Jidoka: An Autonomation In Lean Manufacturing

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Abstract

Machines are the symbols of advanced civilization and industry and evolve with industrial development and become complicated to handle multiple problems. This paper majorly discusses the lean manufacturing concept "Jidoka," and its performances in Industry 4.0 will be mentioned. Jidoka was introduced as autonomation to prevent the occurrence of abnormalities and defective products, and it developed various methods in four generations. Autonomation is not automation, and the main difference is human intelligence. One of the achievements of Industry 4.0 is to construct a Cyber-Physical System in industries, however, adopting the latest generation of Jidoka, Jidoka 4.0, is difficult because limited research studies are not supporting its applications in the industries due to the limited studying. Confusions, unpopularity, and standardization are the barriers in the current industry for Jidoka 4.0. Therefore, it is necessary to establish a information-sharing criteria to clarify and standardize the development of industry so that Jidoka can be adapted easily. Researchers should study other aspects of Jidoka and extend its functions, and those will finally support Jidoka's improvement in the industries.

Introduction

Modern industrial history started from the first industrial revelation in the 1700s [1]. In the first industrial revolution, assembly lines and productions appeared, and low-skilled laborers can operate single-purpose machines for mass production [2]. It was the first time that powered machines appeared in manufacturing history, and products were being unified and massively produced. When industries were developing, machines were becoming more complicating and gradually replacing human labor in manufacturing. During the third revolution, computers and software were the main productivity power in manufacturing, and computer-equipped machines were able to manufacture autocratically with preset programming [3]. At this stage, Toyota Prodcution System was gradually known in the European and American industry.

The Toyota Producing System is under the name of a just-in-time system that was implemented soon after World War Two in Japan, its most important concept was to increase production efficiency by consistently eliminating wastes [4], as a result, the cost of wastes was reduced. Wastes such as overproduction in mass manufacturing were considered undesirable [5]. Jidoka and Just-In-Time manufacturing are the most foundational and significant concepts to achieve good quality and customer satisfaction in Toyota Producing System [6,7]. Just-In-time means to produce necessary units in specific quantities at the essential time [8]. Jidoka means "autonomation," or automation with human intelligence [9]. Both concepts are the pillars in Toyota Production System that had made Toyota's car production effective and competitive in the global market.

Industry 4.0 is a period of developing information and communication technologies between humans, machines, and virtual intelligence based on real-time, intelligent, horizontal, and vertical networking [10]. In this networking, machines should include interoperability that allows machines to connect and work in a coordinated and self-sufficient system [11]. The core concept of Industry 4.0 is a revolution of operation in Internet and artificial intelligence and optimize current manufacturing with intelligent products, for example, Cyber-Physical System, Internet of Things, and Artificial Neural Network.

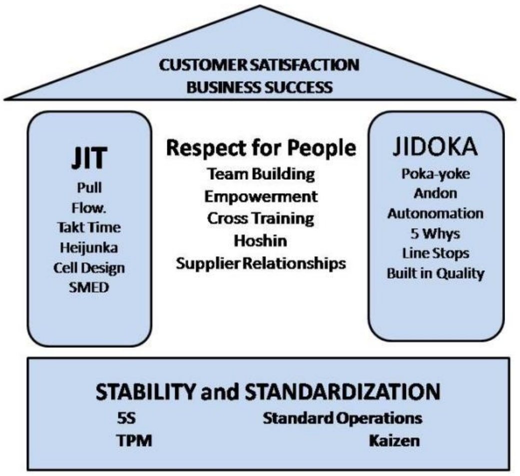

Figure 1. Toyota Producing System [21]

Motivations

In the 21st century, machines are becoming more complicating, and they are equipped with more functions while they coordinate with computers in the digital age. It will make manufacturing more effective and gradually release humans from hands-on production to management on the digital end. Latest technologies enable machines to learn and detect abnormalities accurately with Internet of Things (IoT) and other intelligent methods. Alaloul [13] said the fourth industrial revolution is coming into view that is directed by Cyber-Physical System to amalgamate the physical world with the information era for future industrial improvement. In the digital age, Toyota Production System is essential to evolve with the novel virtual technologies and make manufacturing systems "smart." Therefore, how to interact Jidoka and Just-In-Time with other virtual intelligent tools such as Internet of Things (IoT) and Cyber-Physical System (CPS) will be the core problem to be analyzed during this latest industrial revolution.

Goal of this study

This paper will provide a comprehensive understanding of Jidoka with its history and developing path. The applications of Jidoka from academic researches and recent industries will be introduced and analyzed to reflect the current development. Some applications in academic papers will present the latest concept and impact of Jidoka in Industry 4.0. Barriers related to the current industry will be determined and analyzed so that the limits of Jidoka are revealed. Finally, base on the barriers, feasible solutions will be suggested to industries to overcome the barriers.

Background

Jidoka is a Japanese term referred to as "autonomation". Romero [13] defines it as "a type of automation that enables machines to work harmoniously with their human operators and features intelligent capabilities by automatically stopping a process, by man or machine, in the event of an abnormally, a problem, such as equipment malfunction, quality issues, or late work." It is one of the two fundamental concepts in the Toyota Production System; the other is Just-In-time manufacturing (Toyota). Jidoka targets to create small, independently running control cycles that monitor the manufacturing process to detect and avoid defects at resources and products [10]. This tool is important to industries because it is reacted while a machine is overproducing, irresponsible, and damaged, especially when the operator is not standby the machine. However, Jidoka is more than a simple set of tools for preventing and notifying failures [14]. It prevents machines produce defective products and eliminate wastes, which is advantageous to maintain good manufacturing quality. Since Jidoka makes machines reliable, a single operator can manage numerous machines, and maximize productivity.

Jidoka System Evolution

Jidoka was created in 1896 by the founder of the Toyota group, Sakichi Toyoda (Toyota). It originally applied on self-powered looms and automatically stopped the loom when a thread breakage happened, and its purpose was to stop producing defective products. Since the looms were only behaving correctly, a single operator can manage multiple looms, leading to a gigantic advance in productivity. Jidoka evolves with prevalent technologies and is applied in many various machines. As a result, various related tools and concepts are created. For example, Andon light is a popular tool used in Jidoka, which is an automatic alarm system that reports an error in the process (Szmelter, 2012). Besides, tools like 5 whys, line stops, and built-in quality impact the advance of manufacturing history.

Romero [13] has concluded Jidoka system has experienced four generations. The first generation was Jidoka 1.0 and was characterized by mechanical gadgets and known as "Poka-Yoke." It was capable to detect an undesired state in a manufacturing process and stop producing products. The second generation was Jidoka 2.0. Andon visual control was added to the system so machines can notify the operator if an abnormality is detected. The third generation was Jidoka 3.0. It upgraded with hardware and software features to assist operators to find out abnormalities during fault diagnosis. The Jidoka rules include digital sensors, signal processing, and error lists which were the primary database to support machines to recognize abnormalities. The latest generation is called Jidoka 4.0. The system is characterized by diverse hardware components and software such as sensor and controllers, these allow the system to early-detect problems and correct before they occur. In this generation, the interaction between machines, humans, the Internet, and other intelligent things is the key area to be studied.

Jidoka is not automation!

According to Merriam-Webster [20], the definition of automation is "Automatically controlled operation of an apparatus, process, or system by mechanical or electronic that take the place of human labor." The difference between Jidoka and automation is the human factor. The purpose of automation is to replace human labor with machines that have a preset system and programming to implement orders. However, those machines may not include the function of failure detection and reporting, so that an abnormality or defection is simply ignored. Operators are needed to standby in case a defective product is manufactured or an incorrect manner is triggered. On the other hand, Jidoka includes human intelligence into autonomation so that machines report abnormality automatically, a minimum amount of operator is needed only if an abnormality present. Comparing with Automation, Jidoka makes machines more effective to manage, and fewer people to be assisted for overseeing [13].

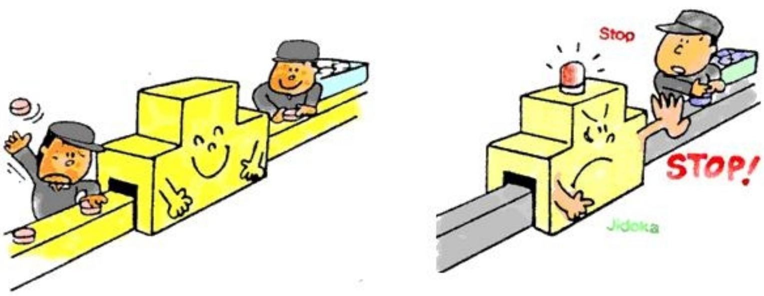

Figure 2. Automation vs. Autonomation

Jidoka in Industry 4.0

Current industries are experiencing the 4th industrial revolution, or Industry 4.0. It is a period of industrial development highly using interconnection, the Internet, artificial intelligence, and other sensitive software [2]. Industry 4.0 broadly describes the concept of a digital factory which to accomplish the all-automated manufacturing process and eventually integrate it into a supply chain [11]. In the digital factory, more flexibility and end-to-end process automation of manufacturing systems are demanded to achieve greater customization in mass production [15]. Modern industry requires Jidoka not only automatically detects problems in process and defections in quality, but also interconnects with other machines in a result, to systematically maintain quality and eliminate wastes [13]. In Industry 4.0, this Jidoka method is described as smart Jidoka, or Jidoka 4.0. it can early-diagnose an abnormality by sensitive hardware and software and correcting it before occurrence [14].

One of the goals for Industry 4.0 is to accomplish Cyber-Physical System, a networking system that integrates computational and physical capacities enables machines to interact with humans through many modalities [16]. A study believes that Jidoka utilizes Cyber-Physical System is considered a cost-efficient and effective approach for improving system flexibility [17]. Interconnected machines can quickly detect abnormality with sensors and cloud database services then report information to an operator and other machines. This system can increase the accurateness of abnormality detection with information technologies so that it eliminates wastes and provides convenience to operators for solving problems.

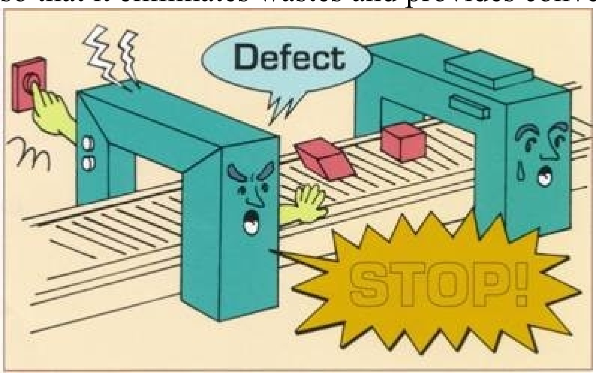

Figure 3. Jidoka and defects detection

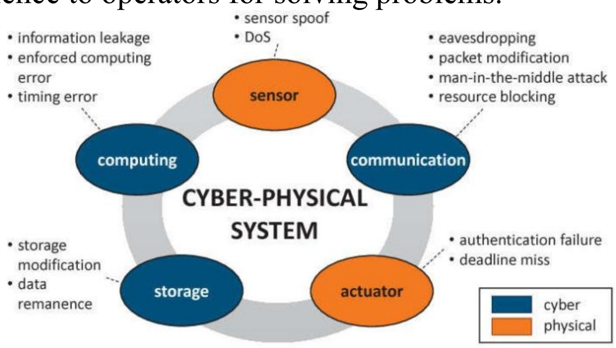

Figure 4. Cyber-Physical System in the Jidoka 4.0 [22]

Applications in industry and academic research

Jidoka has been analyzed in many types of academic research and mostly associates with software. Danovaro [18] developed software with two mechanisms from Jidoka: detection and interruption. He set a clear criteria for the Jidoka approach to decide whether the source code is satisfied with the download process. For the mechanism of detection, Danovaro collected data about resource consumption and process output. He used components to identify “activities” with a rule-based approach, which includes a Prolog syntax to identify the occurrence of activity within a specific period. For the interruption mechanism, the criteria decide whether to stop the software downloading, and a rule engine accesses the data storage and checks the measurements of user-specific rules. If the rules are violated, the notification component will be triggered and stop the software. In Ma’s study [17], a Cyber-Physical-System-based Jidoka was presented as a hybrid system including various components such as analog, digital parts, controllers, software, Jidoka rules, and so on. Cyber-Physical System associate with the Internet of Things, agents, semantics, and cloud to make Jidoka smart and flexible in industries. It is distributed in the network-embedded system that decouples centralized control and assists distributed control. However, Ma [17] found out that the significant components in Industry 4.0: standardization, modularization, and changeability of Jidoka, are temporarily not supported.

In the current industry, applications of Jidoka seem less developed than the ones in researcher studies. Toyota was the “Jidoka” concept inventor in 1924, and the company originally applied Jidoka in automatic looms with the revolutionary thread-breakage automatic stopping device. The loom can stop for identified problems and prevent producing defective products [6,7]. It was the origin of Jidoka. The looms inspired Toyota, and Jidoka developed with an aim for high-quality manufacturing. Inside the Toyota factory, visual control Andon was created with Jidoka. An operator can report abnormalities and display them on the color-coded Andon Kanban board. Different Andon lights represent the seriousness of the abnormality which decides whether to stop the production line. When Andon light is illuminated on the Kanban board, a specialist will diagnose the abnormal section, and turn off the Andon light after the abnormality is resolved. Some Toyota factories have operated robotic manufacturing lines for car production. With the technologies of Industry 4.0, robotic manufacturing enables self-detect, self-diagnose, and self-correct, which reduces the risk of error, line stopping and time-consuming for abnormality diagnosis and correction. Jidoka is also widely applied in many products like printers. Nowadays, printers are compact and equipped with many sensitive sensors and processors. General abnormalities such as paper jam, empty ink cartridge, and else are easily detected and reported to a monitor. Jidoka prevents printers from functioning when a damage or system error is determined. It protects printers from damage because the risk of mechanical damage and software error has raised since printers are more compact and complex than before. It is not only saving paper and ink but also protects printers from unexpected damages.

Figure 5. The first Jidoka device equipped loom [23]

Figure 6. Andon Kanban for abnormality communication [23]

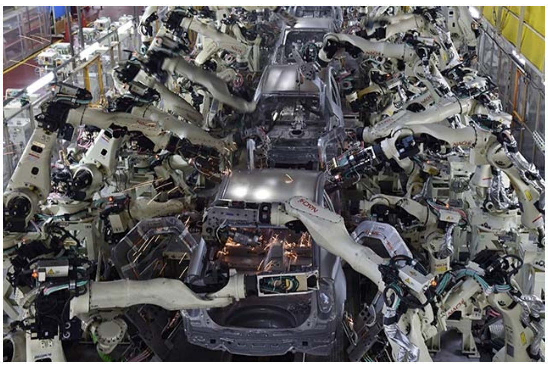

Figure 7. Robotic manufacturing at Toyota [24]

Figure 8. Printer [25]

Barriers and Limitations

Current researches and studies do not fully analyze and develop Jidoka in other aspects. Jidoka is a crucial tool to continuously improve quality in operation and learning system, however, its studies are merely limited to the single idea of "stopping the machine while abnormality has defected, and defections are avoided [13]." Looking at the application of Jidoka in the academic application, the authors highly emphasize the core function of Jidoka, but rarely mention the other functions and contributions to other aspects such as built-in quality and line stop. Jidoka also developed Andon visual control, which provided a basis for the alerting system of abnormality and made manufacturing effective. However, most researchers ignored those extensional applications because they did not see the potential value of developing, and that is why the research development for Jidoka is narrow and limited. Jidoka is not receiving equal attention. An indicator shows that Jidoka has about 30 thousand researching on the Internet, which is far less than a similar lean tool, Muda, a category of seven classic wastes and has 2 million searchings [18]. It reflects that Jidoka is unpopular in public, lacking prevalent industrial applications and comprehensions is the root of the problem. Only if plenty of Jidoka applications are proposed and mentioned to the public, the advantages of Jidoka will be well-known.

In Industry 4.0, Jidoka developed as Jidoka 4.0 under the support of the latest hardware and software, which is beneficial to detect and correct problems in an early stage before occurrence [13]. Jidoka 4.0 should be adapted into a Cyber-Physical System so that fewer operators are needed and productivity increases. A Cyber-Physical System is one of the core concepts of Industry 4.0, its links machines and the Internet so that information flows within the network and minimizes the risk of human error. However, a comprehensive study system has not been fully constructed to support innovative applications of Jidoka 4.0 in reality, which has impeded the progress of studying the Cyber-Physical system based on Jidoka [17]. Though Internet of Things (IoT) and other intelligent tools have been applied in industries, the limitations in standard, system establishment, line remodel, and so on are hindering Jidoka 4.0 to be applied in the industry. Besides, many companies are facing the question of how to upgrade their manufacturing with Jidoka 4.0 [19]. Industry 4.0 targets digitization and comprehensive automation. Upgrading the entire system from Industry 3.0 to industry 4.0 will be a long-term and expensive process. Besides, training workers will be an additional cost. The adoption of new type automation at the shopfloor has historically been expensive and complicated when it replaces skilled workers at the production lines [13]. Therefore, To broadly apply Jidoka 4.0 supported industrial applications, a system of Jidoka 4.0 studies should be completed in order to accelerate the industrial generation upgrade.

Opportunities for Future Research

Nowadays, detective sensitivity and accurateness have been improved in sensors to detect most potential abnormalities and defections. Although data of abnormalities and manufacturing experience are accumulated and abundant, the categories of production abnormalities are addressed incompletely in the current analysis [17]. In most cases, developers and machines don't recognize the uncertain factors and potential defections such as human errors, accidents, and material defections. They are the potential issues in the manufacturing process resulting in creating waste and harming machines and operators. In Industry 4.0, Jidoka machines have higher requirements for detecting and correcting multiple types of abnormalities in the manufacturing processes. It is a challenge for developers to consider all abnormalities, at the same time, it is a chance for machines to learn from experience and shareable data.

Therefore, a Cyber-Physical System should be the solution to collect information on abnormalities and optimize manufacturing. Machines enable to communicate with each other through the connection of the Internet, they can report and share data of abnormality within the connection and integrate with other information as a report in a database. The accumulated data of abnormalities enriches the study of production abnormalities and is advantageous to correct similar abnormalities before occurrence in the future. However, the limited development of Industry 4.0 has impeded the Cyber-Physical System based Jidoka to be applied. On the other hand, Jidoka 4.0 is partially applied in some discrete lines and cells, especially robotic manufacturing stations. Manufacturing lines are separated to minimize the stopping impact from Jidoka when machines are incorrectly processing. Because of the separation, lines can not share production information, so that the waiting time is generated as waste. This method is less effective and productive than integrated manufacturing lines. Cyber-Physical System is essential to unify all discrete lines and even supply chain as one body that implements the entire manufacturing.

Figure 9. Concept of Cyber-Physical System in Industry 4.0

Suggestions overcome barriers

The most significant barriers for Jidoka in the Industry 4.0 are limited study and various but disconnected industrial lines. Though current machines are able to connect to the Internet, information is not shareable between machines because of format and standard differences. Therefore, industries should establish machine communication criteria for Cyber-Physical Systems establishment to standardize information technologies and components such as sensors and controllers. In the criteria, standardized information can reach every corner of the facility so that all machines enable to adjust the progress if one machine stops for abnormality. Standardization of technologies and criteria will decide the level of digitization of the facility. The criteria standardize the communication of machines and interconnection Internet, so that information will be shared and accessed faster, previously systematical detection and problem resolving before occurrence become feasible. It also should be the guideline of constructing a Cyber-Physical System based on the current industrial level. Furthermore, these criteria should provide a direction of development to companies for updating their manufacturing process with the latest technologies, as a result, more applications of Jidoka in Industry 4.0 may appear and be operated, which finally enrich the study of Jidoka and evolve itself.

Researchers should diversely study Jidoka in this revolution. Instead of “abnormality detection and safely stop the machine,” academic researchers should focus Jidoka more on “autonomation with humans touch.” Jidoka has fruitful contributions in many areas, for example, quality control, machine-human-communication, and machine study, but they rarely appear in many academic studies. It is one of the reasons why Jidoka 4.0 is incompletely studied and applied in the current industry. In this digital and smart era, how to make Jidoka smarter as well as interact with humans in innovative ways will be a significant topic to study. Therefore, emphasizing machine-human interaction should the central goal in the analysis of "autonomation." Academic research papers should focus not only performances of Jidoka in other aspects, but also on the autonomation and machine-human interaction in order to extend the meaning and application of Jidoka.

Conclusions/Reflection

Through conducting the study, though Jidoka is crucial and beneficial to machines and industries, researchers believe that Jidoka is unpopular in research and industry results in impeding its evaluation in Industry 4.0. Jidoka's weaknesses, for example, the production line stops if one machine reports an abnormality, operators are required to be well-trained to resolve the problem, those are hindering its development in the industry. One suggestion is to standardize information technologies format system and components for Cyber-Physical System so that information communication between machines is feasible. In this case, Jidoka can integrate the entire system, detect and self-correct abnormalities before the occurrence, and avoid unnecessary system downtime. Besides Jidoka's applications in the manufacturing process, the impacts of Jidoka in other areas such as quality control, human force management, and maximizing human intelligence in autonomation are the research opportunities for researchers.

It is my first time knowing Jidoka, and I have found it interesting in this study. Jidoka has created or impacted other methods such as Andon light, 5 whys, line stops, and else, those methods are unimpressive in the current industry but significant to lean manufacturing and advance of industrial improvement. Jidoka is the autonomation of human intelligence, but the difference between Jidoka and machine automation is the human factor. Jidoka has been applied in daily products, such as printers and microwaves are well-known. There are barriers to Jidoka's improvement. Researchers should focus on Jidoka and its extensional principles on other industrial facets, and so that the impact of Jidoka can be spread and attracted by public attention. If Jidoka 4.0 is well-developed in Cyber-Physical System, Jidoka 5.0 should be characterized as a virtual system and intelligence to detect and correct abnormalities.

Industrial development has been accelerated by technological improvement, and methods of manufacturing are always changing. This paper has covered recent studies of Jidoka, but it is not representing the highest level of the industry. To understand the recent development, the latest applications of Jidoka are needed, especially its applications in Industry 4.0. Jidoka's study should not be limited to a single area, its impacts on other facets such as quality control, human source management, and applying human intelligence should be studied and analyzed so that its functions can be extended and attract more interest of researchers. Since industrial development is always changing, researchers should adopt Jidoka into other advanced concepts besides Cyber-Physical System. Jidoka not only improves industry but also inspires machine products. Therefore, engineers should jump out the frames and look for opportunities to apply Jidoka in appliances so that Jidoka 4.0 may extend its functions and evolve with the current characterizations.

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