Hindawi
Advances in Operations Research
Volume 2023, Article ID 8007474, 9 pages
https://doi.org/10.1155/2023/8007474

Research Article

PDCA from Theory to Effective Applications: A Case Study of Design for Reducing Human Error in Assembly Process

Vi Nguyen,[1] Chuong K. B. Chau,[1] and Thanh Tran [2]

[1]*Faculty of Engineering, Vietnamese-German University, Ring Road 4, Quarter 4, Thoi Hoa Ward, Ben Cat Town, Binh Duong Province, Vietnam*
[2]*School of Science, Engineering, Technology, RMIT University Vietnam, Ho Chi Minh City, Vietnam*

Correspondence should be addressed to Thanh Tran; thanh.tt@vgu.edu.vn

Received 26 February 2023; Revised 1 June 2023; Accepted 19 June 2023; Published 26 June 2023

Academic Editor: Konstantina Skouri

This article describes an efficient and effective way to apply the PDCA (Plan-Do-Check-Act) method in the design process to meet quality and stakeholders' expectations. Through the case study of developing a smart workstation to train workers in the assembly process with a target to reduce the defects and improve the management task, the paper explores the main barriers and success factors for the PDCA cycle implemented in complex quality improvement projects. A prototype of the new workstation design is tested and shows significant benefits not only in defect reduction and management efficiency but also in newcomers' learning process. This research can be used as a benchmark application of PDCA in quality improvement and engineering design processes with systematic and comprehensible guidance of the cycle.

1. Introduction

The assembly or manual assembly process is one vital link in the whole process chain of production enterprises. It is depicted as combining or assembling single manufactured components into a finished product. Major operators predominantly accomplish the assembly process by utilizing their innate competencies and knowledge. The operator's working environment within the assembly process can be a workstation or a smaller part of a whole transfer system [1]. The assembly process is interconnected with the operator's efficiency and performance. The problem is that when human factors are intensely involved, uncertainties and undesired variations may happen in the assembly process. The potential uncertainties and undesired deviations can be listed as the unpresented fault throughout the assembly steps regarding operator manipulation, the variation in process time concerning assembly steps, or the discrepancy between the recorded and the actual finished product that could lead to serious consequences regarding the production plan. Evidently, the specified problems could be overcome by adopting reconfigurability or the integration of viable smart solutions in the system of the assembly process.

PDCA cycle, also known as the Shewhart cycle, is an iterative design and management method used widely in organizations to improve processes and products continually [2]. The PDCA methodology's usefulness for quality improvement has recently been highlighted in manufacturing, services, and other sectors. Matsuo and Nakahara investigated and demonstrated the benefits of PDCA and on-the-job training on appreciable enhancements in workplace learning [3]. Tahiduzzaman et al. employed PDCA and 5S to reduce the sewing errors for the knit T-Shirt product at "Interstoff Apparels Limited," Bangladesh. They concluded that the PDCA cycle is an excellent instrument for continuous improvement planning, enhancing the company's profit and quality [4]. The PDCA cycle is generally recognized in the literature as a logical program for continuous improvements as well as an effective tool for the quality control of product and process development [5–8]. PDCA can also serve as a foundation for integrating with other Lean and six sigma strategies [9, 10].

Nguyen et al. applied the PDCA cycle, Ishikawa diagram, 5W1H method, and nominal group technique to enhance the packing of delicate fountains. They conducted research and came up with ideas for user-friendly packaging designs. The findings demonstrated that PDCA is a practical and successful method for improving not only the caliber of packaging but also other fields [11].

Rather than a simple method, PDCA requires the art of combining different quality tools in a philosophy of effective continuous quality improvement. However, many organizations confuse about implementing PDCA in ongoing improvement activities. If the practitioners do not adequately comprehend the approach, learning and using PDCA cycles can be difficult and time-consuming. Poor studies on a current issue and its barrier, inaccurate data collection, incorrect or improper use of quality tools, failure to identify root causes, insufficient analysis, lack of process standardization, or a lack of sharing learning experiences prior to and following the implementation of PDCA are just a few examples of the many causes of unsuccessful PDCA applications [12, 13]. Based on our surveys, companies tend to meet failures in PDCA implementation due to skipping specific steps or applying them inappropriately. For instance, engineers and operators may think PDCA requires too much time. Improvement actions should be done quickly by individuals. They made plans and then implemented and evaluated results by themselves. The Plan and Do phases are repeated frequently in the factory. However, successful implementation progress is not documented. Learned lessons are not delivered to others. Then, the same problems, obviously, happen again in other sections or with new employees. Especially, quality improvement involving design requirements is normally considered a large or complex project in a company where applying PDCA can bring significant benefits. However, integrating the PDCA in the engineering design process or product development is not published wisely. Plus, there is no clear clarification on when and how employees should apply PDCA from companies for machines, tools, workstations, or layout improvements. This somehow makes employees frustrated and use PDCA very perfunctorily. Then, it leads to inefficiencies or failures in implementations [7, 14, 15]. This research aims to apply the systematic PDCA (Plan-Do-Check-Act) cycle in developing and designing an intelligent workstation for labor training and management for an assembly process. Through the case study, the paper shows a guideline to implement PDCA integrated into the engineering design process and the importance of using flexible tools, encouraging teamwork, leadership, and commitment forward to the target.

2. Implementing PDCA Cycle in the Engineering Design Process

In theory, PDCA is explained as a systematic and straightforward method to use [2, 6]. It includes four stages which are stated below:

(i) Plan: The target of this phase is to identify improvement opportunities, set up goals, and assign resources to implement them. The current situation and problem analysis should be seriously studied to explore possibilities for improvement. Countermeasures or solutions will be proposed based on the problem's causes, and their feasibility and efficiency will be evaluated.

(ii) Do: In this stage, the tackling methods are carried out. A pilot scale firstly is implemented. Data are observed, selected, and documented for further study and analysis. Unexpected events should also be considered.

(iii) Check: In this step, implemented results are compared with established targets. The performance is verified to check whether any improvement is achieved. What are the learned lessons for further actions?

(iv) Act: If the improvements are achieved as established objectives, the changes are adopted, documented, standardized, and applied on a larger scale. If not meeting the goals, the team has to consider revising or adjusting the action plans and modify solutions, or the group may abandon the project due to not yielding any improvements. In this final step, the follow-up activities should also be defined to maintain an improved level of performance and to capture and apply learned lessons during each phase of the PDCA cycle.

The following subsections explain how each PDCA phase was used in this project.

2.1. Plan. The foundation to make a PDCA project successful is the "Plan" phase [11]. However, this step often is ignored, overlooked, or unseriously executed. Then, the project may fail to meet the goals. The plan helps set up a strong team with aligned members who, at the start, understand their responsibilities, project-specific targets, and the right directions.

In the Plan step, identifying and analyzing the opportunity is very important. For human error in the assembly process problem, the current situation of a manual stool assembly process in a furniture manufacturer was observed and analyzed. Firstly, the number of flaws over a week was compiled, and those that had happened more frequently were identified. The defects were then kept in a database to identify the product models with the highest production levels, the most problems simultaneously, and the highest client expectations. The Pareto chart was used for this stage. The Pareto chart in Figure 1 shows that late execution, wrong parts, incorrect tool selection, and missing parts account for nearly 90% of defect problems. Opportunities for improvement were thus found and given the highest priority.

In the Plan step, besides the Pareto chart, several simple and practical tools can be used to improve team communication and problem-solving efficiency.

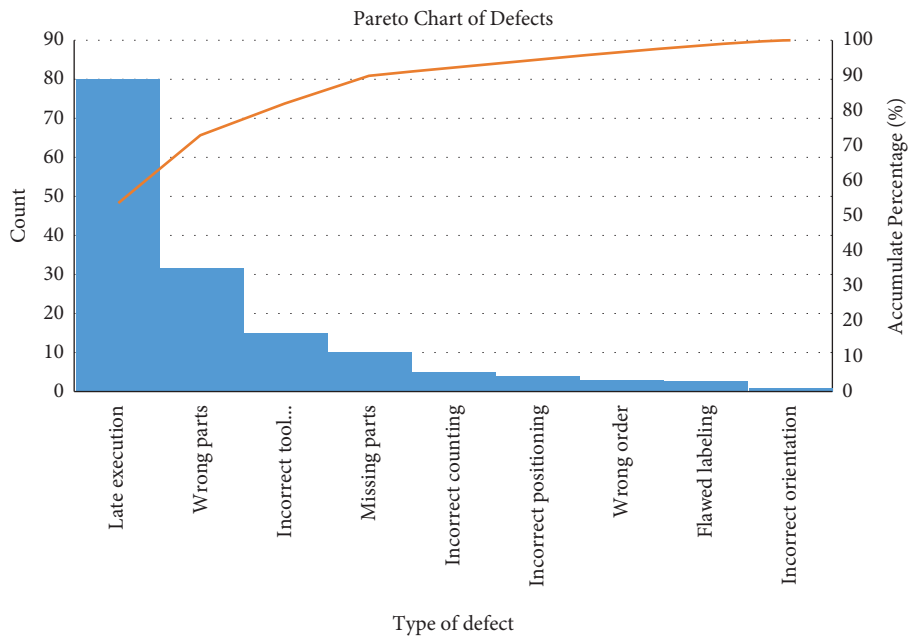


Figure 1: Pareto diagram analysis.

2.1.1. Five Whys Method. It was created by Japanese industrialist and inventor Sakichi Toyoda and is an essential tool for problem solving [16]. Asking why five times for a particular issue is the cornerstone of this successful strategy. Famous quality expert Taiichi Ohno holds that "the nature of the problem, as well as its solution, becomes obvious by repeating why five times." To find a problem's fundamental cause, you might need to question less or more times than five times in general. The five whys aim not to give up until a root cause is identified rather than just having a "symptom." In addition to being utilized alone, the Five Whys strategy is typically part of the cause and effect to identify the causes.

For example (Figure 2): Finding root cause after two Whys.

1st Why: why does the human error occur in the assembly process?

Potential cause: environmental impact.

2nd Why: why can the environment contribute to increased human errors in the assembly process?

Potential cause: distractions caused by loud noise.

Loud noise hampers concentration and focus, disrupts communication, and makes it difficult for workers to hear instructions clearly.

By addressing the noise as a potential root cause, the team can explore solutions to reduce or mitigate the impact of noise in the assembly process.

Another example (Figure 2): Finding root cause after four Whys.

1st Why: why does the human error occur in the assembly process?

Potential cause: poor individual performance.

2nd Why: why do workers have poor performance?

Potential cause: lack of skill and knowledge.

3rd Why: why do workers lack skill and knowledge?

Potential cause: insufficient training.

4th Why: why is the training insufficient?

Potential cause: in-person training is costly and requires planning in advance.

The "why" questions have been expanded to delve deeper into the potential causes. The last why question for each potential cause has provided a more insightful reason. In this example, by identifying the cost and planning constraints associated with in-person training, alternative training methods or strategies should be explored to provide workers continuously with the necessary skills and knowledge.

Fishbone diagram and Ishikawa diagram are other names for a cause-and-effect diagram [16]. All potential failure causes for a given problem can be found, arranged, and shown using this graphic. The problem or effect shown in the chart is on the right or its head. There is a spine, represented by large bones or ribs and straight lines. These skeletons depict the causal chain between important causes and effects. The team will need to brainstorm (or utilize the first Why) to identify the primary reasons for the issue. Small bones represent root causes, while medium-sized bones show secondary causes. The Ishikawa diagram assesses the underlying problems and generates potential remedies.

Figure 2 shows the analysis of human error caused in the assembly process. Many human errors take place because of system implementation insufficiency. Management errors can include inadequate training methods for the workforce, communication problems, and information transfer due to poor procedures such as assembly step-by-step work instructions, manufacturing Standard Operating Procedures (SOPs), or confusing interface systems between operator and machine. Facility and layout design also influence the potential for errors in an assembly, such as inadequate space, poor visualization, or unclear labels in material containers, buttons, tools, and defective equipment. Inadequate

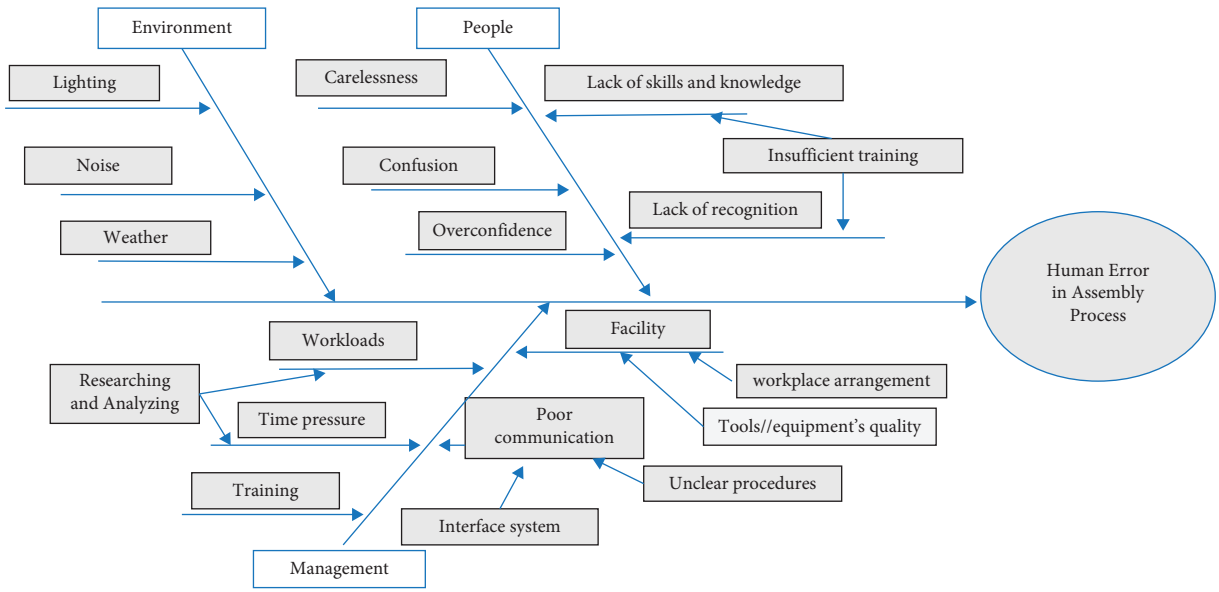


Figure 2: Five Whys method integrated with fishbone diagram for potential causes of human error in the assembly process.

workplace arrangements can prevent optimizing the motions of workers and create extra unnecessary movements. Besides, errors in assigning the workload, types of employees, and task duration time can add a lot of pressure on the labor, leading to mistakes in the assembly process. These potential causes happen due to deficient research and analysis of the pre-manufacturing process or incorrect data collection.

Although many researchers prove that most problems cause the error by management systems rather than labor [7, 17–21], fitness for duty is critical to guarantee the best performance of workers. Mistakes in assembly can be caused by individual perception, competency, and qualification. Workers or operators may lack skills, knowledge, and recognition of the importance of precise, meticulous, and careful requirements for specific tasks due to insufficient training. As human beings, they also have moments when they are careless, distracted, tired, or confused, or they may be overconfident in their experience, not follow instructions, or be subjective in decision making. The problem is that many organizations do not consider these unavoidable error preventions as part of the system design.

Other factors which can also be taken into account are environmental conditions. Lighting, noise, and weather may affect defining mismatch of small parts, handling ability, and mood of humans, which are likely generated errors in working.

After finding the problem and its root causes, brainstorming is a productive way of generating ideas to solve them [16]. There are various brainstorming "rules" to follow to ensure a fruitful session. Suspending judgment and being open to all options are essential for effective brainstorming. At the first point of the brainstorming section, quantity is more important than quality. All ideas are shared with the group and have equal value, even the strange or crazy ones. Then, the group thoroughly discusses or analyzes the ideas. When brainstorming takes shape as a mind map, it can help to evaluate ideas better and create boundary-generating regions forward to the focus. Well-defined topics will support generating enough directly applicable ideas for each particular problem.

The poor lighting, loud noise, and adverse weather conditions were then effectively addressed by implementing measures such as installing additional lighting, providing earplugs, and using fans. This study prioritized finding solutions to address causes related to human factors and management systems (mentioned in Figure 2) with a smart workstation. Figure 3 illustrates the brainstorming in the shape of a mind map for the conceptual designs of the intelligent workstation. The development group includes the design team, operators, and manufacturing engineers. The members have faced or have the expertise and experience related to the problem. Some members are new operators and students who can bring some fresh ideas also to the brainstorming section. The members first brainstormed the required functions of the new workstations. Next, a team discussion will narrow down the demand or wish requirement list with the design and categorize them into subgroups. These subgroups will then be used in developing a modular or integral architecture for components of the workstation.

As the result shown in Figure 3, the new workstation should incorporate features to prevent errors resulting from carelessness, confusion, overconfidence, and lack of knowledge. This necessitates the integration of hardware components such as sensors and mechanical mechanisms, along with software components like information communication and user interface, into an integrated knowledge module. The module should encompass functions such as mistake prevention, displaying relevant information about the task and product, and generating error warnings. Additionally, the smart workstation should include a module to

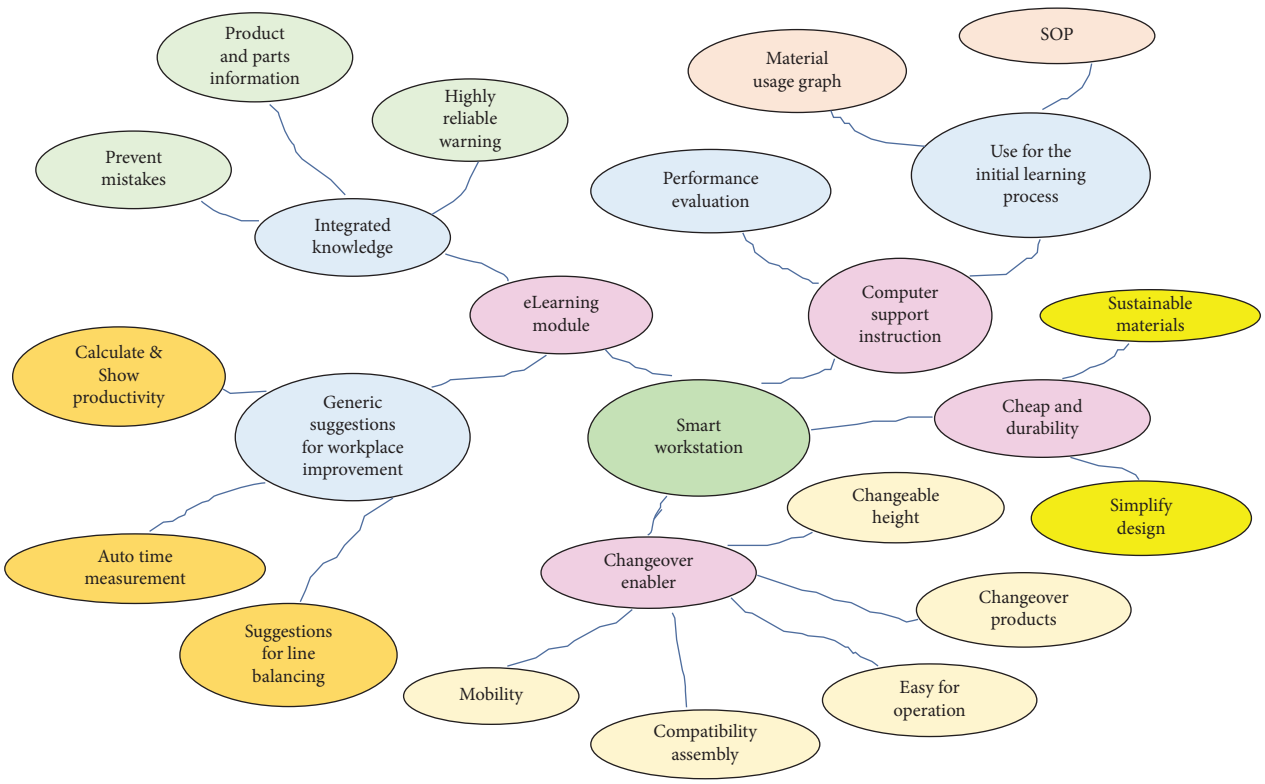


Figure 3: Brainstorming in shape of a mind map for smart workstation conceptual design.

support data collection, storage, and analysis, enabling effective management strategies for workload assignment, setting target times for workers, monitoring and evaluating tool and equipment quality, and suggesting workplace arrangement strategies.

The computer-supported instruction module will contribute to preventing misunderstandings in communication, assisting operators and managers in managing material usage effectively. This module should include functions for initial on-the-job learning as well as continuous study, making it easy to access and verify information comprehensively.

Furthermore, the group brainstormed aesthetic requirements for the workstation's design, taking into account cost and operational constraints within the factory.

2.2. Do Phase. In this stage, based on analyzing the process and identifying the root that needs to be fixed, the team ideates and develops potential solutions, ideally on a small and inexpensive scale, to allow for multiple iterations and measure the results. The design and testing require many steps and need strict commitment from team members.

Figure 4 is the prototype of a new design. Two separated moving parts can easily be assembled to form a complete workstation. The first one is a multipurpose mobile rack. Its usage is flexible. It can be used as a simple rack to store the materials or an integrated board and table. The frame has wheels to be mobile. It can move around the factory, be attached to the production line, and work as a material shelf, or it can be used as a packaging station or a training desk. The second part is a multipurpose table. This table has two top levels at 92.3 and 74 cm heights. They are convenient for workers because they fall within the ideal working height range. The third level is at the height of 10.8 cm. It can be used for bulky components like carton packaging boxes. The table can also work as a trolley to carry the product bins and packages. Workers can quickly push the trolley around without their feet obstructed by any part. Aluminum profiles are used as the materials for workstations.

The prototype is strong, solid, and balanced. The operation of the prototype is stable. It can withstand loads up to 100 kg and is easy to move due to the wheels' smoothness. Due to its separate mobile parts, the workstation can be flexible for many functions, such as accessibility in changing feeding material, easiness in transporting products, and convinience in maintenance. The prototype uses all environmental-friendly materials which suit the sustainability requirements. Its appearance looks lean and bright with the shiny silvery-white color of aluminum and stainless steel. All the materials are resistant to oil, water, moisture, and dust. The control system includes a central processor (CPU), user interface, relays, TIA portal software, weighing transmitter, load cell, and electric components.

The screen enables the ability to guide the employee in completing assembly steps for a product, acts as a human-machine interface for controlling the workstation components, and displays information related to assembly aspects directly at the workstation, as shown in Figures 5(a) and 5(b). The guiding module comprises electric devices to activate the "locate and pick to light" as well as the barriers to

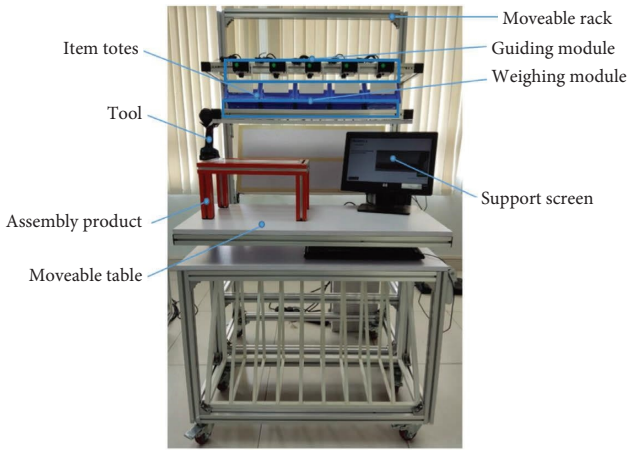


Figure 4: First prototype of the smart workstation.

prevent the wrong picking of items during the assembly process as shown in Figures 6, 7(a), and 7(b). The weighing module is used to control the things at the workstation. More specifically, it handles the function of measuring the current status of the item's quantities so that the item's replenishment can be processed without affecting the primary assembly or production procedure. The weighing module plays a vital role in losing item control by enabling "Reconciliation." Item controlling-based inventory reconciliation helps to avoid discrepancies in material management.

Discrepancies in assembly can come from the broken item during assembling or some unallowed reasons, which require a greater number of the same item to complete a product. Item controlling at the smart workstation can be executed by performing the difference between the actual complete product and the current item at the totes, concerning the weight scaling, compared with the theoretical item needed to complete a product. It can be seen that if the current tote weight is relatively proportionate, the assembly process was properly performed. If the current tote weight is considerably less or more than the theoretically used item (in the weight scale), the issues obviously appeared during the assembly process. These issues then must be perceived and require handling action.

A rigid or margin line pacing can be installed (Figure 8) to assess and control the operation of the workstation operators. Higher administration employees or staff can access the station to define the constraint so that the workstation can function at the required output rate of the line. It is likewise an approach to avoid the underlying variation from the operators that could potentially cause shortages for the assembly line. Concurrently, a warning will be displayed on the user interface if one assembly step is detected to exceed the defined pace. The performance is then accumulated to the operators' efficiency, as well as to leave proof for the pace constraint of the assembly line.

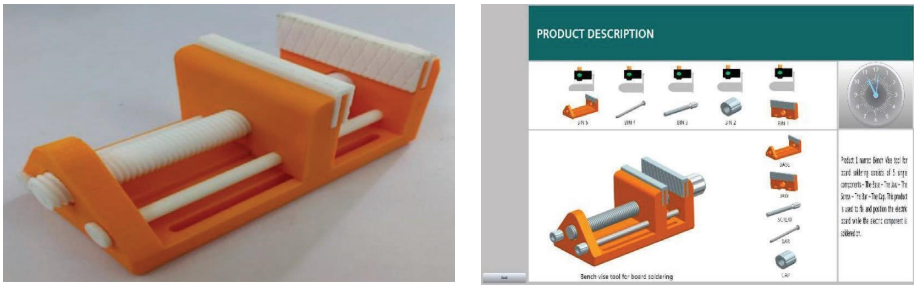
2.3. Check: Study the Results to Evaluate Effectiveness of Solution and Decide Whether the Best Solution Was Developed. Experiments were conducted to evaluate the impact of the additional technology on the less experienced workstation operators between the conventional and the digital assembly guiding. Employees unfamiliar with the product and the prototype of the workstation were invited to perform particular assembly work.

In the experiments, the requirement for the invited employees was to obtain the task times to process all the steps of an assembly job for later operation. In the conventional method, the employees were given paper documents related to the product, consisting of the needed assembly parts and pictures depicting the assembly steps. Using the intelligent assembly workstation, the employees follow the instruction from the user interface and the guiding module. Performed works on the workstation and cycle time from both models were then finalized and compared as shown in Table 1.

For a more complex product with similar shape assembly parts, some employees were running into problems, including how to transfer the proper understanding of paper documents to the actual assembly job and locate the correct part to pick one specific assembly step. The reworks were caused mainly by the employee picking the incorrect part or the wrong assembly step. It is noticeable that even though the technical name of the assembly part was clearly stated in the paper document, the employee was still reluctant to pick one corresponding part to the assembly step, as the paper document cannot illustrate the specification of the assembly part thoroughly, using its technical parameter. These mistakes were prevented and tackled with a smart digital station with fully activated modules.

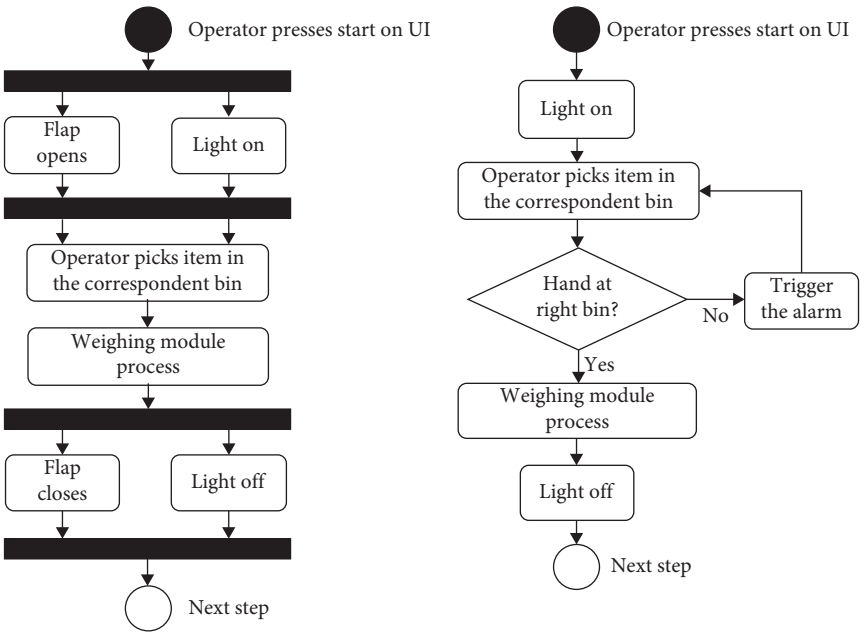
The smart workstation seamlessly integrates a comprehensive set of computer guidelines, complete with step-by-step instructions and a visual aid function, alongside a robust mistake-proofing system. Obviously, this integration eliminates the need for time-consuming searches for components, appropriate tools, and assembly locations, ultimately minimizing the occurrence of rework. As a result, the smart workstation significantly reduces both the time required for locating and picking components and the overall assembly time.

2.4. Act: If the Solution Was Successful, Implement and Control It. The team records the findings and decides whether to accept or reject the changes during the Act phase. PDCA is not a start-to-finish procedure because it is used for continual improvement. Another plan to continue looking for an even better-improved method should be carried out throughout the Act phase. For this case study, the team decides to apply the workstation for training purposes. Another version with a better aesthetic appearance will be a new target for continuous cycle PDCA.



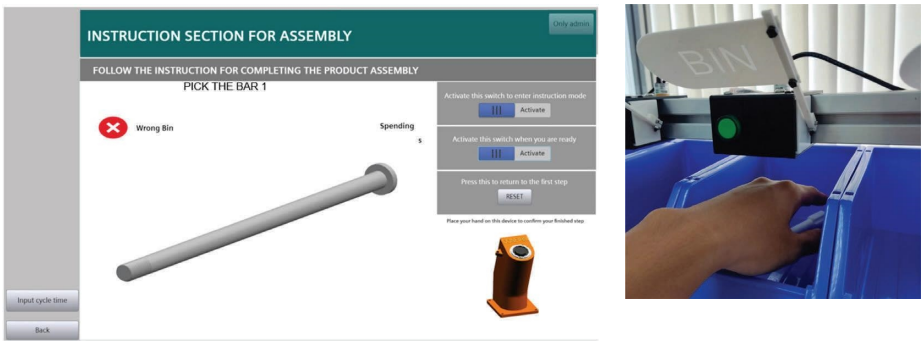
(a) (b)

Figure 5: (a) Actual and (b) digital visual of the assembly product.



(a) (b)

Figure 6: Algorithm flowchart process of guiding module.



(a) (b)

Figure 7: (a) Error caution on UI and (b) wrong part picking detection.

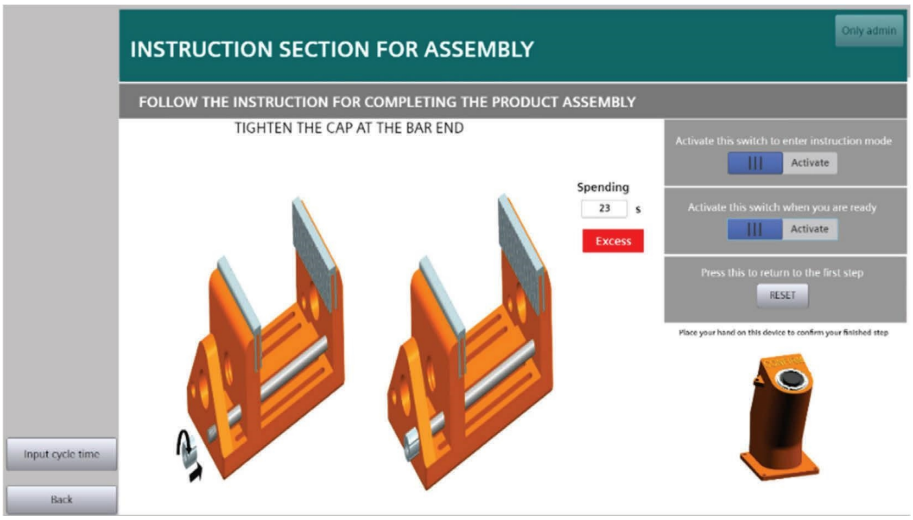


Figure 8: Management of assembly line pacing.

Table 1: Comparison of station average cycle time.

Model	Product	Part locating and picking (s)	Assembling (s)	Station cycle time (s)
Conventional station	A	39	85	244
Smart digital station	A	25	62	91

3. Conclusion and Discussion

PDCA is highlighted in this paper as a simplified methodology for continuous quality improvement problems and the engineering design process. The priorities to implement PDCA successfully are teamwork spirit, defining specific improvement targets, applying PDCA steps consistently with proper tools, and sharing learnings. By integrating the PDCA cycle into the engineering design process, this research designed and prototyped an intelligent work-assembly station integrated and equipped with the hardware to enable a more efficient assembly environment for the operators. The prototype proves its practicability and efficiency in reducing significant mistakes in the assembly process. It aids in the learning process for assembly newcomers through the digital approach of guiding and mitigating defects during product assembly. It also enables data gathering transparency through the Internet of Things application, allowing visual management, tracking materials, and the progress of employees and processes. The collected and documented data are also helpful for future labor, workload assignments, and layouts. This research can be used as a benchmark application of PDCA in quality improvement and engineering design processes with systematic and understandable guidance of the cycle.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

We would like to acknowledge the support from the Vietnamese German University and RMIT University Vietnam.

References

[1] K. Swift and J. Booker, *Manufacturing Process Selection Handbook*, Butterworth-Heinemann, Oxford, United Kingdom, 2013.

[2] E. Gidey, K. Jilcha, B. Beshah, and D. Kitaw, "The plan-do-check-act cycle of value addition," *Industrial Engineering & Management*, vol. 3, no. 124, pp. 2169–0316, Article ID 1000124, 2014.

[3] M. Matsuo and J. Nakahara, "The effects of the PDCA cycle and OJT on workplace learning," *International Journal of Human Resource Management*, vol. 24, no. 1, pp. 195–207, 2013.

[4] M. Tahiduzzaman, M. Rahman, S. K. Dey, and T. K. Kapuria, "Minimization of sewing defects of an apparel industry in Bangladesh with 5S & PDCA," *American Journal of Industrial Engineering*, vol. 5, no. 1, pp. 17–24, 2018.

[5] M. Hussin, Z. Zailani, A. Hasnul Hadi, M. Sanuddin, and M. Hamzas, "Process improvement on manufacturing floor through PDCA methodology," *International Review of Mechanical Engineering (IREME)*, vol. 6, pp. 1441–1448, 2012.

[6] E. Lodgaard, I. Gamme, and K. E. Aasland, "Success factors for PDCA as continuous improvement method in product development," in *Proceedings of the Advances in Production Management Systems. Competitive Manufacturing for*

Innovative Products and Services, pp. 645–652, Paris, Ile-de-France, France, January 2013.

[7] M. Jagusiak-Kocik, "PDCA cycle as a part of continuous improvement in the production company-a case study," *Production engineering archives*, vol. 14, no. 14, pp. 19–22, 2017.

[8] R. E. Nugroho, A. Marwanto, and S. Hasibuan, "Reduce product defect in stainless steel production using yield management method and PDCA," *International Journal of New Technology and Research*, vol. 3, no. 11, Article ID 263201, 2017.

[9] E. C. Jones, M. M. Parast, and S. G. Adams, "A framework for effective Six Sigma implementation," *Total Quality Management and Business Excellence*, vol. 21, no. 4, pp. 415–424, 2010.

[10] D. M. Clark, K. Silvester, and S. Knowles, "Lean management systems: creating a culture of continuous quality improvement," *Journal of Clinical Pathology*, vol. 66, no. 8, pp. 638–643, 2013.

[11] V. Nguyen, N. Nguyen, B. Schumacher, and T. Tran, "Practical application of plan–do–check–act cycle for quality improvement of sustainable packaging: a case study," *Applied Sciences*, vol. 10, no. 18, p. 6332, 2020.

[12] R. Maruta, "Maximizing knowledge work productivity: a time constrained and activity visualized PDCA cycle," *Knowledge and Process Management*, vol. 19, no. 4, pp. 203–214, 2012.

[13] Z. Wani, J. Chin, and N. Muhammad, "Common mistakes in running PDCA: a survey on university student PDCA projects," *IOP Conference Series: Materials Science and Engineering*, vol. 530, no. 1, Article ID 12042, 2019.

[14] S. Isniah, H. Hardi Purba, and F. Debora, "Plan do check action (PDCA) method: literature review and research issues," *Jurnal Sistem dan Manajemen Industri*, vol. 4, no. 1, pp. 72–81, 2020.

[15] A. Chakraborty, "Importance of PDCA cycle for SMEs," *International Journal of Mechanical Engineering*, vol. 3, no. 5, pp. 30–34, 2016.

[16] N. Tague, *The Quality Toolbox*, Quality Press, Welshpool, Australia, 2004.

[17] J. Reason, *Human Error*, Cambridge University Press, Cambridge, England, 1990.

[18] J. J. Gallimore, *Importance of Human Factors in Quality Improvement*, Retrieved from Dept. of Biomedical, Industrial, and Human Factors, Wright State University, Fairborn, OH, USA, 2004.

[19] C. Lewis and D. A. Norman, "Designing for error," in *Readings in Human–Computer Interaction*, pp. 686–697, Elsevier, Amsterdam, Netherlands, 1995

[20] C. Furman and R. Caplan, "Applying the Toyota Production System: using a patient safety alert system to reduce error," *Joint Commission Journal on Quality and Patient Safety*, vol. 33, no. 7, pp. 376–386, 2007.

[21] T. S. Lee and E. E. Adam, "Forecasting error evaluation in material requirements planning (MRP) production-inventory systems," *Management Science*, vol. 32, no. 9, pp. 1186–1205, 1986.