Check the direction of motor rotation and appearance of the terminal.
7	Responsible for packaging and shipping.

The production line frontliners are responsible for implementing withstand voltage test and insulation size inspection procedures. Some production lines have introduced a special model, which has an arm that can automatically put parts into the machine for testing. The workflow is a semi-automated state as personnel operate the machine. The Solen company have already introduced automatic arms in other production lines. The main plan is to automatically take the rotor to the intermediate process after rotor assembly. This can save time and allow the allocation of manpower to where it is more necessary. The company will keep the production line in a semi-automated state in the short term. At most, a small number of intelligent systems will be introduced because of cost considerations. If future orders increase or there are other influencing external factors, then there will be opportunities to plan for more work processes, such as adding more functions (e.g., robotic arms) and intelligent systems.

2. What intelligent systems can be imported into the production line?

This study recommends three possible intelligent systems.

The first is an image recognition system. There are many processes in the production line that check the appearance of parts. If the image recognition system can be used to automatically check the parts, the manpower responsible for visual inspection can be reduced. At this time, however, it is not feasible to acquire an image recognition system because of the lack of background data. According to certain existing conditions and negotiations with equipment manufacturers, the company's practical experts can first install the CCTV for each part that should be identified. The images can then be stored as background information for future image recognition.

The second is the use of a robot arm. In the same production line, the arm is still used to pick up parts and operate the machine. Only the conveyor belt is employed to transfer the parts to the next workbench, and the finished product is transported through different production lines; all these

processes are performed by humans. If robot arms are introduced, then a more efficient production can be achieved.

The third recommendation is the use of a big data analysis system. In the production line, there are numerous operational processes that should be tested; however, not all test data are retained. If most of the available data are retained for analysis, these can be employed to facilitate identifying problems and fix errors as soon as they occur.

4. Discussion

Based on secondary data (SOP and working time chart), it is found that the manpower currently used in the production line has been reduced from 50 to 25. According to the analysis of secondary data and expert interviews, the statistical table of the working time of the production line. Expert experience indicates the total working time of the original design, which was 600 seconds, and the total working time after the introduction of the intelligent system was 306.1 seconds. This also proves the efficiency of the current production line. In the future, related intelligent systems, such as big data and image recognition systems, will be introduced. It is expected that the production line manpower will be reduced to 4–5 persons; it will then become a demonstration production line of Industry 4.0 and resolve the manpower shortage in various countries.

1. Implementation of intelligent systems

The introduction of systems, such as big data and image recognition, can make the production line intelligent as well as link data that are originally independent in each machine. Such a connection can achieve the machine-to-machine effect and reduce manpower. This study achieved the effectiveness of the intelligent system through the improvement of the process of the coil and motor assembly line. Based on the list in Table 3, there are currently six workbenches in the coil assembly line, and each workbench is assigned to a person to operate the machine. With the introduction of a robotic arm and an image recognition system, the number of personnel will be reduced from six to two. One personnel will be responsible for setting the winding, commutator spot welding, and cutting machines, and the other will be responsible for the second half of the pressure cleaning of parts and testing machine operation. Both workers are responsible for checking the machine at any time and immediately report any problematic situation.

Based on the list in Table 4, there are currently seven workbenches in the motor assembly line. Each workbench is assigned to a worker to operate the machine. A total of seven workers are in this production line. If robot arms, image recognition systems, and big data systems are introduced, the number of workers may be reduced to three. One person is responsible for the assembly and inspection of coils, brushes, and washers; the other is responsible for the assembly, press-fitting, and performance testing of the motor, and final visual inspection. The first two workers should check the machine at any time. If a problem is detected in the machine, this should be reported immediately. The third personnel will be responsible for packaging and shipping the finished product. In the future, it should be evaluated whether the introduction of automatic packaging machines will be useful to the entire production line.

2. Changes in process management

After the introduction of the intelligent system, the process in each production line will inevitably change and follow a systematic process. The following describes the expected changes in the processes of the coil and motor assembly lines after the introduction of the intelligent system. It is mainly divided into three parts.

(1) Robot arm

The main purposes of introducing a robot arm is to change the original process where humans get the parts and put them into the machine. Moreover, with the robot arm, the number of machine

operators will be reduced. The following will explain the function of the two production lines after the robot arm is introduced and replaces manpower. The process sequence is as follows. Put the rotor in the winding machine, the coil in the spot welder, the commutator in the cutting machine, the bolt gauge tool on the cut commutator, and the washer in the test machine, bearing, and coil. Put the stamping machines and bearings into the gap inspection machines. In Figure 5, the processing sequence of the part is as follows. Put the coil into the machine, the brush into the machine for assembly, the brush into the machine to assemble the washer, the motor into the machine for stamping, the motor into the gap machine, and the motor into the performance inspection machine.

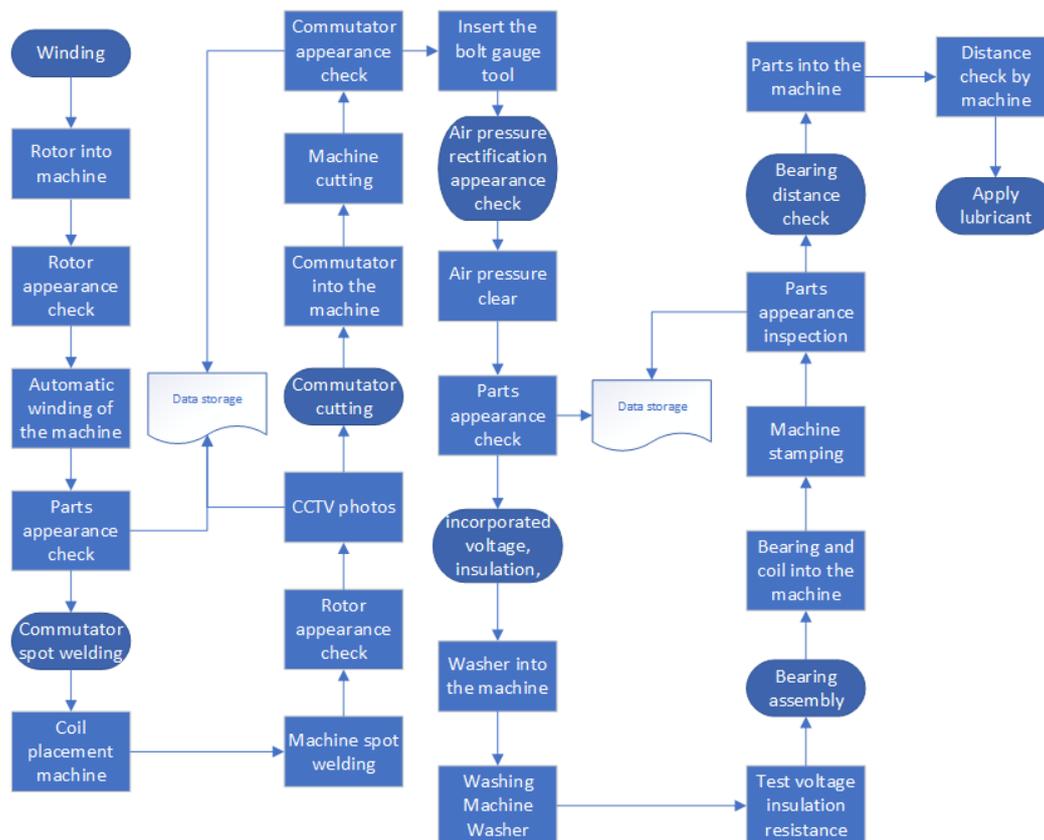


Figure 5. Coil assembly intelligent line.

At present, to replace manpower, robotic arms may be introduced only to the robotic assembly line. Taking parts from the coil assembly line to the motor assembly line is labor-intensive. Future research may start on investigating the delivery of parts among the production lines.

(2) Image recognition

The main purpose of introducing image recognition is to replace the original process where humans visually inspect parts, thereby increasing efficiency while maintaining product quality. After image recognition is introduced to the two production lines, the intelligent system will automatically perform visual inspection. The process sequence of visual inspection is as follows: the appearance of the rotor before and after winding, the appearance of the commutator spot welding, the appearance of the commutator cutting, the appearance of the cleanliness of the commutator pressure, and the appearance of the rear assembly of the bearing. In Figure 6, according to the sequence, the fitting conditions of the washer and iron frame are checked, the appearance of brushes is inspected, the appearance of rear parts assembled by the washer is checked, the eight gaps of the parts are visually inspected, and the final appearance is checked. Image recognition allows the machine to accurately identify people and

things in an image faster and more efficiently than humans. It also further improves the product quality and manufacturing efficiency of the industry.



Figure 6. Motor assembly intelligent line.

(3) Big data analysis

The image recognition system includes big data analysis. In addition to the identification of parts based on the original images provided, it can also perform image data analysis. It can automatically capture, analyze, classify, and understand useful information from a single image or a series of images. The images provide information to achieve better productivity and quality.

The motor assembly line is shown in Figure 6. In the motor performance inspection process, the inspection machine is provided by a partner manufacturer. A total of 88 motor performance data points are tested, and the information on a product that passed the inspection is retained. According to the opinions of the three practical experts interviewed, these data are only stored and not used for any purpose. In the future, these 88 data points can be studied and analyzed. Models can also be created to improve the production line (e.g., increasing production capacity or identifying process problems and optimizations).

5. Conclusions

In this study, it is demonstrated that the implementation of intelligent systems (i.e., robotic arms, image recognition, and big data analysis) can aid the coil and motor assembly lines; it also has a practical reference value. Firstly, the introduction of a big data analysis system is reported. In the motor performance testing part of the motor assembly line, big data analysis is introduced to aid the motor production line by collecting 88 motor data points generated by the machine. The motor coil assembly production line and image recognition system included in the motor assembly line introduce big data analysis, and the system then makes judgments based on the pre-set images. Subsequently, the system classifies and analyzes the acquired images to allow the image recognition system to make more accurate and quick judgments or even identify the defects that may cause motor problems. According to the research argument of Mayr et al. [10], the Industry 4.0 technology can significantly optimize motor production, particularly with the use of big data analysis. It has considerable potential and can be used in a wide range of motor production. The conclusion (i.e., the introduction of big data analysis into the motor production line) is found to be consistent. Secondly, Mayr et al. [10] only reported that the introduction of an intelligent system impacts the motor production, but the changes in the production process were not discussed. This study therefore proposes a change in the intelligent system for the production process. Moreover, a robotic arm and an image recognition system are introduced. As a result, manpower is reduced, and the operation process is optimized.

Finally, Mayr et al. [10] theoretically confirmed that the Industry 4.0 technology can optimize motor production but did not discuss practicality. This means that the introduction of the technology may cause practical impossibility. Through interviews conducted with practical experts, this research evaluates the theoretical results obtained by literature analysis as well as the possibility of implementation based on the inputs of practical experts. Among the many Industry 4.0 technologies, the robotic arm, image recognition, and big data analysis are obtained. These three techniques can be practically used in the company's production line.

As a result of this research, the "SM" production line can be introduced with a robotic arm and image recognition system to make the current production line more intelligent. Research question 1 has been answered. The research question 2 is also answered through the research method. The coil assembly line can be turned into an automated production line when using an intelligent system.

Limitations of Study

This study only investigates and proves the feasibility of the introduction of intelligent systems to the coil and motor assembly lines of the Solen company. The three intelligent systems that can be used in the steps of the motor production line are proposed; some parts, however, have not yet been explored. Firstly, 88 big data points are not analyzed. In the future, the correlation between the values and 88 motor test data points will be determined. This should correspond to the operating process of the motor production line so that it can be used to build a model to facilitate the company's continuous optimization, monitoring, and management of the production line. Secondly, the study results do not indicate whether the intelligent systems can be used in other motor production lines or whether the production line of the manufacturing industry can achieve other effects (e.g., manpower reduction and production process optimization). These can be included in a future research to supplement the contents of this study.

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Appendix A

Table A1. English Abbreviations.

Acronym	Definition
ANN	Artificial Neural Network
	Closed Circuit Television
CCTV	Photographic equipment on the production line and equipment for capturing images to improve quality, etc
CNC	Computer Numerical Control
CPS	Cyber Physical System
IoT	Internet of Things
	OPC is the interoperability standard for the secure and reliable exchange of data in the industrial automation space and in other industries. It is platform independent and ensures the seamless flow of information among devices from multiple vendors. The OPC Foundation is responsible for the development and maintenance of this standard.
OPC	Source: https://opcfoundation.org/
OPC UA	OPC Unified Architecture
SM	Solen Company Vietnam Motor Production Line

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