

Article

Industrial Internet of Things Enabled Kata Methodology of Assembly Line Productivity Improvement: Insights from a Case Study

Pratap Sriram Sundar ¹, Chandan Chowdhury ² and Sagar Kamarthi ^{3,*}

¹ Operations Management (MIGM and PIILM), Indian School of Business, Mohali 140306, India; pratap_sundar@isb.edu

² Indian School of Business, Gachibowli, Hyderabad 500111, India; chandan_chowdhury@isb.edu

³ Department of Mechanical and Industrial Engineering, Northeastern University, 360 Huntington Avenue, Boston, MA 02115, USA

* Correspondence: s.kamarthi@northeastern.edu; Tel.: +1-617-373-3070

Abstract: Lean manufacturing focuses on perfection, trying to eliminate all types of *Muda* (waste), *Mura* (inconsistency), *Muri* (overburden), defects, injuries, and accidents through a continuous improvement process. Assembly lines are the final stages of manufacturing before the product is delivered to customers. Kata methodology provides a practical approach to achieving perfection in assembly lines, but its effectiveness is often hindered by delays in data collection, analysis, and diagnostics. In this study, we address these challenges by leveraging industrial internet of things (IIoT) solutions in an industrial setting. The research question of this paper is as follows: “Why was the full potential of traditional Kata to achieve assembly line perfection not realized, and will IIoT-integrated Kata address the limitations of the traditional Kata?” We demonstrate the integration of IIoT and Kata methodology in a factory assembling automobile heating, ventilation, and air conditioning (HVAC) systems to enhance assembly line productivity. We observe that the integration of IIoT with Kata methodology not only addresses existing limitations but drives substantial gains in assembly line performance. We validate improvements in both productivity and efficiency through quantitative and qualitative outcomes. We underscore the pivotal role of real-time data for Kata’s effectiveness, discuss the process for digital transformation, and explain the need for data monetization. We recommend the development of an IIoT-savvy workforce, traceability of 4M (men, method, materials, and machine), and present the task scorecards and dashboards for real-time monitoring and decision-making. We highlight the positive impact of IIoT-enabled traceability on overall equipment effectiveness (OEE). The company reduced its workforce from 15 to 13 operators, increased OEE from 75% to 85%, and improved average throughput from 60 to 90 assemblies per hour. The time for traceability of 4M (men, machines, material, and method) was reduced from hours to minutes. The factory eliminated 350 paper documents to achieve a paperless shop floor. This real-world case study serves as a model for companies looking to transition from traditional continuous improvement processes to IIoT-supported lean manufacturing.

Keywords: Toyota Kata; improvement Kata; assembly line; continuous improvement; IIoT; industry 4.0; digital transformation; data monetization



Citation: Sundar, P.S.; Chowdhury, C.; Kamarthi, S. Industrial Internet of Things Enabled Kata Methodology of Assembly Line Productivity Improvement: Insights from a Case Study. *Processes* **2024**, *12*, 2611. <https://doi.org/10.3390/pr12112611>

Academic Editor: Diane Mynors

Received: 29 September 2024

Revised: 5 November 2024

Accepted: 8 November 2024

Published: 20 November 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The term “Kata” has various meanings in Japanese, but in this context, we refer to it as a “model way”. Competitive companies like Toyota exemplify Kata through “The Toyota Way”, uniquely combining explicit and implicit knowledge acquired by Toyota workers over decades. Jeffrey Liker’s book, “The Toyota Way: 14 Management Principles from the World’s Greatest Manufacturer”, outlines the management principles behind Toyota’s global reputation for quality and reliability [1]. Implementing a Kata like “The Toyota Way”

requires companies to develop a Kata-savvy human resources plan and provide hands-on, on-the-job coaching to their workers [2].

Evolution and Application of Kata: In the past 15 years, the term Kata has been adopted in English to refer to any form, routine, or pattern of behavior practiced to various levels of mastery, particularly in manufacturing, assembly lines, and services. Mike Rother's book, "Toyota Kata", provides a detailed methodology for implementing *starter Kata*, *improvement Kata*, and *coaching Kata*, which are essential for establishing a continuous improvement culture within an organization [3]. This practice extends beyond manufacturing; for instance, software craftsmanship programmers use Kata to enhance their skills [4].

A defining feature of an organization's Kata culture is its relentless focus on thinking and practicing routines. Appendix A provides additional history and perspectives on Kata methodology.

Kata Methodology in Assembly and Fabrication Lines: Kata methodology is particularly effective in optimizing assembly and fabrication lines. The concept of the assembly line, which is closely associated with mass production, was first implemented in 1913 and has since become integral to many mass-production factories producing automobiles, home appliances, electronics, and other consumer goods. However, the term "assembly line" did not appear in the technical literature until 1923 [5]. Key elements of mass production include interchangeable parts, division of labor, and product standardization. Frederick Taylor's principles of scientific management, standard operating procedures (SOPs), and the conveyORIZED pull system also contributed to the efficiency of mass production.

Thousands of companies worldwide have adopted the lean system based on the Toyota production system (TPS) to eliminate waste (*Muda*) and design out overburden (*Muri*) and inconsistency (*Mura*) [6]. Lean manufacturing focuses on perfection, trying to eliminate all types of *Muda* (waste), *Mura* (inconsistency), *Muri* (overburden), defects, injuries, and accidents through a continuous improvement process. Assembly lines are the final stages of manufacturing before the product is delivered to customers. Kata methodology provides a practical approach to achieving perfection in assembly lines, but its effectiveness is often hindered by delays in data collection, analysis, and diagnostics. The research question of this paper is "Why was the full potential of traditional Kata to achieve assembly line perfection not realized, and will IIoT-integrated Kata address the limitations of the traditional Kata?". Kata methodology, emphasizing continuous improvement and problem-solving skills, offers numerous benefits for balancing assembly lines. However, a traditional Kata methodology is limited by the absence of real-time data and insights. Data collection using a stopwatch and clipboard is time-consuming, error-ridden, and tamper-prone; these factors hinder the achievement of perfection and efficiency afforded by Kata methodology.

IIoT-Supported Kata: To address these drawbacks, we propose integrating Kata methodology with the industrial internet of things (IIoT). Few research papers have studied the integration of Kata methodology with the IIoT on assembly lines. This paper addresses this gap in the literature. The IIoT involves a network of intelligent, highly connected industrial components that enable high production rates with reduced operational costs through real-time monitoring, efficient management, and control of industrial processes, assets, and operational time. By providing a robust data collection and analysis infrastructure, the IIoT allows factory supervisors to make informed decisions based on up-to-the-minute information [7]. Data collection is automated with sensors such as light diffusion sensors that capture the cycle times processed by software with built-in statistical tools, such as histograms, max-min values of cycle times, and graphical displays. The integration of IIoT brings many benefits:

- **Real-Time Data Collection and Analysis:** IIoT systems can collect data continuously and provide real-time insights, eliminating the delays associated with manual data collection methods.

- **Enhanced Decision-Making:** the IIoT reduces the risk of data manipulation and errors, ensuring accurate and reliable information-driven decisions to address root causes for inefficiencies and wastage.
- **Increased Efficiency:** automated data collection and analysis streamline operations, allowing for more efficient resource usage and better alignment with production goals.

Case Study: Implementation in Automobile HVAC System Factory: We implemented the IIoT–Kata integration in a factory assembling automobile heating, ventilation, and air conditioning (HVAC) systems. This advanced manufacturing factory, with a high-volume assembly line, supplies parts to an OEM (original equipment manufacturer). We selected this company because we have access to the implementation process as subject matter experts to work jointly with a commercial software company. The results showed significant improvements in both productivity and efficiency. We validated the results through quantitative and qualitative measures. This real-world case study demonstrates the tangible benefits of integrating the IIoT with Kata methodology. It serves as a model for companies transitioning from traditional continuous improvement processes to IIoT-supported lean manufacturing.

The first part of this paper presents the journey and challenges in integrating “improvement Kata” with the IIoT to improve assembly line productivity significantly. It discusses essential elements of implementing the IIoT for “improve Kata” methodology. These elements include design principles, real-time data collection, digital transformation, data monetization, workforce development, traceability of 4M (men, method, materials, and machine), overall equipment effectiveness (OEE), task scorecard, and dashboard. The second part of this paper presents the successful implementation in the automobile HVAC system factory, highlighting the potential of this approach to transform manufacturing processes and create a sustainable competitive advantage.

2. Drawbacks of Traditional Kata

The authors have implemented traditional Kata methodology in over 100 assembly lines across 20 or so companies to eliminate waste and enhance efficiency from a lean manufacturing perspective. These assembly line sizes ranged from 4 to 31 workstations. In this paper, “the authors” refers to the subject matter experts in Kata methodology and the IIoT, while “the team” denotes the managers, line supervisors, and operators in the factory under study.

Data Collection Challenges: Typically, the authors and teams spent several hours collecting data using manual methods, which included the following:

- **Props and Tools:** Using a clipboard, square-ruled notebook, pencil, eraser, stopwatch, and calculator to sketch the layout, workplace, material storage, bin arrangements, jigs and fixtures, hand motions, and body movements.
- **Data Collection:** Gathering data to calculate takt time (TT) and planned cycle time (PCT). Takt time is the ratio of available production time to customer demand, where available production time is the total time minus breaks, cleaning, maintenance, and shift changeovers.
- **Calculations:** Timing 40 or more cycles with a stopwatch to collect data, followed by statistical analysis of the data.
- **Graphing and Analysis:** Creating dot plot graphs for each workstation and analyzing extreme values.

Limitations of Traditional Kata Methodology: While traditional Kata methodology promotes continuous improvement and enhances problem-solving skills among supervisors and workers, its potential is significantly limited by the lack of real-time and reliable data and timely insights. The authors observed several issues as follows:

- **Overloaded Supervisors:** Line supervisors often have multiple responsibilities, including inventory management, paperwork, handling 4M changes (men, method, materials, machine), addressing traceability issues, maintaining equipment, managing

spare parts, training new operators, and maintaining discipline. This heavy workload makes it challenging for them to collect data consistently using manual methods.

- **Data Manipulation:** Instances of data manipulation and falsification in manual entries are not uncommon. For example, if the standard output was 60 assemblies per hour but actual production was 55 or 58 units, supervisors often recorded 60 units in the logbooks, hoping to make up for the shortfall in subsequent shifts. This falsification extended to production, quality, maintenance, and downtime data recording.
- **Lack of Real-Time Visibility:** Top managers are often unaware of the actual conditions on the production lines due to infrequent Gemba walks (direct observation on the shop floor) or review logbooks. This lack of real-time visibility hampered effective decision-making.

We used a systematic approach to investigate the potential of integrating the IIoT with operation technology (OT). We identified key performance delays caused by traditional data collection and analysis. Using real-time data from industrial internet of things (IIoT) sensors, we aimed to expedite information flow, minimize time lost waiting for data, and enhance responsiveness to issues on the production floor. This study included physical simulations and pilot testing to compare performance metrics between traditional Kata and IIoT-supported Kata. While the IIoT-supported Kata promised significant advantages in speed and accuracy of decision-making, it also introduced potential limitations, such as dependency on a stable Internet infrastructure and high initial investment. Nevertheless, we argue that the advantages, particularly the potential for real-time data, timely data analytics, significant cost savings, and productivity gains, outweigh the initial limitations and justify the need for upgraded real-time data-driven Kata practices.

These observations led the authors to explore the usefulness of IIoT solutions to drastically reduce delays due to data collection and analysis, as well as problem-solving delays. The authors developed a graph (see Figure 1) to illustrate business loss due to data collection and analysis issues and convince the management to invest in upgrading traditional Kata to IIoT-supported Kata.

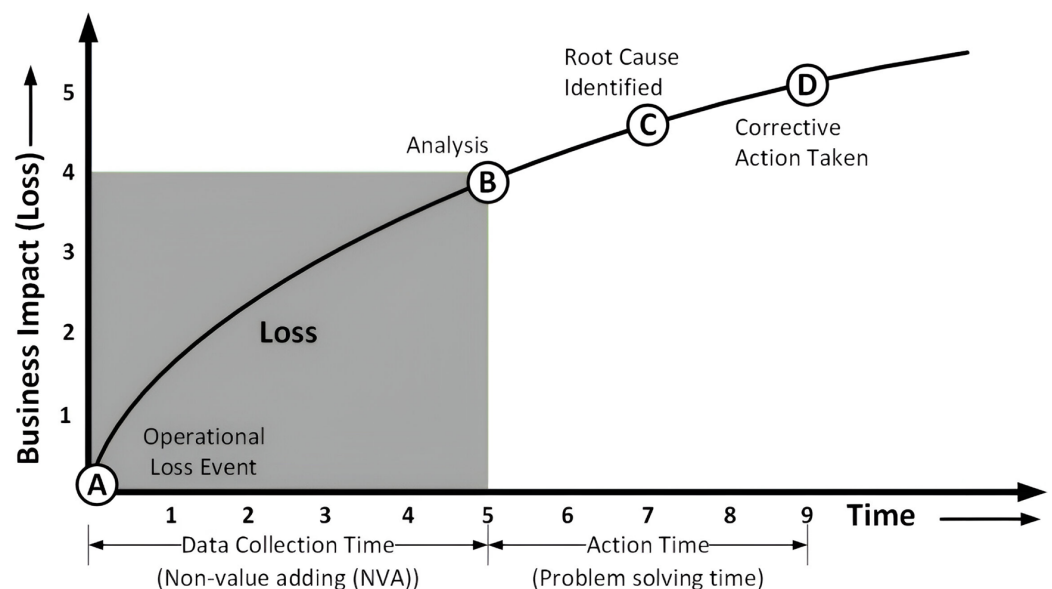


Figure 1. Business loss due to delay in data collection and analysis.

3. Integration of IIoT with Kata

The sensors trigger the start and end of cycle times, from which the software, written in Python, calculates the cycle times and pace of production, and displays real-time information on a 50-inch LED TV placed at the end of the assembly line, which aids the line supervisor to address any issues quickly. The information is transparent for everybody

to see. To address the limitations of traditional Kata methodology, the authors explored integrating IIoT solutions to reduce delays in data collection, analysis, and problem-solving. IIoT technology offers several advantages:

- **Real-Time Data Collection:** Automated data collection through IIoT devices eliminates the need for manual data entry, reducing the risk of errors and manipulation.
- **Enhanced Analytics:** Real-time data analytics provide immediate insights, allowing for quicker identification and resolution of issues.
- **Improved Decision-Making:** IIoT-supported dashboards and scorecards enable real-time monitoring and more informed decision-making.

The term IoT means that the Internet connects smart devices with computational capabilities to support data sharing in formats that can be used for further analysis in factories, warehouses, and industrial processes. The primary difference between the IoT (internet of things) and the IIoT (industrial internet of things) lies in their application domains. The IoT encompasses a broad range of everyday devices and applications, such as smart home appliances, wearable fitness trackers, and connected cars, to enhance convenience and lifestyle. By contrast, the IIoT focuses on industrial and manufacturing environments. Gilchrist [8] explored the potential of the IIoT, big data, cyber-physical systems (CPS), and smart factory technologies to replace mechanical, people-based systems of offshore locations. Appendix B presents additional exposure to IIoT technology.

The IIoT system collects, processes data, and delivers it in a suitable format in real-time. A problem such as increased cycle time can reduce line output. To visualize the point, consider an assembly line with an output of 80 units per hour and a takt time of 45 s; a 10% decrease in output can cut down profit by about \$600 per hour. This translates into a loss of \$360,000 per month (8 hours a shift, 3 shifts a day, 25 days a month) on one assembly line. To leverage value from data, delays in data collection should be eliminated or minimized, as shown in Figure 2, which can be used to convince the company executives why IIoT–Kata integration is needed. Early detection allows timely correction, thereby improving the line’s productivity and the company’s net profit. Furthermore, artificial intelligence (AI) combined with the IIoT can improve processes and capture value through enterprise cognitive computing (ECC), which emphasizes business domain proficiency—a deep understanding of existing processes’ tasks, workflows, and logic—and establishes the essential link between data science and business value [9].

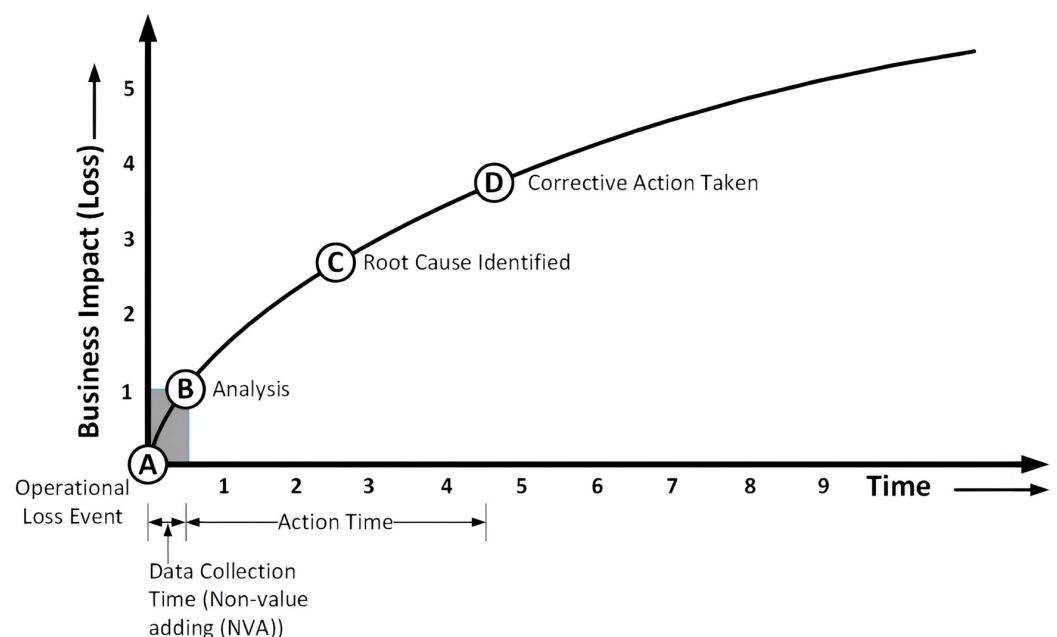


Figure 2. Business loss minimization with the IIoT.

3.1. Real-Time Data Collection

In the rapidly evolving landscape of Industry 4.0, the literature identified four fundamental design principles to guide companies in implementing effective scenarios [10]. These principles also apply to implementing the IIoT technology, facilitating seamless integration and operational efficiency.

Interconnection: Interconnection is the cornerstone of Industry 4.0 and the IIoT. Leveraging wireless communication technologies, the IIoT connects machinery, sensors, and other devices to the individuals responsible for monitoring and managing processes. This interconnectivity allows operators to gather extensive data from every point within the factory. Recent advancements in 5G technology and edge computing have further bolstered interconnection capabilities, enabling faster data transfer and more reliable connectivity. Such comprehensive data collection enhances functionality and helps identify critical areas ripe for innovation and improvement.

Information transparency: Information transparency in the IIoT is critical for providing operators with abundant valuable information necessary for informed decision-making. The transparency facilitated by the IIoT systems ensures that data collected from interconnected devices is readily accessible and interpretable. This wealth of information helps operators understand the intricacies of their manufacturing processes, identify inefficiencies, and implement timely interventions. Emerging technologies like digital twins and advanced analytics platforms have enhanced information transparency, offering real-time insights and predictive maintenance capabilities.

Decentralized decisions: Decentralized decision-making directly benefits interconnection and information transparency. With access to local and global data, operators at various workstations can make informed decisions that enhance overall productivity. Decentralization empowers operators to respond swiftly to changing conditions on the production floor, reducing downtime and increasing efficiency. Integrating machine learning (ML) algorithms and AI in IIoT systems has refined decentralized decision-making, enabling predictive analytics and autonomous decision-making processes.

Technical assistance: Technical assistance through the IIoT transforms workforce roles from basic machine operators to proactive problem solvers and decision-makers. IIoT solutions are designed to provide real-time information and support, focusing on scalability and plug-and-play architecture. AI-driven companion systems offer technical assistance by monitoring processes, predicting potential issues, and suggesting corrective actions. This shift enhances productivity and fosters a more engaging and fulfilling work environment. The development of human-machine interfaces (HMIs) and augmented reality (AR) applications has enriched technical assistance and provided intuitive and interactive support to operators.

The integration of these four design principles—interconnection, information transparency, decentralized decisions, and technical assistance—forms the foundation of successful Industry 4.0 and the implementation of the IIoT. As technologies advance, these principles will remain vital in driving innovation, improving efficiency, and transforming the manufacturing landscape.

Data values vary significantly at different levels and functions within a management pyramid. As shown in Figure 3, at the top of the pyramid where strategic decisions are made, data hold immense value as they provide critical insights into market trends, competitor analysis, and long-term planning. Executives rely on data to formulate corporate strategies and set overarching goals. Moving down to the middle management level, data become essential for tactical decision-making. Managers use data to optimize processes, allocate resources, and ensure day-to-day operations align with the broader strategy of the business. At the base of the pyramid, where front-line employees operate, data are tools for efficiency and effectiveness. Line supervisors and operators utilize data and alerts displayed on the dashboard (LED TV) to improve their workflows, solve immediate problems, and enhance customer experiences. In essence, the value of data cascades

through the management pyramid, transforming from a strategic asset at the top to a practical tool at the bottom, driving the organization's overall success.

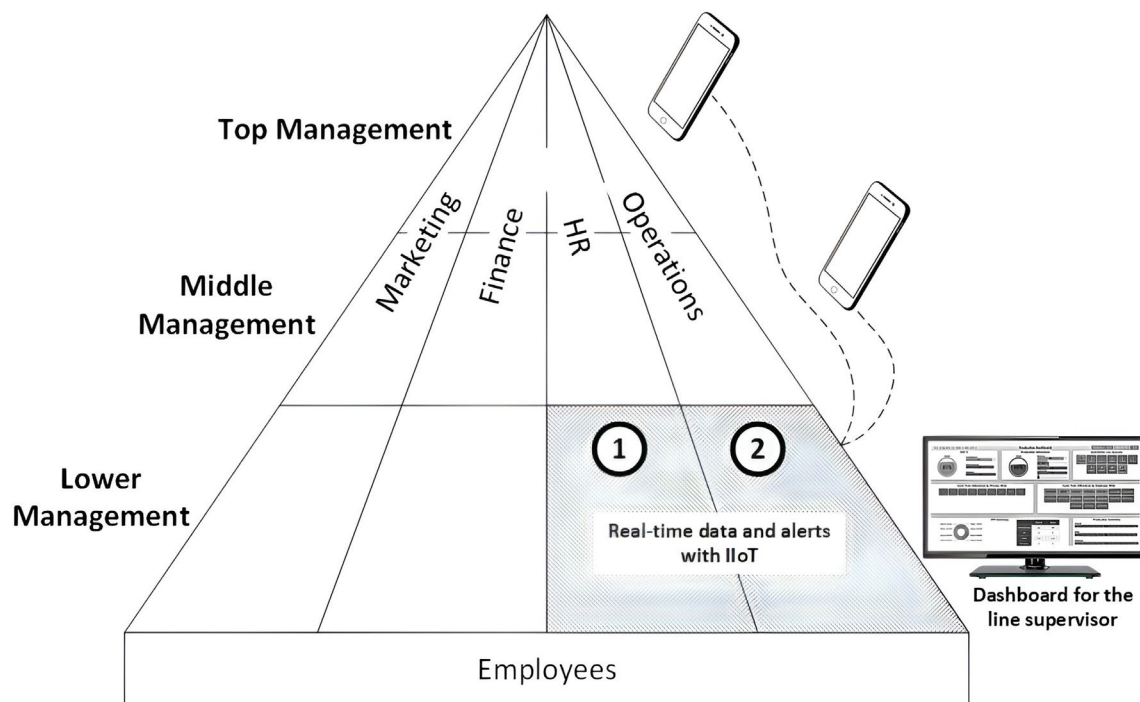


Figure 3. Value of real-time data for lower-level supervisors and managers.

In the current work, the authors focus on the value of real-time data to the front-line supervisors in operations and human resources functions; see hatched areas 1 and 2 in Figure 3, where 1 represents HR functions, and 2 represents operations. The middle and top managers, who can see real-time dashboards and receive alerts on their smartphones or tablets from anywhere, anytime, can detect and address disturbances in real time.

3.2. Digital Transformation

Industries globally have embraced digital transformation to catch up with Industry 4.0 environments. We have summarized key aspects of Industry 4.0 in Appendix C.

Digital transformations in IIoT implementation can be very challenging and expensive. McGrath and Ryan [11] advocated adopting an incremental experimental approach in a five-step process. This discovery-driven digital transformation approach builds digital competencies gradually while benefiting from the employees' knowledge and insight. However, the digital transformation team must consider redesigning the operations so that technology adds value.

A company can prepare a list of use cases based on two dimensions: potential financial impact and ease of implementation of digital transformation. A company embarking on a digital transformation can utilize a 2×2 matrix developed by Behrendt et al. [12]. This matrix, depicted in Figure 4, has the following quadrants: (1) Strategically important use cases that will have high impact, but will be harder to implement; (2) Quick payoff use cases that will have high impact and, at the same time, will be relatively easy to implement; use cases with quick payoff earn cash to fund additional ones; (3) 2nd-tier use cases that have low impact, but are easier to implement; and (4) Wait-and-see use cases that have low impact and are, at the same time, harder to implement.

- Type-1 (Strategically important): (1) Advanced robotics: Integrating advanced robotics in manufacturing processes can increase efficiency, but this involves high initial investment and the need for specialized expertise; (2) Blockchain for supply chain transparency: Utilizing blockchain technology for supply chain transparency can

enhance traceability, but its implementation in a complex automotive parts supply chain requires significant coordination among multiple stakeholders.

- Type-2 (2nd-tier use cases): Employee training and collaboration tools: Implementing digital platforms for training and collaboration, such as virtual reality-based training or cloud-based collaboration tools, can improve employee skills and teamwork. These tools are relatively easy to deploy and can enhance workforce efficiency.
- Type-3 (Wait-and-see): Supply chain control tower: Implementing a supply chain control tower (digital twin) to optimize supply chain processes with advanced analytics and AI algorithms can significantly enhance efficiency. However, integrating these technologies into existing systems and ensuring data security might pose challenges.
- Type-4 (Quick payoff): (a) Assembly line automation with IIoT; (b) IIoT for inventory management in raw material stores, finished goods stores, and warehouse management; and (c) Logistics including tracking trucks, travel times, delivery times, and fuel consumption monitoring.

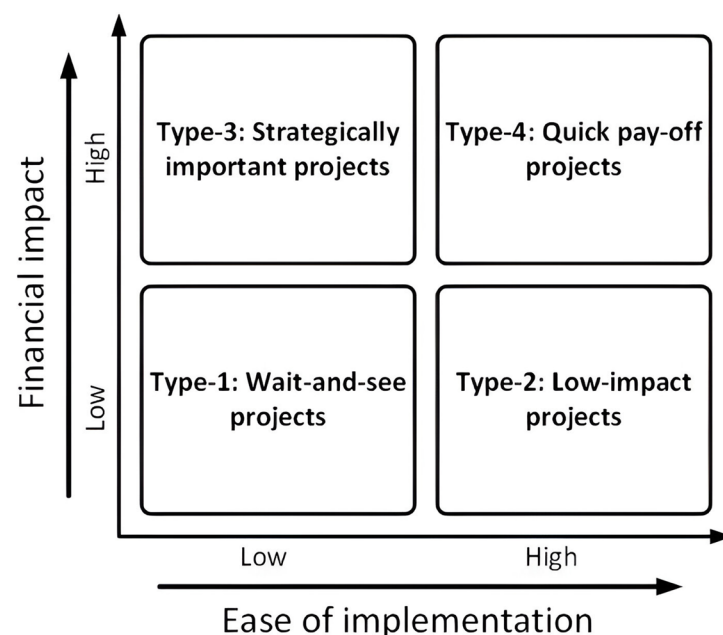


Figure 4. Four types of use cases (adopted from Behrendt et al. [12]).

Wixom et al. [13] presented a similar 2×2 matrix with four quadrants called the “value-effort matrix”, billed as *easy wins*, *maybes*, *duds*, and *future possibilities*. Some examples of use cases for the automotive supplier are listed below.

After identifying use cases, the next step in the IIoT implantation process is integrating operations technology (OT) and information technology (IT), which have distinct but interdependent roles. The authors observed, over five years of professional experience in about 20 companies, that many companies are poor at specifying what they want regarding OT. Unless this is specified, the IT team cannot move the projects forward to the implementation stage. As shown in Figure 5, OT deals with the “what” and IT deals with the “how” aspects of the IIoT. OT manages the physical processes and control systems that ensure efficient assembly lines. They must answer the question, “What do they want from an IIoT solution?” On the other hand, IT deals with selecting hardware items, such as sensors, scanners, IIoT gateway, servers, routers, LED TVs, etc. IT also must develop software for data collection, analysis, communication, display, and cybersecurity. IT experts must answer the question, “How will they provide what OT people want?” Return on investment (ROI) must be estimated. A clear project plan is required to integrate OT and IT seamlessly using an IIoT solution. By leveraging this integration, manufacturers can enhance quality control, optimize production schedules, and reduce downtime, ultimately improving the overall performance of their assembly lines. Alerts and analytics can provide

insights into process efficiency, identifying potential issues, and solving problems. For example, Chow et al. [14] presented a case study of integrating web-based and RFID technology in visualizing logistics operations.

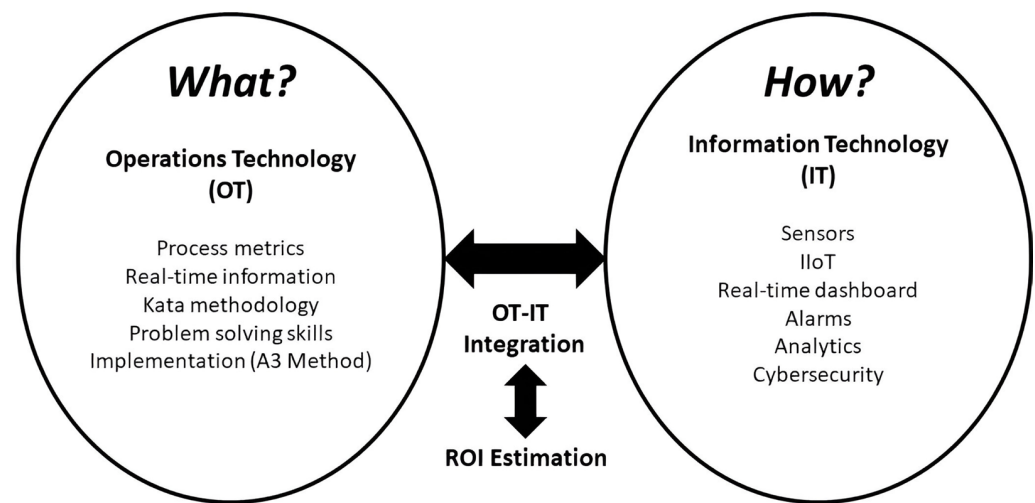


Figure 5. OT–IT integration elements.

In the case of an IIoT solution for assembly lines, OT experts must define process metrics and the necessary real-time information. They must also be trained in Kata methodology, time and motion study, statistical process control, design of experiments, ergonomics, problem-solving skills, and implementation of solutions using the A3 methodology [15], a common practice in continuous improvement. This should be completed about six months before the actual implementation of the IIoT project begins. IT experts select hardware such as sensors and IoT gateways. They develop the code to maintain the real-time dashboard, send alarms when abnormalities occur, facilitate analytics, and maintain cybersecurity. Figure 5 shows the OT–IT integration elements. Operations experts such as the Chief Operating Officer (COO) can use this diagram, which the authors developed over many years of our experience, to specify the OT–IT integration challenge. The IIoT–Kata methodology presented in this paper can be used by any company to improve the productivity and quality of its assembly lines. Appendix D briefly presents ongoing efforts for digital transformation certification.

3.3. Data Monetization

In Industry 4.0 and the IIoT, data monetization emerges as a crucial strategy for justifying investments and achieving tangible financial benefits. Organizations often hesitate to embark on Industry 4.0 projects without a clear understanding of the return on investment (ROI), particularly those with narrow profit margins. Consequently, ROI becomes a pivotal factor in selecting and approving IIoT projects.

All Industry 4.0 and IIoT projects demand significant investment, making data monetization important in ROI estimation. This phase involves calculating the monetary value of sensorization, real-time data acquisition, and analytics. Even an approximate ROI estimation can significantly influence the approval and implementation of IIoT projects by demonstrating potential financial returns.

Multi-tiered Strategy of Data Monetization: Data monetization functions as a multi-tiered strategy that spans various levels of an organization’s management pyramid, each contributing uniquely to the overall financial gain. At the strategic level, i.e., the strategic decision-making stage, executives leverage data assets to generate new revenue streams. They explore innovative business models, products, and services that can offer value to customers or partners. Data monetization at this level involves creating and selling data-driven products, licensing data to third parties, or developing new data-centric services. Middle management, interested in process optimization and value extraction, emphasizes

optimizing existing processes and extracting value from operational data. By analyzing data, middle management can streamline operations, reduce waste, and improve service delivery, contributing to better financial performance and customer satisfaction. At the base level, front-line employees are interested in data collection and operational improvement. Their efforts directly impact product quality and customer service. This grassroots contribution is essential for the overall data monetization strategy.

The Data Value–Creation Process: According to Wixom et al. [13], organizations can utilize a data value-creation process or the data–insight–action process to derive substantial benefits. There are three key steps in this process: data collection and aggregation for gathering data from various sources, including sensors, customer interactions, and operational systems; data analysis and insight generation for utilizing advanced analytics and machine learning to uncover patterns, trends, and actionable insights from the collected data; action and implementation for applying insights to make informed decisions, optimize processes, and innovate products or services.

Value Realization by Turning Data into Money: Creating value from data is necessary but insufficient. The final and most critical step is value realization—ensuring that the value created translates into financial gains. This involves converting data-driven improvements and innovations into monetary benefits that enhance the organization’s bottom line. Without this step, data monetization remains incomplete, and operations risk becoming costlier without corresponding financial returns.

Data monetization is integral to successfully implementing Industry 4.0 and IIoT projects. By meticulously estimating ROI and leveraging data at every management level, organizations can unlock the full potential of their data assets. This multi-tiered approach ensures that data-driven insights are effectively translated into financial value, driving revenue growth and creating competitive advantages. As technological advancements continue, the ability to monetize data will remain a key differentiator for organizations seeking sustainable success in the digital age.

3.4. Workforce Development

Any company embarking on IIoT implementation must train its workforce to understand, operate, and leverage the IIoT technology. Each workstation must be attached with a biometric device. These devices capture the employee’s name and code and retrieve the employee’s skill level, which is stored in the database. The human resources (HR) department should measure the skill levels using the “ILUO” levels and the guidelines shown in Table 1.

The percentage points of skill level allocated to Identified, Learning, Understand, Others (ILUO) are 25%, 50%, 75%, and 100%. The ILUO skill chart is used to train the operators. Liker and Meier [16] presented an example of a multifunction worker training timetable. The training scheme has a “3-3-3” skill development guideline. This means every operator must master at least three operations (manage operations at three workstations), every workstation must have at least three operators who can operate them, and each line (consisting of many workstations) must have at least three operators to manage the whole line. The operators are to be trained not only in the technical tasks of a workstation but also in work-study tools [17], standardized work, time/attendance, total productive maintenance (TPM), statistical process control (SPC), design of experiments (DOE) [18], scrap processing, and A3 methodologies [19]. In addition, they play key roles in safety task forces, quality circles, cost committees, *Kaizen* teams (*Kaizen* is a Japanese term that refers to a process involving all employees to affect the continuous improvement of productivity and efficiency), and suggestion systems. This approach helps companies to develop competent and able group leaders. At the end of four or five years, the team leader is already developed and trained to perform most of the tasks that would step into the role of the group leader when they get promoted [20].

Table 1. Skill levels of operators.

Skill-Level Symbol	Percentage Skill-Level	Skill Tasks	Description
I	25%	Operation and cleaning	“I” indicates that the person has undergone training for the skill and can perform the task with some supervision.
L	50%	Operation, cleaning, and lubrication	“L” indicates that the person can perform at the basic level and needs some help occasionally.
U	75%	Operation, cleaning, lubrication, and machine setting	“U” indicates that this person can execute this task solo within the standard time.
O	100%	Operation, cleaning, lubrication, machine setting, and minor maintenance (the maintenance department will be called for major maintenance).	“O” indicates that this person is an expert at this task and can train others.

3.5. Traceability of 4M (Men, Machines, Material, and Method)

Traceability is a system’s ability to trace the presence, absence, movement, and change of elements and components in the system. In manufacturing and assembly, it is interpreted as the ability to verify an item’s history, location, or application and changes in 4M (men, machines, material, and method) through documented recorded identification. The ability can chronologically interrelate uniquely identifiable entities in a verifiable way. An IIoT solution provides complete traceability of all its products through all phases of our production process. When a customer complaint is received, the IIoT solution provides a quick traceability of the following.

- All relevant raw materials and child parts.
- Which supplier made or sold the raw material and child parts that went into a specific product?
- Process parameters tagged to the product at the time and date of production.
- Manpower allocated (which operator, supervisor, and skill levels).
- Which shift, date, and time was a specific unit made?
- Was any machine maintenance performed on that day or a day before?
- Was there any quality problem experienced on that day?
- Who packed the product?
- When was it shipped?

Changes are constant in an assembly line. Operators leave and are replaced by new employees. Machines change due to the implementation of new tools, jigs, and fixtures. Materials used in the assembly process might change. Methods change by the *Kaizen*. The authors suggest that factories must capture changes in 4M for traceability purposes. Any change in 4M may improve the process or lead to problems in productivity and quality. If there is a problem with quality or productivity, the 4M change information is useful in the root cause analysis. Approved by an appropriate authority, 4M changes are recorded using an IoT device such as a tablet. Some examples of changes in 4M are given below.

- Man (Example: Change of operators such as a new operator, a trainee, and contract manpower)
- Machine (Example: New machine, new tool, new die, spare part change, and process parameter changes)
- Method (Example: Changes in process sequence, working conditions, packaging method, and inspection change)
- Material (Example: Supplier of raw material change, child-parts change, and specification changes).
- Method (Example: Changes in process parameters or workstation layout)

3.6. Overall Equipment Effectiveness (OEE)

Implementation of the IIoT plays a significant role in overall equipment effectiveness (OEE), which measures how well the asset is used compared to its full potential. The measurement of OEE is also commonly used as a key performance indicator (KPI) in conjunction with lean manufacturing efforts. Combining OEE with focused continuous improvement converts OEE from a lagging to a leading indicator. The first focused improvement stage of OEE improvement is to achieve a stable OEE. Once an asset's effectiveness is stable and not impacted by variability in equipment wear rates and working methods, the second stage of OEE improvement (optimization) can be carried out to remove chronic losses. Combining OEE and TPM (total productive maintenance) improvement tactics creates a leading indicator that can be used to guide performance management priorities. As the TPM process delivers these gains through small cross-functional improvement teams, the process of OEE improvement raises the front-line team engagement/problem ownership, collaboration, and skill levels. This combination of OEE as a KPI (key performance indicator) locks in the gains and delivers the TPM goal of year-on-year improvement in OEE [21].

Before the IIoT solution can be implemented, OEE measures are calculated manually. First, the data is recorded in paper-based forms and then typed into Excel. After manually analyzing the data in Excel, the information (such as tables and graphs of OEE) is incorporated into PowerPoint presentations for management meetings (weekly, monthly, quarterly, etc.). After the IIoT solution was implemented, the data is captured in real time. This automatic data collection eliminates the opportunities for data manipulation, which clandestinely happens in the manual system. All the gap codes are stored in the database in standard format. When there is downtime, the PLC triggers the machine number and time. The line supervisor immediately assigns a "gap code" from the pull-down menu. In one company, there are about 50 gap codes grouped into availability loss (raw material shortage, child-parts shortage, start-up loss, and power shortage), performance loss (low skill level of the operator and speed loss of the machine), and quality loss (rejection and rework). The accumulated data can generate automatic reports reflecting what happened on the shop floor. From these reports, problems can be identified and solved to increase OEE. Line supervisors and management time are saved due to the elimination of paper and Excel-based systems.

3.7. Zero Paper Shopfloor

One of the goals of the IIoT solution is to eliminate all paper-based systems on the shop floor. Standard operating procedures (SOPs) are converted into soft forms and displayed on LED screens. Similarly, maintenance check sheets, quality reports, changeover approvals, production reports, inventory reports, and abnormality reports are digitized. In the case study presented below, 350 paper-based documents are digitized. Abnormalities are the problems that are prioritized for solving and assigned to specific cross-functional teams (CFTs) to solve. This concept of a "zero paper" shopfloor reduces the cost of paper and the time spent filling, filing, and retrieving it. Some of the activities related to 5S (sort, set-in-order, shine, standardize, and sustain) related to filing and maintaining the physical forms in box files are eliminated. This also saves office space.

3.8. Task Scorecard

Besides managing line production, line supervisors have many tasks, such as quality, maintenance, discipline, and operator training. They have to set maintenance priorities, order spare parts, and order office supplies (such as a new water cooler). Conventionally, these are communicated through emails, phone calls, and SMS text messages) which consumes a lot of time. In the IIoT solution, these are communicated on the portal (avoiding phone calls, emails, and SMS messages) with set due dates. Therefore, this saves supervisors' time and reduces overheads. A task scorecard visible in the dashboard displays real-time information on the status of these tasks, which the middle managers and factory heads can check and act on in case of any delays.

3.9. Dashboard

In IIoT implementation, dashboards accomplish two key principles of lean: simplicity and visibility. Visual control methods aim to increase the efficiency and effectiveness of a process by making the steps in that process more visible. The theory behind visual control is that if something is visible in plain sight, it is easy to remember and keep at the forefront of the mind. Another aspect of visual control is that everyone is given the same visual cues, so it will likely have the same vantage point. Visual controls are designed to make the control and management of a company as simple as possible. This entails making problems, abnormalities, or deviations from standards visible to everyone. When these deviations are visible and apparent, corrective action can be taken to correct these problems immediately [22].

A dashboard is designed on important metrics for the line supervisor to help enhance productivity and reduce costs. A dashboard with real-time information allows quick recognition of the problems to avert value loss. The dashboard displays the operating or progress status in an easy-to-see format, provides instructions, and conveys information. A visual control system has an action component if the visually represented SOPs are not followed in the real production process or the actual production lags behind the targeted production plan. Immediate feedback is provided to workers to correct mistakes, solve problems with the help of line supervisors (coaching Kata), and speed up production to achieve the daily production plan. Display devices, such as TVs, tablets, and smartphones, are connected to the IIoT server and placed on the shop floor or in the hands of the line supervisor. The dashboard displays the following information in graphical form: production (units per hour; target vs. actual); OEE; quality parameters, rejection, and rework; skill-level adherence; cycle time adherence; 4M changes; star performers; critical process parameters; 5S score.

The dashboard helps in managing the shop floor. It helps supervisors to monitor and identify gap areas. A consolidated score (on a zero to five scale) is based on a set of supervisor's daily activities displayed. The dashboard is always accessible to all executives and managers at all levels on their smartphones. The product flow paths have built-in sensors to signal problems automatically. Therefore, corrective actions can be taken immediately. Sensors in the assembly line play a crucial role in achieving Jidoka (as defined by Toyota, it refers to automation with a human touch or intelligent automation) objectives. Jidoka makes problematic situations and deviations from the standard stand out as quickly as possible so that it is possible to look at the conditions of the problem. At the same time, they remain before the bad conditions evaporate quickly. This is achieved by having machines self-diagnose and signal when they are out of standard conditions and by people self-inspecting and calling when they doubt the quality of the work [23]. As problems are solved and work is better understood, solutions can be incorporated into the normal workflow, and the system progresses.

An early warning system is a part of IIoT solutions. If the assembly line is running slow due to various problems (low skill levels, quality issues, parts shortages, and unplanned breakdowns), the system can predict the future with built-in programs. For example, if the line is slow, the system can predict that the target output cannot be achieved in the specified shift time. The system can also predict the expected overtime to achieve the target output. The system can predict the machine's potential failure in the maintenance module if the vibration levels are abnormal. Data analytics can be performed based on the data accumulated over several months. For example, Ungermann et al. [24] presented an approach to how data analytics projects for process optimization should be carried out in manufacturing with an example of OEE of an ablative process for metallic parts. Windmann et al. [25] presented a model for process monitoring, data analysis, and fault detection in industrial and agricultural processes.

4. Case Study: Auto HVAC System Manufacturing Factory

In the current case study, the authors share their experience implementing traditional Kata methodology and IIoT-supported Kata methodology. The business in this study is a real tier-1 automotive factory that manufactures and assembles HVAC (heating, ventilation, and air conditioning) subsystems for an automobile OEM (original equipment manufacturer). The HVAC system produced in the factory cleans, cools, heats, regulates, ventilates, and dehumidifies the air entering an automobile's cabin. To implement IIoT at the automobile HVAC factory, the authors used the framework described in the first part of this paper.

4.1. Assembly Line Design

As shown in Figure 6, the HVAC assembly line in this study consists of eight main workstations (WS-2 to WS-8) and four feeder workstations (WS-1, WS-4-1, WS-5-1, and WS-6-1). The assembly line has an eight-meter-long part-picking station (WS-1) operated by two people. The operators pick the parts that go into the kits placed on trolleys, which constantly circulate along the loop shown by a dashed line in Figure 6. Three workstations (WS-4-1, WS-5-1, and WS-6-1) perform the sub-assembly operations and feed them to the workstations (WS-4, WS-5, and WS-6) in the main assembly line. After the firewall inspection station (WS-8), the finished product goes into the finished goods (FG) area to be packed and shipped to the customer according to a pull system between the customers and the FG area.

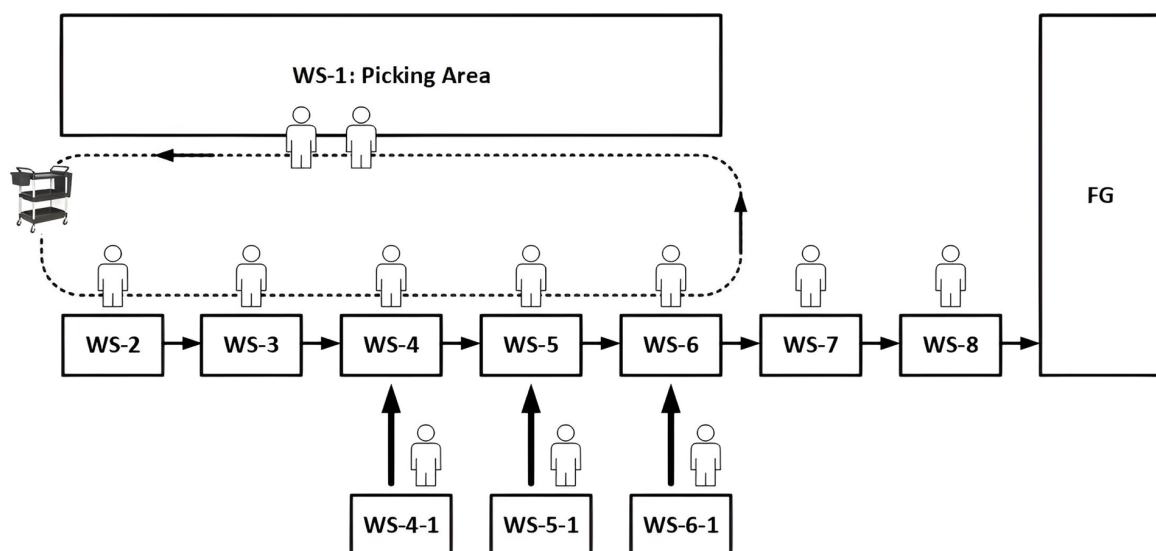


Figure 6. The factory explored in this case study is an HVACE assembly line with 11 workstations.

4.2. Application of Traditional Improvement Kata

Before we delve into the IIoT-supported Kata, we share our experience of improving Kata (without IIoT) for assembly line balancing. In the Kata implementation, the authors and the team performed the following steps:

- We used the following items to collect and analyze data at the workplace (Gemba): clipboard; square-ruled notebook to make sketches of the layout, workplace, material storages, bin arrangement, jigs and fixtures, hand motions, and body movements; graph papers or a laptop with Excel; stopwatch with 1/10th or 1/100th second accuracy; pencil and eraser; calculator.
- We collected data to calculate the takt time (TT) and planned cycle time (PCT).
- We calculated the TT and created a Kata graph. The authors set the PCT between 80% and 95% of the TT, depending on each workstation's natural variation in cycle times. If the variation is less, the PCT can be close to the TT; if the variation is high, the PCT is kept much lower than the TT. In calculating the PCT, planned downtime

and changeover time are included, and unplanned downtime and changeover time are excluded.

- We employed a stopwatch to clock 40 cycles or more to the collected data. We analyze the data using statistical measures. The central tendency of the cycle time data can be the mode (which is what the operator can achieve most times), or average. When a mode is not present in a dataset, the average of the data serves the purpose. In addition to mode or average, the variation (Range = Max–Min) is calculated. The operator–machine systems include machine elements and manual elements. Usually, machine elements are constant without variation. Manual elements may have some natural variation. In many situations, manual elements can be converted to machine elements using the framework presented by Daugherty and Wilson.
- We created a dot plot graph for each workstation and analyzed the extreme values.

This assembly line has eleven workstations with twelve operators doing the assembly, testing, and final inspection. The authors collected forty cycles of time study data at each workstation. The authors observed that the takt time is 54 s, and the planned cycle time (PCT) is 46 s, which is 85% of the takt time. The authors created dot plots to analyze the reasons for the extreme values and eliminated the root causes of these extreme values. The authors removed the extreme values from the dataset and created a Kata graph of the “current condition”, as shown in Figure 7. Gemba walks indicated that a consistent cycle time must be achieved by reducing variability. Since the assembly line must achieve the most frequently observed cycle time value, the authors considered mode as an appropriate representation of the cycle time centrality instead of the average.

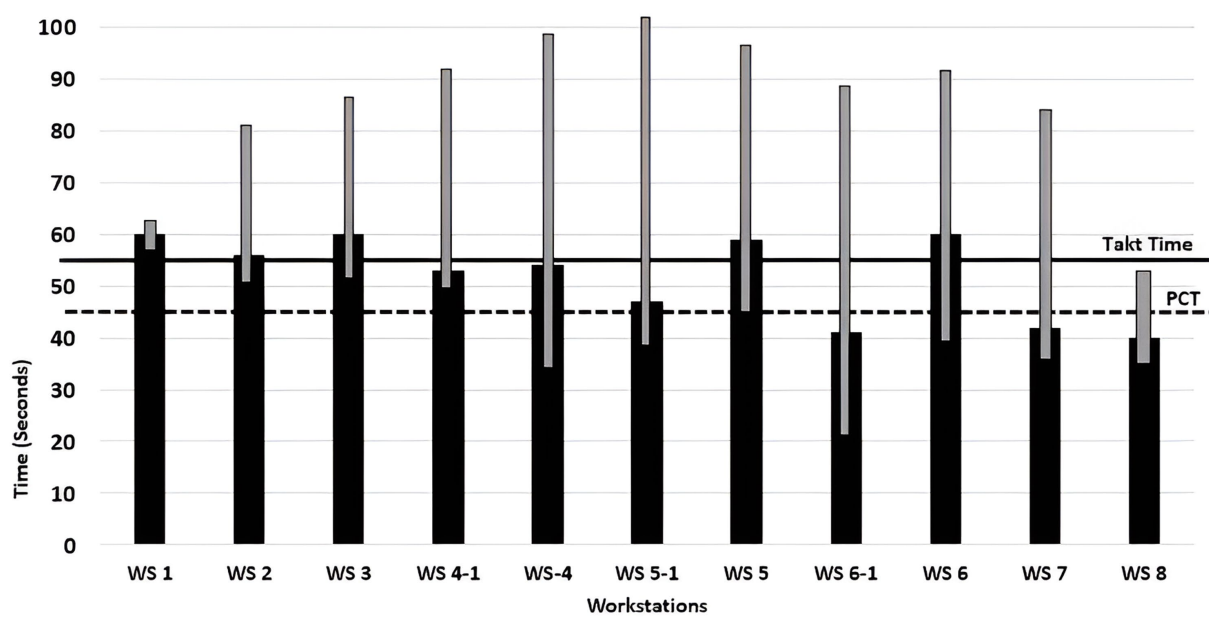


Figure 7. The cycle times performance of the HVAC line in the current condition.

A quick look at the Kata graph Figure 7 reveals that the workstations’ cycle times are inconsistent. The variation is due to the inherent physiological nature of manual elements, quality problems, and sometimes parts shortages. These variations affect meeting takt times and PCTs. In its current state, this assembly process cannot meet customer demand. In almost every shift, the target output is achieved through overtime operation. Under the authors’ guidance, the team created a target condition and identified and implemented fifteen *Kaizen* to achieve the target condition in about two weeks. The authors and the team used the standard methodology described by Masaki Imai [26]. After this goal was met, the team defined the next target condition per Kata methodology and the authors’ guidance. Table 2 presents the details of the sample *Kaizen* undertaken by the team.

Table 2. A sample of *Kaizen* implemented at the HVAC factory.

Kaizen #	Issue	Root Cause	Corrective Measure	Source of Data or Scientific Tool Used
1	Part picking delay.	Model change without advanced information.	Hourly plan display at the picking area.	Observation during Gemba.
2	WIP delay from the previous process.	The long separation between processes and no WIP visibility.	Layout change and implementation of visual management.	Flow process chart and flow diagram.
3	Fatigue at WS-1.	The operator turns three times to grasp and move the main case, motor, and slide door.	All three parts' feeding positions are realigned to fit the revised layout.	Micromotion analysis and workstation redesign.
4	Pick-up screw gun three times at WS-2.	Excessive motion	Reduce the number of screw gun pick-ups from 3 to 2.	Micromotion analysis and workstation redesign.
5	Pick-up screw gun three times at WS-3	Excessive motion	Reduce the number of screw gun pick-ups from 2 to 1.	Micromotion analysis and workstation redesign.
6	Two separate couplers are used for leak testing at WS-4	Excessive motion	Reduce the number of pick-ups from 3 to 1 by joining the two couplers with a connector.	Micromotion analysis and workstation redesign.
7	Fatigue at WS-4	Excessive motion in manually ticking the "commitment mark".	Automate with the press of a button.	Automation
8	Fatigue at WS-4	Excessive motion in reaching for and grasping the shutter-box subassembly.	Provide chute with rollers.	Principles of motion economy. Low-cost automation.
9	Repeated operation at WS-4	Re-check the tightness of the connector.	Avoid this repetition by fixing the problem at WS-3.	Assembly process improvement.
10	Extra time for part identification at WS-4	There is no identification on Motor models.	Different color bins are provided for different models.	Micromotion analysis and workstation redesign.
11	Fatigue at WS-7	Excessive motion	The slide door and sleeve are assembled by combining the operation of the pinion gear assembly with a rod.	Micromotion analysis and workstation redesign.
12	Fatigue at WS-7	Excessive motion. Parts are not provided on the left-hand side for assembling the pinion gear with a rod.	The side pinion gear is provided for assembly on both the left-hand and right-hand sides.	Micromotion analysis, Two-hands process chart, and workstation design.
13	Fatigue at WS-7	Reach, grasp, and move the rod every time from the bottom of the worktable.	Place a bin with rods close to the assembly fixture to micro-motions (move).	Micromotion analysis and workstation design.
14	Fatigue at WS-8	Excessive motion. Parts (motor and flange) are placed only on the right side.	The motor and Flange are kept on the left and right sides to reduce reach, grasp, and move times.	Micromotion analysis, Two-hands process chart, and workstation design.
15	Fatigue at WS-10	Excessive time to peel off the release paper.	Help the supplier to produce an improved PE (polyethylene) sheet.	Supplier development.

The team used the personal kanban system to visualize the *Kaizen* (improvement Kata) for effective implementation by limiting the work-in-progress (WIP). Here, the team adopted the personal kanban system described by Benson and DeMaria and the Kata-

improvement-inspired design method proposed by Kurdve et al. [27]. Under the guidance of the authors, the team implemented these *Kaizen* in basic work study (including method study and time study), safety, ergonomics, Kata methodology, and the principles of work embedded in Toyota's four rules—three rules of design, which show how Toyota sets up all its operations as experiments, and one rule of improvement, which describes how Toyota teaches the scientific method to operators at every level of the organization [28].

4.3. Integrating OT and IT for the HVAC Assembly Line

Kata methodology for managing an assembly line is related to OT and the various Industry 4.0 IT technologies. Figure 8 shows the architecture of the IIoT solution for the HVAC assembly line, which the authors developed in collaboration with the IT team. Python was used for IIoT data collection programming. Java and MySQL DB are used for server-side programming. Java, Chart Libraries, and MySQL DB are used for dashboard displays. The salient features of the assembly line with IIoT, which the authors finally implemented, are given below.

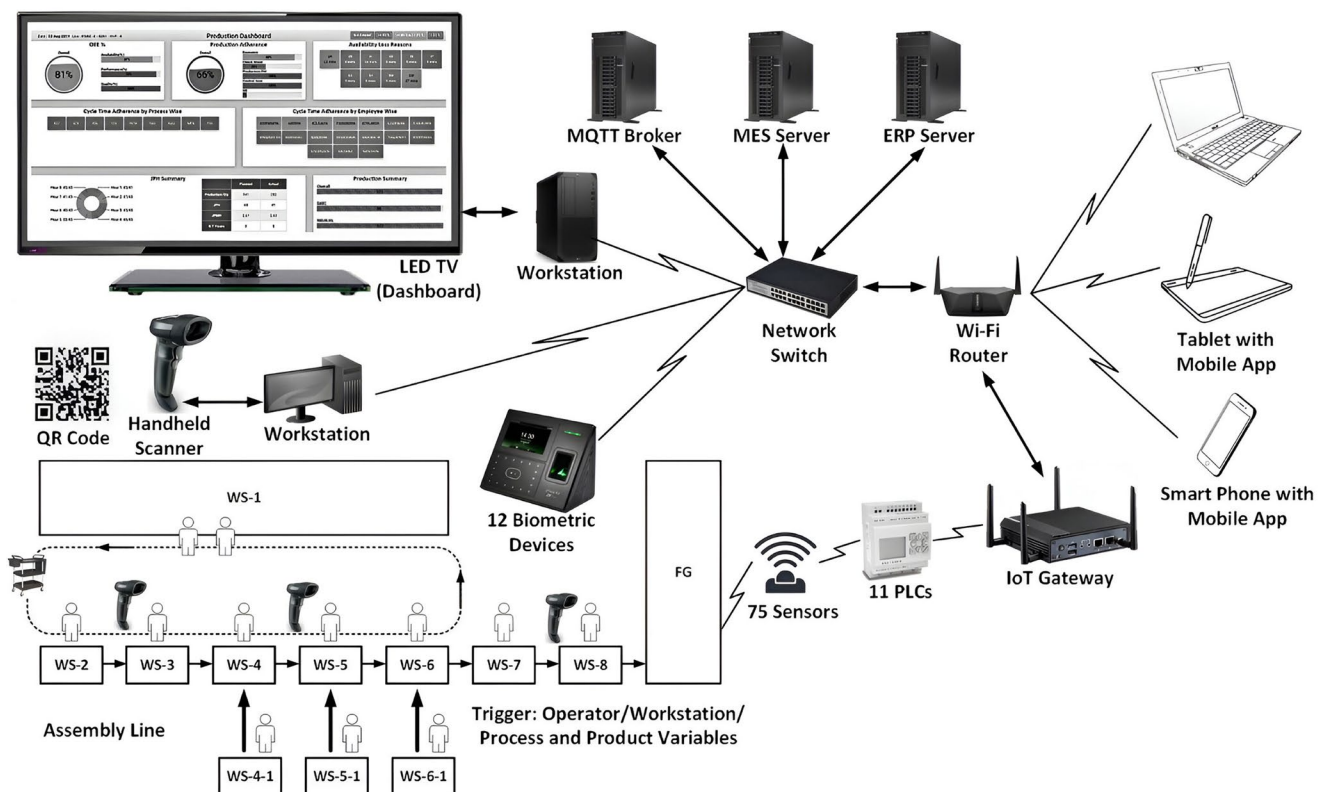


Figure 8. Architecture of the IIoT solution for the HVAC assembly line.

The HVAC assembly line has 75 sensors for measurements, such as pressure, vibration, acoustic, amperage, voltage, resistance, leak test, and photoelectric diffuse sensors for the position and alignment of the parts. It also has one bar code scanner, one QR code scanner, 12 biometric devices, and 11 PLCs. In this case study, additional sensors are attached as part of the IIoT implementation. The sensors act as data tags collecting and sending data on many state variables, such as which operator is at which workstation, which child part went into which assembly unit, production count, cycle times, and process parameters such as voltages, amperages, pressures, noise levels, and leak quantities. Preconfigured PLC signals determine cycle time in all equipment. An IIoT gateway captures a specific signal related to the “cycle start”. The cycle time trigger for the IIoT for the assembly line (see Figure 8) is presented in Table 3, which is the outcome of our efforts in defining the “begin and end” of cycle times automated by new sensors integrated with the IIoT.

Triggers come from the biometric device when an operator scans their finger or from the sensors (light diffusion sensors) in workstations. Triggers happen at the start and end of cycle times when a part is scanned and when process and product parameters detected by PLCs are abnormal, i.e., beyond their lower and upper control limits. For example, fan balancing (how many times the fan is balanced by adding small metal clips to its blades), leak testing value, airflow at different locations, voltage, activator current (which causes speed variation), vibration, and many parameters at the end-of-line (EOL) testing. Triggers record abnormalities that can help traceability issues when a product fails in the field. Using the time-stamp information, cycle time is calculated. Data from sensors are transmitted via PLC to the IIoT gateway (programs are written in Python), which is connected to the communication backbone of the MQTT (message queuing telemetry tracking) broker. The MQTT is a lightweight, publish–subscribe, machine-to-machine network protocol for message queuing service [29]. The MQTT is fast becoming the de facto protocol for IIoT message communication to the enterprise or the cloud. Portable scanners are also used in select workstations (where some parts are added to the product in the assembly process), such as WS-3, WS-5, and WS-8 (see Figure 8). The fan is added to WS-3, and the compressor is added to WS-5. End-of-line (EOL) testing happens at WS-8. The MQTT server, MES server, and ERP server are connected to the network switch, which transmits data to PCs, tablets, and display devices such as LED TVs. A few images of the HVAC assembly line with the IIoT are provided in Appendix E.

Table 3. Cycle time trigger for the IIoT.

Workstation Code	Workstation Name	Cycle Time Trigger
WS-1	Part Picking	Time elapsed between successive QR code scans of a critical part.
WS-2	Main Assembly Station	Time elapsed between successive cycle starts, when the main part is loaded into the fixture, or by operator trigger (Push button).
WS-3	Main Assembly Station	Same as above
WS-4	Main Assembly Station	Same as above
WS-4-1	Subassembly	Same as above
WS-5	Main Assembly Station	Same as above
WS-5-1	Subassembly	Same as above
WS-6	Main Assembly Station	Same as above
WS-6-1	Subassembly	Same as above
WS-7	End-of-the-Line Testing	Time elapsed between successive cycle starts, when the completed unit is loaded into the fixture.
WS-8	Firewall Inspection	Time elapsed between the successive push button activations by pressing it
FG	Finished Goods Storage	Not applicable (in this use case)

4.4. Analysis and Improvement

To keep it brief, we present the analysis and improvements of only WS-1 and WS-6 using IIoT solutions. These workstations are selected based on their criticality to the “flow” of the product through the assembly process.

WS-1: The line supervisor used the IIoT solution to generate a sample cycle time data dot plot. This was performed in real-time as the line is running. The line supervisor can set a sample collection frequency at one hour, half a shift, or one entire shift, as desired. The dot plot of WS-1’s cycle times is shown in Figure 9. WS-1 is a part picking line, which is operated entirely manually. As can be observed in the figure, only one data point is way off at 540 s among forty cycle time values. The team discovered it was due to a parts shortage and delay in material transport from the stores. This is an assignable cause, and the team has fixed it permanently. This extreme value was removed from the data set, and

the dot plot was re-created with the remaining values. This dot plot was superimposed over the Kata graph of the WS-1, as shown in Figure 10. The Kata graph was drawn with an average value of 100 s, a minimum value of 48 s, a maximum value of 201 s, and an output time of 70 s. The variation was 153 s, which was very high. In Figure 10, the black bar represents the average cycle time (i.e., 100 s), and the gray bar represents the minimum, maximum, and range of the cycle time data (i.e., the lower limit of 48 s, upper limit of 201 s, and spread of 153 s). Next, the supervisor arbitrarily divided the dot plot into three zones, as shown in Figure 10. About 15% of the time, the cycle time is well within the takt time in Zone A. The line supervisor focused on Zone B and Zone C values to find and eliminate the causes, reducing variation and bringing the average cycle time below 70 s. A target condition of 60 s was set as a goal, as shown in Figure 11. To achieve the target condition, common scientific tools were initiated, such as part-storage methods in the bins, micromotion analysis, Toyota Rule# 1 about “sequence” (parts will be picked up in the same sequence to fill the kits that will be kept on moving trolleys), and training for the operators to achieve higher skill levels. After all the improvements were made, the Kata graph of WS-1 looked like what is shown in Figure 11. For the improved condition, in this figure, the black bar represents the average cycle time (below PCT of 60 s), and the gray bar represents the minimum, maximum, and range of cycle time data (the upper limit below Takt time of 70 s).

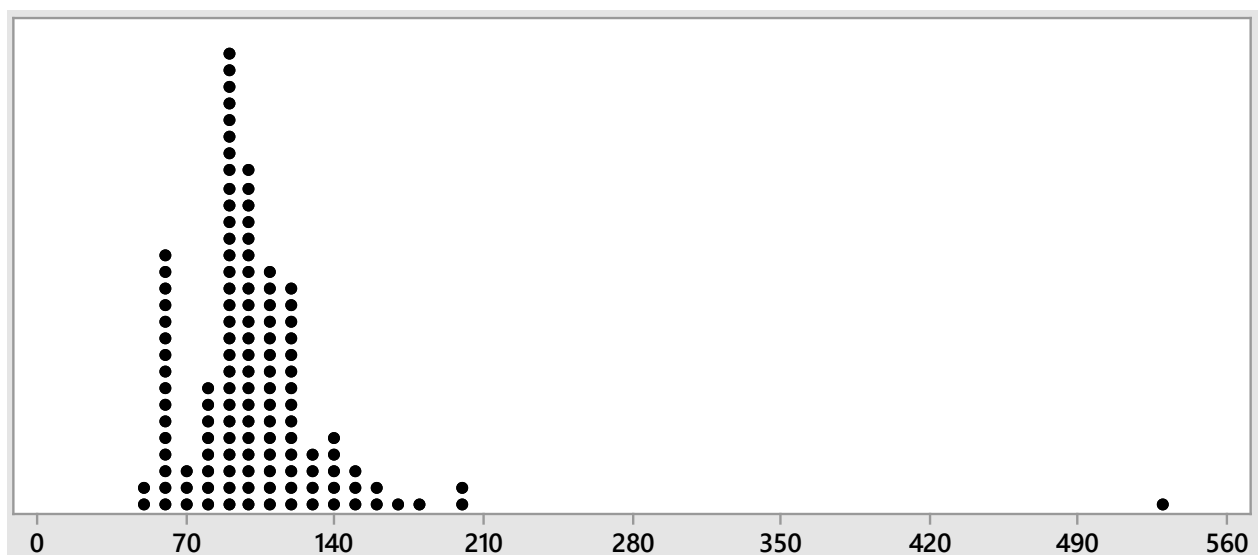


Figure 9. Dot plot of cycle time data of WS-1.

WS-6: At WS-6, the operation involves a fan and motor assembly and testing for imbalance. The current condition revealed very interesting issues. This process is not capable of meeting a takt time of 70 s. The dot plot shown in Figure 12 revealed that the data is clustered in three groups centered around 65, 125, and 185 s. The reason for this was obvious to the engineers, the line supervisor, and even to the operator at this workstation. The operation involves loading fan and motor units into their fixture and assembling them with one washer and a bolt and nut. Then, an automated testing jig is switched on, which runs for about 60 s, checking if the running motor-fan unit is well balanced, causing no vibration and noise. If the assembled unit is good, it is passed on to the next stage, the “End-of-the-Line Testing” station labeled WS-7. If the assembled unit has some imbalance, the testing jig helps identify which fan blade (fan is an injection molded part of nylon material with 35 blades) needs to be balanced with a tiny extra metal clip of 3, 5, or 7 milligrams weight. The operator fixes the small metal clip to the blade identified by the testing jig. This takes a few seconds. Then, the testing is performed again. The unit is usually good, but occasionally, the balancing must be carried out one more time.

So, the cycle time data is clustered at 65 s for the units that pass the first time, at 125 s for the units that pass the second time, and at 185 s for the units that pass the third time.

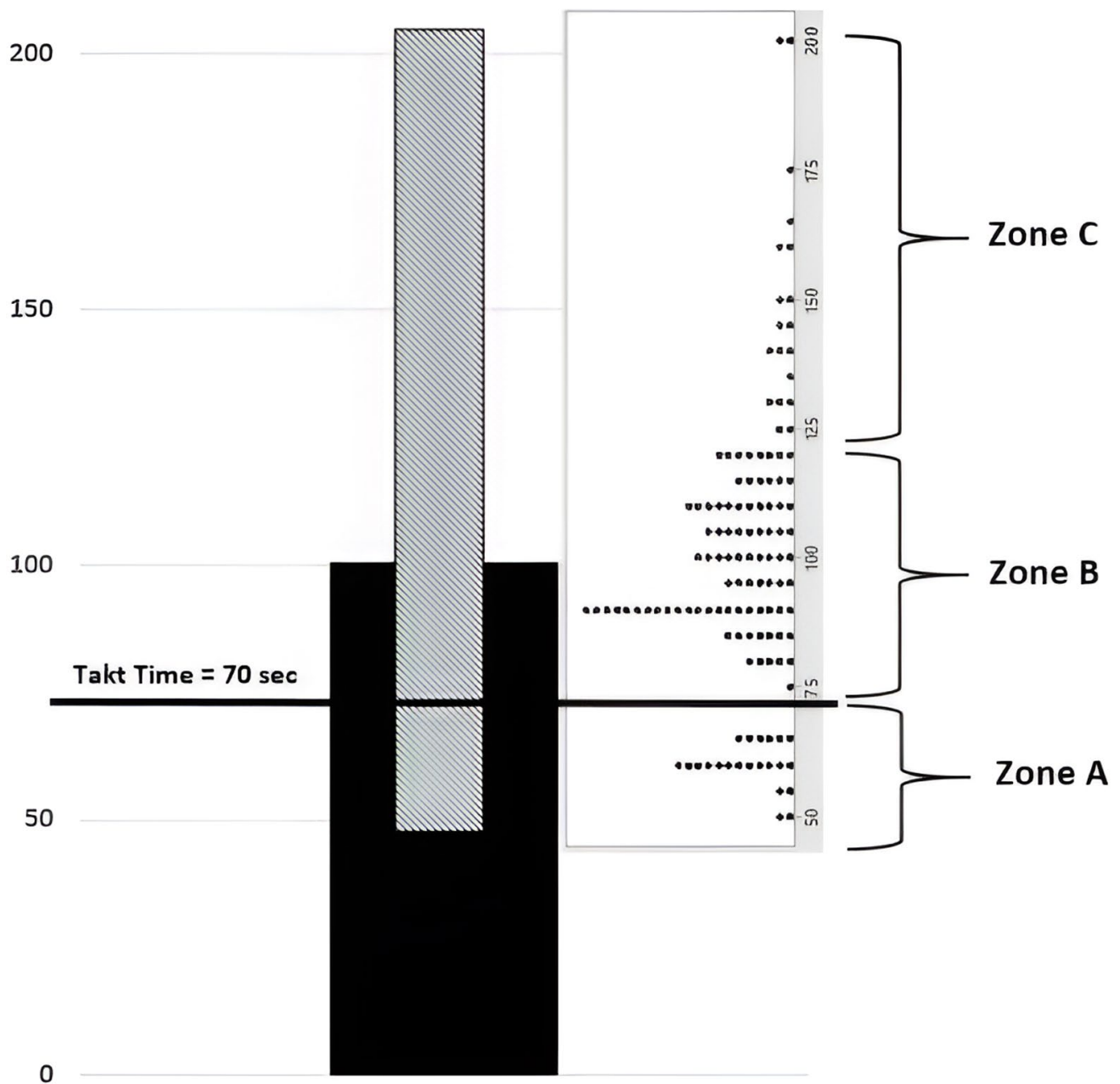


Figure 10. Kata graph with superimposed dot plot of WS-1.

Under the authors' and the teams' guidance, the engineer, who plays the coach role, undertook this problem. Operators made a "concentration chart" (one of the Shainin tools for clue generation). They found that about 90% of the time, the problem is with blade numbers 8, 9, 10, 11, 12, and 13, with a maximum frequency of the problem occurring at blade number 10. Operators investigated the mold used on an electric injection molding machine to produce this part. They discovered that imbalance is caused by less than specified material in the blade. Operators made mold corrections and solved the issue permanently. This solution was validated by using "B versus C" which is again a Shainin tool for conducting design of experiments (DOE). Finally, the two clusters centered at 125 and 185 s are eliminated. The Kata graph of WS-6 in its current condition is shown in Figure 13; the black bar shows the average cycle time of 96 s; the gray bar shows the

minimum cycle time of 64 s, maximum of 187 s, and the range is 123 s (a measure of variation). After improvement, a revised dot plot shown in Figure 13 looked like the cluster of points centered at 65 s. The black bar indicates that the average cycle time is smaller than the takt time; the gray bar indicates that the upper limit on the cycle time is also lower than the takt time. This improvement also eliminated the need for the metal clips used in the assembly process for balancing, which resulted in the elimination of a part number from the inventory database. Therefore, many activities of *Muda*, such as sourcing, negotiation, placing purchase orders, receiving, inspecting, storing in the bins, issuing, and updating the records, were eliminated. These improvements led to the elimination of *Muda*. An important principle of lean production is that shop floor goals should be linked to the metrics applied to the CEO’s performance. The Japanese call this Hoshin Kanri, or policy deployment, to best align an organization’s activities with its strategic objectives.

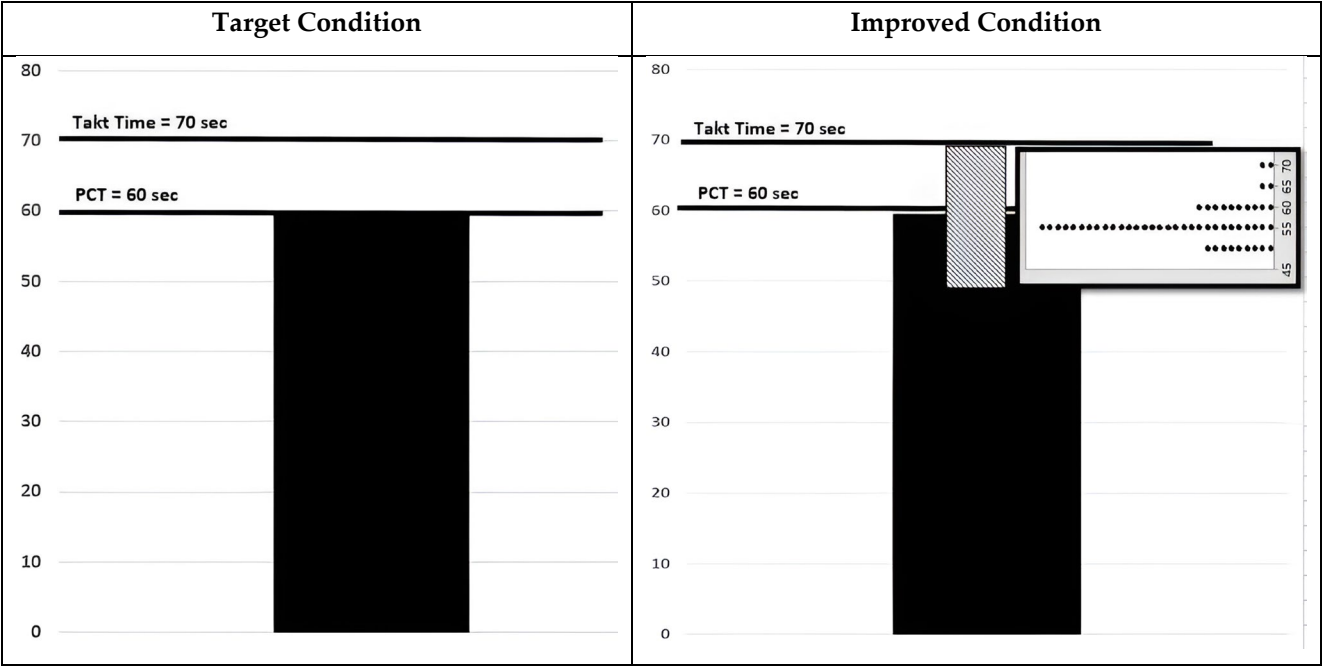


Figure 11. Target condition and improved condition of WS-1.

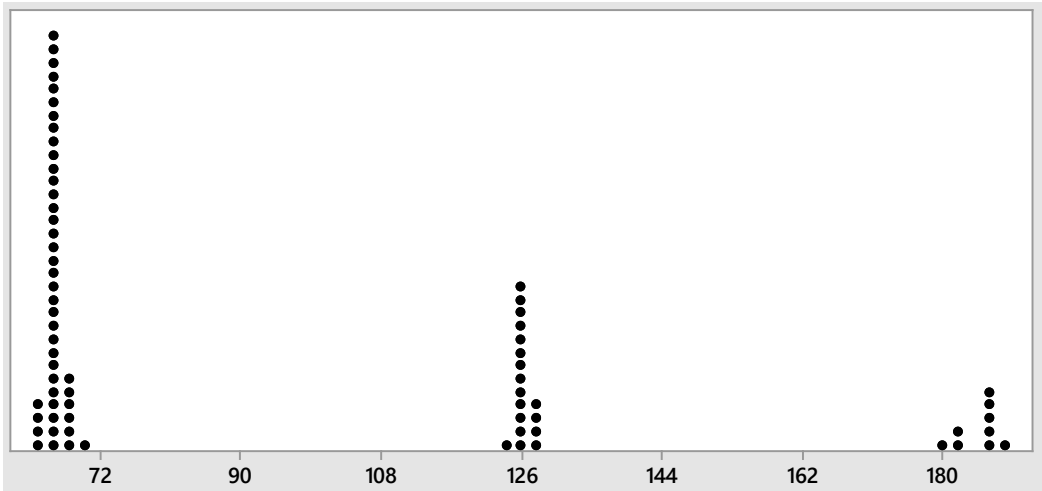


Figure 12. Dot plot of WS-6.

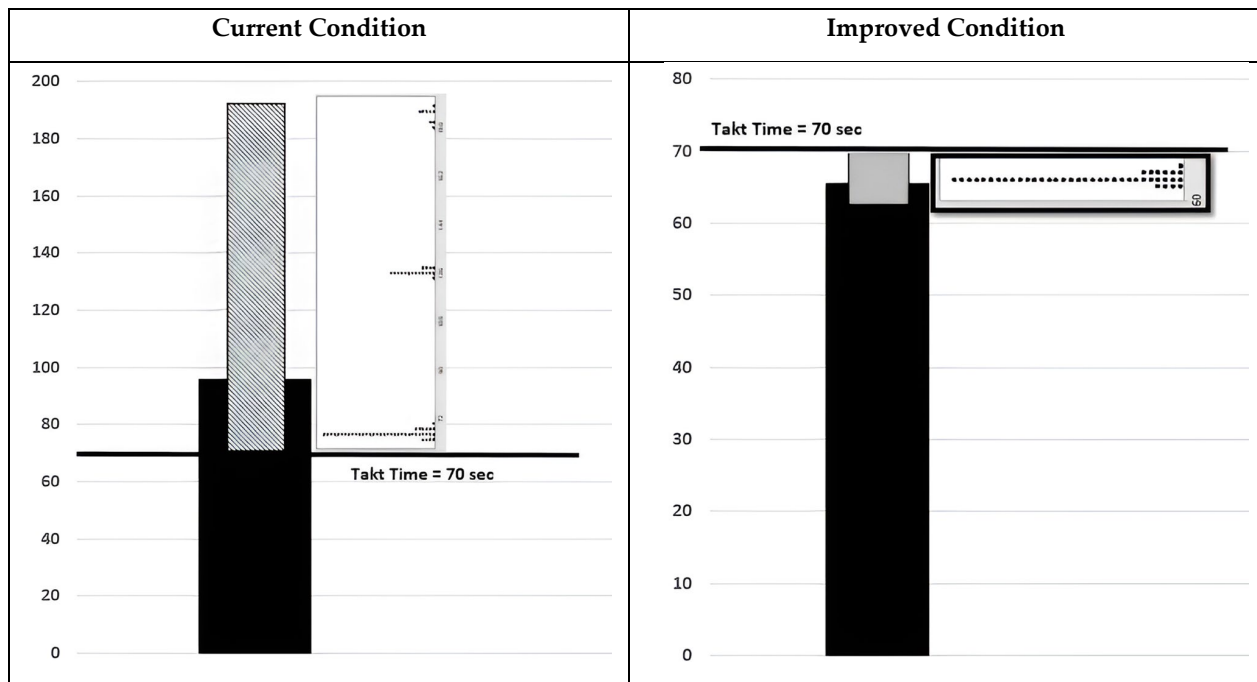


Figure 13. Kata graph and dot plot of WS-6.

4.5. Workforce Development

The authors used the “3-3-3” guideline (see the earlier section on “Workforce Development”) as the basis for developing the training program through a skill matrix. In an HVAC assembly line, multi-skilled workers play a crucial role in boosting productivity and flexibility. By possessing a range of competencies—such as electrical, mechanical, and troubleshooting skills—these workers can adapt quickly to different tasks, reducing downtime and ensuring a smooth operation. This versatility enables faster responses to production issues and supports lean manufacturing by minimizing the need for specialized personnel at each stage. Ultimately, a multi-skilled workforce in HVAC assembly enhances efficiency, quality control, and overall production resilience. The “Skill-level Adherence” metric was computed and displayed from the data collected by biometric devices for every production shift. The authors observed that productivity and quality are strongly correlated with the skill level of the operators. A workstation might be set to have a minimum skill level to operate it. For example, if a workstation (say, WS-4 in Figure 14) is set to a minimum skill level of “U”, and if the assigned operator is of only “I” skill level, a signal will pop up on the display device to take corrective action immediately before the quality and productivity might suffer.

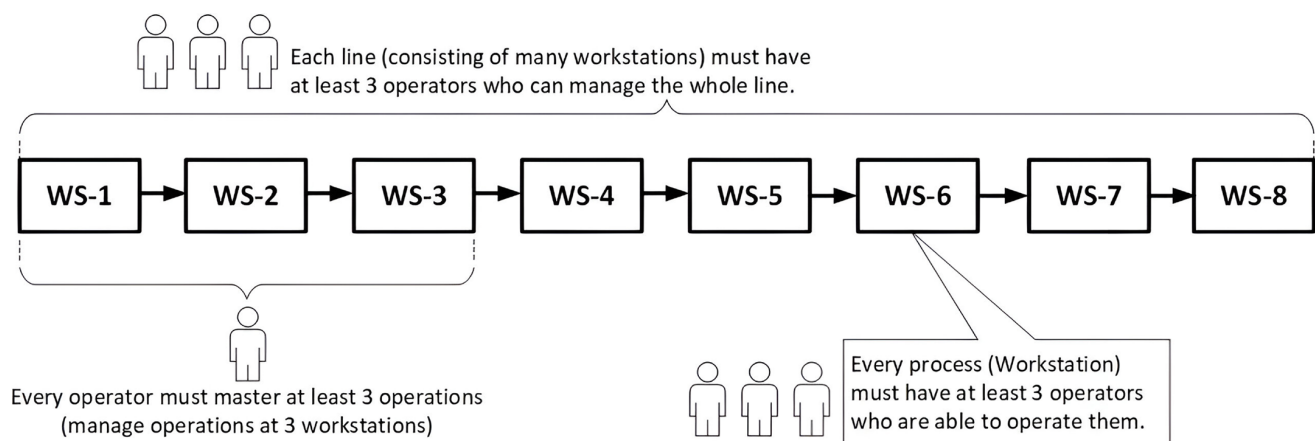


Figure 14. “3-3-3” Guideline for the skill development.

5. Results

The company that implemented the IIoT solution for the HVAC assembly line described in this paper invested about \$30,000 in the hardware and software. This amount does not include the cost of time spent by the factory head, middle managers, and line supervisors. A team of eight IT experts worked during the implementation phase for over six months, spending about 8500 h. During the tuning phase, a team of five IT experts worked for three months, spending about 2500 h. On the operations side, the factory head, five heads of departments (HODs), and engineers spent a total of 1500 h. The IIoT project implementation on one of the assembly lines among eleven such lines took about nine months. The IIoT solution is well integrated with the existing enterprise resources planning (ERP) without many issues. All the stakeholders learned tremendously during the implementation of the IIoT project. During the implementation, the team encountered a problem when cell phones were not allowed during working hours (excluding coffee and lunch breaks). Operators went on strike. Management solved this problem by creating a hotline managed by a human resources person for emergencies and essential communication.

The tangible benefits of the IIoT implementation included a reduction in factory personnel, a 10% increase in OEE, and a 50% increase in line output (units per hour). The IIoT solution reduced energy consumption, in-house rejection and warranty, inventory, and paper consumption costs. The IIoT solution also improved line capacity, which reduced capex, i.e., capital expenditure. All these savings led to a payback period of 18 months. There were many intangible benefits, such as accurate 5S score calculation and display, reduced time for problem-solving, improvement in shopfloor team discipline, and improved customer satisfaction. It created a better approach to operator training and conflict management among cross-functional teams (CFTs). The IIoT solution broke the data silos dedicated to assembly line operations, production planning and control (PPC), maintenance, quality, human resources, learning and development (L&D), procurement, and supply chain. The top management concluded that this project was a great success. The major improvements due to the IIoT solution are listed in Table 4.

Table 4. Benefits resulting from the IIoT integration to support Kata.

Item#	Description	Before IIoT Integration	After IIoT Integration
1	Workforce reduction	15 operators	13 operators
2	Overall Equipment Effectiveness (OEE)	75%	85%
3	Average Throughput	60 assemblies per hour	90 assemblies per hour
4	Traceability of 4M (men, machines, material, and method)	Time consuming (takes many hours)	Fast (takes only a few minutes)
5	Number of paper documents to be maintained	350 (time-consuming effort with enormous paperwork)	0 (Paper-free shopfloor)

6. Conclusions and Recommendations

The factory management and the team were very satisfied with the efficacy of the IIoT-supported Kata solution that the company implemented under the authors' guidance. Therefore, plans were made to horizontally deploy this solution on the other ten assembly lines in the same company.

Key Insights:

- **Real-time Data Utilization:** The case study demonstrated the critical role of real-time data in effectively applying the IIoT-supported Kata methodology to identify and address inefficiencies promptly.
- **Digital Transformation:** The case study outlined the digital transformation process for integrating the IIoT with Kata methodology.

- **Data Monetization:** The case study made the management aware of the importance of data monetization in justifying the investment in IIoT technologies.

Key Recommendations:

- **IIoT-Savvy Workforce Development:** Training employees to use IIoT tools and technologies effectively is crucial for successful implementation. We recommend comprehensive workforce development programs to build IIoT competencies.
- **4M Traceability:** Ensuring traceability of the four key elements—men, method, materials, and machine—is vital for maintaining high standards of production quality and efficiency.
- **Task Scorecards and Dashboards:** Task scorecards and dashboards for real-time monitoring and decision-making are essential to provide actionable insights for optimizing operations and improving OEE.

Limitations of this Work: The insights and recommendations of this work are drawn from an extensive implementation of IIoT-supported Kata methodology in a real-world factory. While these observations certainly provide valuable guidance for practitioners, these observations are still empirical in nature. We cannot say that it will work in all types of assembly lines manufacturing different products in many companies. Assembly lines can take various architectures based on product design. For example, the assembly line of a lead-acid battery is much different from the assembly of an HVAC system. Due to confidentiality and intellectual property protection safeguards, we do not have access to companies that manufacture different products. However, this study can lead to mathematical modeling, application of operations research models, simulation, and AI in future papers. This effort is beyond the scope of this paper due to the limitations of the length and focus of the paper.

Historically, from the beginning, the problems on assembly lines are “mechanical pacing” and “repetitive job patterns”, which are the main sources of worker dissatisfaction because they cause too much pressure and feelings of impersonality [30]. To this day, these problems are not fully solved. However, Kata methodology offers a humanistic approach emphasizing learning, problem-solving, coaching, job rotation, automation practices, and promotion of job satisfaction. The burden on repetitive tasks is partly reduced by the automation of some workstations (if not all), including cobots, poka-yoke (mistake-proofing) systems, and augmented reality (AR) devices. For example, cobots can reduce the operator’s fatigue by doing repetitive, hard, and dangerous tasks. Similarly, exoskeletons can reduce the operators’ fatigue [31].

Manufacturing companies can use the Smart Industry Readiness Index (SIRI) framework. The World Economic Forum (WEF) established this framework to accelerate the adoption of the Smart Industry Readiness Index (SIRI) as the international standard for Industry 4.0 benchmarking and transformation. The goal is to catalyze the adoption of Industry 4.0 methodologies and technologies across the global manufacturing community and provide quantitative indicators for international benchmarking. The project reported in this case study was sponsored by the World Economic Forum’s Centre for Advanced Manufacturing and Supply Chains. So far, SIRI has been adopted internationally by both multinational corporations and SMEs, with more than 850 manufacturing companies across more than 30 different countries having completed the Official SIRI Assessment (OSA) [32]. The IIoT solution is one of the best means for OT–IT integration, which we have demonstrated in this case study on the automotive HVAC factory.

Author Contributions: Conceptualization: P.S.S. and C.C.; methodology: P.S.S. and S.K.; software: P.S.S.; validation: S.K.; formal analysis: P.S.S., C.C. and S.K.; investigation: P.S.S. and S.K.; resources: P.S.S. and C.C.; data curation: P.S.S.; writing—original draft: P.S.S.; writing—review and editing: S.K.; visualization: P.S.S.; supervision: C.C.; project administration: P.S.S. and C.C.; funding acquisition: P.S.S. and S.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Overview of Kata Theory and Practice

Kata is a Japanese word which means “form”. The literature on *Kata* methodology has not discussed the origin and practice of *Kata* in many areas of Japanese culture. Therefore, this section briefly reviews its origin, evolution, and adoption by industry. Many professions use the term *Kata*, but its usage is more prevalent in the world of martial arts, such as *Aikido*, *Judo*, *Kendo*, *Kenpo*, and *Karate*, to refer to a series of pre-arranged defensive or offensive movements through which one can realize the essence of the art [33]. During training, an individual practices a choreographed pattern of movements, either alone or in unison with a group, to memorize and perfect the movements in the task executed [34]. *Kata* is also used in many traditional Japanese arts, such as theatre forms like *kabuki* and schools of tea ceremony [35].

Kata also means “way of doing things”, with special emphasis on the form and order of the process. The common uses of *Kata* include the following: *yomikata*, way of reading; *tabekata*, way of eating; *kakikata*, way of writing; *kangaekata*, way of thinking; and *ikikata*, way of living. Japanese companies use the suffix *Kata* in their training and development programs. Job Instruction (JI) was called *Shigoto no Oshie-Kata*, which means the way to teach jobs. Job Relations (JR) was called *Hito no Atsukai-Kata*, which is the way to handle people. Job Methods (JM) was called *Kaizen no Shi-Kata* to indicate the way to conduct *Kaizen* [36,37].

Toyota *Kata* comes from Mike Rother’s research on Toyota’s management system. It’s a way of developing a scientific-thinking culture in individuals, teams, and organizations by practicing *starter Kata*. There are two main elements within Toyota *Kata*. One is the four-step scientific *improvement Kata*, which helps anyone develop fundamental working skills like a scientist. The other is the *coaching Kata*, which is about practicing the learner-coach relationship for teaching the improvement *Kata*. The improvement *Kata* and coaching *Kata* each come with a starter *Kata*. Practicing that starter *Kata* increases the speed and scalability of learning and is particularly helpful when companies want to develop a shared scientific mindset in a group of people because everyone starts with the same basics. Starter *Kata* comprises compact routines practiced deliberately at the beginning to build new skills and habits. An example is playing scales in music.

The book, “The Toyota *Kata* Practice Guide”, which is a companion to the book “Toyota *Kata*”, by Mike Rother, explains the process of improving, adapting, and even innovating routine behavior [38]. This book is designed to help a coach (the manager) and a learner work collaboratively to develop new skills, modify behavior patterns, experiment to achieve tough goals, and nurture employee learning.

Another book, “Toyota Culture—The Heart and Soul of the Toyota Way”, discusses how Toyota selects, develops, and motivates its employees to promote their commitment to a culture of quality, safety, and a fair work environment. The soul of the Toyota culture is a unique sense of judiciousness in balancing the needs of employees, respect, and productivity concerns [39].

The book, “Seven *Kata*: Toyota *Kata*, TWI, and Lean Training”, explains time-tested tools of Training Within Industry (TWI) and the Toyota *Kata* for boosting organizational synergies and enhancing any lean transformation journey. It explains key lean concepts, including *Gemba* walks, *Genchi Gembutsu* (the practice of going and observing firsthand the process where the problem exists to solve it quickly and efficiently), and PDCA (Plan, Do, Check, Act), and offers guidelines for coaching *Kata* [40].

Toyota Kata, as an inherent part of the TPS, promotes Toyota's meticulous behavior and thinking in production and office environments. Global Kata aims to design, integrate, adapt, systematize, and scale lean practices across the entire enterprise and beyond. Global Kata is a broader adaptation of Kata for organizations to define, create, nurture, and reinforce patterns of behavior and attribute codes in their enterprise-wide culture [41].

Dinis-Carvalho et al. [42] presented a case study of improvement Kata in a wooden frame manufacturing firm. Toivonen [43] described a method for improving Kata methodology with TRIZ [44] techniques such as contradiction analysis, function/attribute analysis, and inventive principles to deal with complex problems. Ferenhof et al. [45] offered a new perspective on how managers use Toyota Kata to implement knowledge management (KM) and analyze inhibitors in lean services. Ehni et al. [46] presented a case-study-based approach to lean management implementation and empowers employees to engage in a decentralized and goal-oriented improvement process considering behavioral aspects.

Toyota Kata methodology was also used to enhance operational efficiency in the service industry. For example, Merguerian et al. [47] presented a multidisciplinary clinic to optimize value using variables such as cost, time to perform a task, number of patients in the clinic, percent value-added time (VAT) to patients (face-to-face time), and family experience scores (FES). Suárez-Barraza et al. [48] explored, analyzed, and implemented *Kaizen-Kata* methodology in a service organization (first-level restaurant) to achieve a 70% reduction in problems. Brandl et al. [49] presented an integrated business process innovation Kata framework for deploying Kata in the daily project routine of business process (re-)design. Casten et al. [50] combined conformance Kata, improvement Kata, and coaching Kata to formulate construction Kata, for lean construction projects. Lodgaard et al. [51] reported an action research case study applying Toyota Kata to identify enablers and inhibitors of continuous improvement at a leading Norwegian construction company and its key suppliers. Michels et al. [52] explained the main barriers and opportunities in using Toyota Kata routines naturally with a diminishing learning curve. Toivonen [43] presented an approach combining Kata with TRIZ techniques to promote continuous innovation.

Appendix B. Overview of Industrial Internet of Things (IIoT)

Kevin Ashton first used it in 1999 to promote radio frequency identification (RFID) technology. The industrial internet of things (IIoT) has revolutionized various industrial sectors by enabling the seamless integration of connected devices and data analytics into their operations. In manufacturing, the IIoT enhances production efficiency through real-time monitoring of equipment, predictive maintenance, quality control, energy management, water usage, lighting control, and safety. In agriculture, smart sensors and automation improve crop yield and resource management. Energy and utilities benefit from the IIoT by optimizing energy consumption and grid management. Healthcare leverages the IIoT for remote patient monitoring and equipment maintenance. Transportation and logistics streamline supply chains through tracking and predictive analytics. Thousands of companies worldwide have adopted the IIoT successfully. Suresh et al. [53] presented many use cases of the IIoT in areas such as smart manufacturing, smart grids, smart agriculture, traffic control, smart homes, smart health care, smart retail, telematics, solar farm monitoring, oil and gas, and pollution control. Alloui et al. [54] provided a comprehensive survey of the impact of the IIoT on improving operational efficiency, decision-making processes, and overall productivity in sectors such as smart cities, smart homes, remote learning, transportation, retail, healthcare, supply chain, logistics, agriculture, and financial services. Kumar et al. [55] discussed important application domains and different challenges and key issues associated with the IIoT architecture and implementation. It involves the integration of sensors, automation, and data analytics into industrial processes and equipment to improve efficiency, productivity, and safety.

Yang et al. [56] reviewed the IIoT technologies and systems that are the drivers and foundations of data-driven innovations in smart manufacturing. This article also discussed the evolution of the Internet from computer networks to human networks to the latest era of smart and connected networks of manufacturing things (e.g., materials, sensors, equipment, people, products, and supply chains) and presented a framework that leverages the internet of manufacturing things (IoMT) and cloud computing to develop a virtual machine network. Jha and Prashar [57] discussed the challenges and opportunities of adapting the IIoT in lean manufacturing. Shunmughavel [58] discussed the challenges for making the IIoT a reality. These challenges include connectivity, cost, data integration, trust, privacy, device management, security, interoperability, collaboration, and integration. Anandan et al. [59] showcased industrial automation through the IIoT by including case studies in the areas of the IIoT, predictive maintenance, robotic and intelligent systems, and web-based applications in a broad cross-section of technical disciplines. While the IoT and the IIoT leverage connectivity and data, the IIoT is tailored to address the unique needs and challenges of industrial sectors, making it a better match for optimizing industrial operations. This paper describes a case study in which they integrated the IIoT with Kata methodology to improve factory productivity.

Appendix C. Industry 4.0

Industry 3.0 is a significant phase in the evolution of industrial technology and manufacturing processes. It is characterized by the widespread use of automation and computerization with technologies such as PLCs (programmable logic controllers), CAD/CAM (computer-aided design/computer-aided Manufacturing), SCADA (supervisory control and data acquisition), FMS (flexible manufacturing systems), robotics, and the Internet. These technologies have greatly impacted all business functions in various areas, including insurance services, elevator service call centers, supermarket inventory management, production management, sales management, and incentive systems [60]. In the evolution of production scheduling from Industry 3.0 through Industry 4.0, production scheduling also embraced Industry 4.0 technologies to boost customer-centricity and improve global supply chains [61]. Haeckel and Nolan [62] introduced an enterprise model called “manage-by-wire” to represent the operations of an entire business. Based on this model, expert systems, databases, software objects, and other technical components are integrated to perform the equivalent of flying by wire. The executive crew then pilots the organization, using controls in the information cockpit of the business.

Industry 4.0 (known as “Industrie 4.0” in Europe) was brought to life as a term and a concept in 2011 at Hannover Messe, where Bosch described the widespread integration of information and communication technology in industrial production. The entire manufacturing industry and the German government found the idea promising [63]. A smart factory is the heart of Industry 4.0, where the IIoT is a key technology enabler. A variety of sensors embedded in the part storage bins, machines, assembly stations, and inspection stations send data through bar codes, QR (quick response) codes, RFID (radio-frequency identification), biometric devices, and programmable logic controllers (PLCs). Data can be a part identification code, operator data, a process parameter such as spindle speed in a CNC machine, injection pressure in an injection molding machine, a quality parameter such as vibration or voltage, and so on. An IIoT gateway processes the data before sending it to an IIoT server for further processing and display as real-time visual information on the shop floor. This new technology provides efficient real-time manufacturing systems, increasing context awareness to assist people and machines in perfectly executing their tasks. Awareness refers to the availability of knowledge of system components, the history of system performance, and the ongoing state of the system.

Industry 4.0 enlists current automation and data exchange trends in manufacturing. Mabkhot et al. [64] provided an overview of key components of Industry 4.0. These components are smart sensors, IoT, big data, AI, cloud manufacturing, and cyber-physical systems. They also presented a set of design principles for a smart factory, such as modularity, interoperability, decentralization, virtualization, service orientation, and real-time capability. Ober6 et al. [65] presented a practical learning approach to learning factories and the possibility of bringing the impact of AI closer to blue-collar workers.

Appendix D. Digital Transformation Certification

Scaling up digital transformation can be challenging. The World Economic Forum (WEF) [66] established a process to identify and certify companies to become global lighthouses that excel in manufacturing processes, product quality, and sustainability practices. Manufacturing sites are evaluated based on capabilities such as digital assembly and machines, digital maintenance, digital performance management, digital quality management, and digitally enabled sustainability. Lighthouses are judged based on the improvements in key performance indicators (KPIs) of sustainability, productivity, quality, speed-to-market, and customization. The WEF states that 70% of companies are still stuck in what they call “pilot purgatory”. As of October 2023, 132 companies have been certified as “4IR Lighthouses” from different industry sectors and 13 companies as sustainability Lighthouses. This is a negligible fraction of the total number of companies worldwide. These companies champion responsible and sustainable manufacturing, aligning with global goals such as reducing carbon emissions, promoting ethical supply chain management, and shaping the future of manufacturing. The WEF report [66] presented many use cases. Digital transformations must be made with a clear roadmap to reap the benefits of Industry 4.0 technologies. Scaling up with plug-and-play IIoT applications in automotive assembly lines promises to transform the industry’s manufacturing processes. In the next few years, use cases may be broadcast on the industrial metaverse.

Appendix E. A Few Photographs of the Assembly Line



HVAC Assembly Line



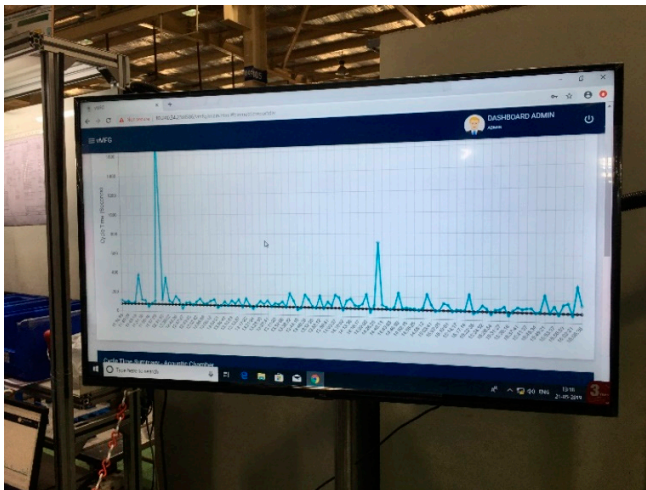
WS-1: Part Picking



Biometric Device at Each Workstation



WS-6: Fan and Motor Assembly



Cycle time Graph Displayed in Real-time



IIoT Gateway

References

1. Liker, J. *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*; McGraw-Hill: New York, NY, USA, 2004.
2. Ichijo, K.; Nonaka, I. *Knowledge Creation and Management—New Challenges for Managers*; Oxford University Press: New York, NY, USA, 2006; p. 285.
3. Rother, M. *Toyota Kata—Managing People for Improvement, Adaptiveness and Superior Results*; McGraw-Hill: New York, NY, USA, 2010.
4. CodeKata: How It Started. Available online: <http://codekata.com/kata/codekata-how-it-started/> (accessed on 19 November 2024).
5. Nye, D.E. *America's Assembly Line*; MIT Press: Cambridge, MA, USA, 2013; pp. 1–10.
6. Womack, J.; Jones, D. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*; Free Press: New York, NY, USA, 2003.
7. Ahmed, H.; Ramadan, A.A.; Elkordy, E.H.; Elngar, A.A. Introduction to Industrial Internet of Things (IIoT). In *Industrial Internet of Things—Technologies, Design and Applications*; Jha, S., Tariq, U., Joshi, G.P., Solanki, V.K., Eds.; CRC Press: Boca Raton, FL, USA, 2022; pp. 1–18.
8. Gilchrist, A. *Industry 4.0: The Industrial Internet of Things*; Springer Science+Business Media: New York, NY, USA, 2016.
9. Tarafdar, M.; Beath, C.M.; Ross, J.W. Using AI to Enhance Business Operations. *MIT Sloan Manag. Rev.* **2019**, *60*, 38–44.
10. Hermann, M.; Pentek, T.; Otto, B. Design Principles for Industrie 4.0 Scenarios. In Proceedings of the 2016 49th Hawaii International Conference on System Sciences (HICSS), Koloa, HI, USA, 5–8 January 2016; pp. 3928–3937. [CrossRef]
11. McGrath, R.; McManus, R. Discovery-driven Digital Transformation. *Harv. Bus. Rev.* **2020**, *98*, 124–133.
12. Behrendt, A.; De Boer, E.; Kasah, T.; Koerber, B.; Mohr, N.; Richter, G. *Leveraging Industrial IoT and Advanced Technologies for Digital Transformation*; McKinsey & Company: New York, NY, USA, 2021; p. 26.
13. Wixom, B.H.; Beath, C.M.; Owens, L. *Data Is Everybody's Business: The Fundamentals of Data Monetization*; MIT Press: Cambridge, MA, USA, 2023; p. 67.
14. Chow, H.; Choy, K.L.; Lee, W.B.; Felix, C. Integration of web-based and RFID technology in visualizing logistics operations—A case study. *Supply Chain. Manag. Int. J.* **2007**, *12*, 221–234. [CrossRef]

15. Pereira, J.; Silva, F.J.G.; Bastos, J.A.; Ferreira, L.P.; Matias, J.C.O. Application of the A3 Methodology for the Improvement of an Assembly Line. *Procedia Manuf.* **2019**, *38*, 745–754. [\[CrossRef\]](#)
16. Liker, J.; Meier, D. *Toyota Talent: Developing Your People: The Toyota Way*; McGraw Hill: New York, NY, USA, 2007; p. 208.
17. Kanawaty, G. *Introduction to Work Study*, 4th ed.; International Labor Office: Geneva, Switzerland, 1992.
18. Bhote, K.R.; Bhote, A.K. *World Class Quality: Using Design of Experiments to Make It Happen*; AMA Publications: New York, NY, USA, 2000.
19. Sobek, D.K., II; Smalley, A. *Understanding A3 Thinking: A Critical Component of Toyota's PDCA Management System*; Productivity Press: New York, NY, USA, 2008.
20. Liker, J.; Hoseus, M. *Toyota Culture: The Heart and Soul of the Toyota Way*; McGraw Hill: New York, NY, USA, 2008; pp. 105–147.
21. Levitt, J. *TPM Reloaded: Total Productive Maintenance*; Industrial Press Inc.: New York, NY, USA, 2010.
22. Ortiz, C.A.; Park, M.R. *Visual Controls: Applying Visual Management to the Factory*; Productivity Press: New York, NY, USA, 2011.
23. Baudin, M. *Working with Machines—The Nuts and Bolts of Lean Operations with Jidoka*; CRC Press: Boca Raton, FL, USA, 2018.
24. Ungermann, F.; Kuhnle, A.; Stricker, N.; Lanza, G. Data Analytics for Manufacturing Systems—A Data-Driven Approach for Process Optimization. *Procedia CIRP* **2019**, *81*, 369–374. [\[CrossRef\]](#)
25. Windmann, S.; Maier, A.; Niggemann, O.; Frey, C.; Bernardi, A.; Gu, C.; Pfrommer, H.; Steckel, T.; Krüger, M.; Kraus, R. Big Data Analysis of Manufacturing Processes. *J. Phys. Conf. Ser.* **2015**, *659*, 012055. [\[CrossRef\]](#)
26. Imai, M. *Kaizen (Ky'Zen), the Key to Japan's Competitive Success*; McGraw-Hill Education: New York, NY, USA, 1986.
27. Kurdve, M.; Harlin, U.; Hallin, M.; Söderlund, C.; Berglund, M.; Florin, U.; Landström, A. Designing visual management in manufacturing from a user perspective. *Procedia CIRP* **2019**, *84*, 886–891. [\[CrossRef\]](#)
28. Spear, S.; Bowen, H.K. Decoding the DNA of the Toyota Production System. *Harv. Bus. Rev.* **1999**, *77*, 96–106.
29. Hillar, G. *MQTT Essentials—A Lightweight IoT Protocol*; Packt Publishing Ltd.: Birmingham, UK, 2017; pp. 30–45.
30. Turner, A. Management and the assembly line. *Harv. Bus. Rev.* **1955**, *33*, 40–48.
31. Harbour, R.; Schmidt, J. Tomorrow's Factories Will Need Better Processes, Not Just Better Robots. *Harv. Bus. Rev.* **2018**. Product #: H049NG-PDF-ENG.
32. World Economic Forum. Global Smart Industry Readiness Index Initiative. Available online: <https://www.weforum.org/projects/global-smart-industry-readiness-index-initiative> (accessed on 10 October 2023).
33. Rowen, C. *Kata Tensho*; Summersdale Publishers: Chichester, UK, 2005; p. 12.
34. Kogel, H.C. *The Secret Karate Techniques—Kata Bunkai*; Meyer & Meyer Sport (UK) Ltd.: Maidenhead, UK, 2010; pp. 88–244.
35. Abernethy, I. *Bunkai-Jutsu—The Practical Application of Karate Kata*; NETH Publishing: Cockermouth, UK, 2002; pp. 5–13.
36. Graupp, P.; Steward, S.; Parsons, B. *Creating an Effective Management System Integrating Policy Deployment, TWI, and Kata*; CRC Press, Taylor & Francis Group: Boca Raton, FL, USA, 2019; p. 14.
37. De Mente, B.L. *Kata, The Key to Understanding and Dealing with the Japanese!* Tuttle Publishing: Tokyo, Japan, 2003; pp. 1–15.
38. Rother, M. *The Toyota Kata Practice Guide*; McGraw-Hill: New York, NY, USA, 2018.
39. Rother, M.; Aulinger, G. *Toyota Kata Culture: Building Organizational Capability and Mindset Through Kata Coaching*; McGraw-Hill: New York, NY, USA, 2017.
40. Soltero, C.; Boutier, P. *The 7 Kata—Toyota Kata, TWI, and Lean Training*; Productivity Press Taylor & Francis Group. A Productivity Press Book: Boca Raton, FL, USA, 2012.
41. Burton, T.T. *Global Kata—Success Through the Lean Business System Reference Model*; McGraw-Hill: New York, NY, USA, 2016; pp. 39–42.
42. Dinis-Carvalho, J.; Ratnayake, R.M.C.; Stadnicka, D.; Sousa, R.M.; Isoherranen, J.V.; Kumar, M. Performance enhancing in the manufacturing industry: An improvement KATA application. In Proceedings of the 2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Bali, Indonesia, 4–7 December 2016; pp. 1250–1254. [\[CrossRef\]](#)
43. Toivonen, T. Continuous Innovation—Combining Toyota Kata and TRIZ for Sustained Innovation. *Procedia Eng.* **2015**, *131*, 963–974. [\[CrossRef\]](#)
44. Ilevbare, I.M.; Probert, D.; Phaal, R. A review of TRIZ and its benefits and challenges in practice. *Technovation* **2013**, *33*, 30–37. [\[CrossRef\]](#)
45. Ferenhof, H.; Cunha, A.; Bonamigo, A.; Forcellini, F. Toyota Kata as a KM solution to the inhibitors of implementing lean service in service companies. *VINE J. Inf. Knowl. Manag. Syst.* **2018**, *48*, 404–426. [\[CrossRef\]](#)
46. Ehni, M.; Kersten, W. Toyota Kata: Empowering Employees for Target-Oriented Improvement—A Best Practice Approach. In *Innovations and Strategies for Logistics and Supply Chains: Technologies, Business Models and Risk Management*; Kersten, W.B., Ringle, T., Christian, M., Eds.; Proceedings of the Hamburg International Conference of Logistics (HICL); Epubli GmbH: Berlin, Germany, 2015; Volume 20, pp. 175–200; ISBN 978-3-7375-4059-9. Available online: <https://EconPapers.repec.org/RePEc:zbw:hiclh:209255> (accessed on 19 November 2024).
47. Merguerian, P.A.; Grady, R.; Waldhausen, J.; Murphy, W.; Melzer, L.; Avansino, J. Optimizing value utilizing Toyota Kata methodology in a multidisciplinary clinic. *J. Pediatr. Urol.* **2015**, *11*, 228.e1–228.e6. [\[CrossRef\]](#)
48. Suárez-Barraza, M.F.; Miguel-Dávila, J.A.; Morales-Contreras, M.F. Application of Kaizen-Kata methodology to improve operational problem processes. A case study in a service organization. *Int. J. Qual. Serv. Sci.* **2021**, *13*, 29–44. [\[CrossRef\]](#)
49. Brandl, F.J.; Ridolfi, K.S.; Reinhart, G. Can we Adopt the Toyota Kata for the (Re-)Design of Business Processes in the Complex Environment of a Manufacturing Company? *Procedia CIRP* **2020**, *93*, 838–843. [\[CrossRef\]](#)

50. Casten, M.; Plattenberger, J.; Barley, J.M.; Grier, C. Construction Kata Adapting Toyota Kata to a Lean Construction Project Production System. In Proceedings of the 21st Annual Conference of the International Group for Lean Construction 2013 (IGLC-21), Fortaleza, Brazil, 29 July–2 August 2013; Fortaleza, B., Ed.; pp. 62–73.
51. Lodgaard, E.; Mogos, M.F.; Iakymenko, N. Lessons Learned from Toyota Kata Implementation in the Norwegian Construction Industry. In *Learning in the Digital Era: 7th European Lean Educator Conference, ELEC 2021, Trondheim, Norway, 25–27 October 2021*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 365–372. [CrossRef]
52. Michels, E.; Forcellini, F.; Fumagali, A. Opportunities and barriers in the use of Toyota Kata: A bibliographic analysis. *Rev. Gestão Produção Operações Sist.* **2019**, *14*, 262–285. [CrossRef]
53. Suresh, A.; Nandagopal, M.; Raj, P.; Neeba, E.A.; Lin, J.-W. *Industrial IoT (IIoT) Application Architectures and Use Cases*; CRC Press: Boca Raton, FL, USA, 2020.
54. Alliou, H.; Mourdi, Y. Exploring the Full Potentials of IoT for Better Financial Growth and Stability: A Comprehensive Survey. *Sensors* **2023**, *23*, 8015. [CrossRef]
55. Kumar, S.; Tiwari, P.; Zymbler, M. Internet of Things is a revolutionary approach for future technology enhancement: A review. *J. Big Data* **2019**, *6*, 111. [CrossRef]
56. Yang, H.; Kumara, S.; Bukkapatnam, S.T.S.; Tsung, F. The Internet of things for smart manufacturing: A review. *IIE Trans.* **2019**, *51*, 1190–1216. [CrossRef]
57. Jha, N.; Prashar, D. Adoption of Industry 4.0 in Lean Manufacturing. In *Industrial Internet of Things—Technologies, Design and Applications*; Jha, S., Tariq, U., Joshi, G.P., Solanki, V.K., Eds.; CRC Press: Boca Raton, FL, USA, 2022; pp. 107–125.
58. Shunmughavel, V. Challenges to Industrial Internet of Things (IIoT) Adoption in Innovations. In *The Industrial Internet of Things (IIoT) and Smart Factory*; Goundar, S., Avanija, J., Sunitha, G., Madhavi, K.R., Bhushan, S.B., Eds.; IGI Global: Hershey, PA, USA, 2021; pp. 117–132.
59. Anandan, R.; Gopalakrishnan, S.; Pal, S.; Zaman, N. *Industrial Internet of Things (IIoT): Intelligent Analytics for Predictive Maintenance*; Wiley-Scrivener: Beverly, MA, USA, 2021.
60. Bruns Jr, W.J.; McFarlan, E.W. Information technology puts power in control systems. *Harv. Bus. Rev.* **1987**, *65*, 89–94.
61. Jiang, Z.; Yuan, S.; Ma, J.; Wang, Q. The evolution of production scheduling from Industry 3.0 through Industry 4.0. *Int. J. Prod. Res.* **2022**, *60*, 3534–3554. [CrossRef]
62. Haeckel, S.H.; Nolan, R.A. Managing by Wire. *Harv. Bus. Rev.* **1993**, *71*, 122–132.
63. Winter, J. The Birth of Industry 4.0 and Smart Manufacturing. *InTech* **2022**, *68*, 10–12.
64. Mabkhot, M.M.; Al-Ahmari, A.M.; Salah, B.; Alkhalefah, H. Requirements of the Smart Factory System: A Survey and Perspective. *Machines* **2018**, *6*, 23. [CrossRef]
65. Oberc, H.; Fahle, S.; Prinz, C.; Kuhlentötter, B. A Practical Training Approach in Learning Factories to Make Artificial Intelligence Tangible. *Procedia CIRP* **2020**, *93*, 467–472. [CrossRef]
66. World Economic Forum (WEF), Global Lighthouse Network: Shaping the Next Chapter of the Fourth Industrial Revolution, White Paper, January 2023. Available online: https://www3.weforum.org/docs/WEF_Global_Lighthouse_Network_2023.pdf (accessed on 25 October 2023).

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.