Low-Cost Digitization for Monitoring Manual Processes: A Case Study of Tray Cleaning in Semiconductor Manufacturing

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Abstract—**The increasing global adoption of Industry 4.0 technologies has transformed many aspects of manufacturing through automation, data analytics, and smart systems. However, high implementation costs often prevent labor-intensive processes, particularly in developing regions and smaller enterprises, from realizing these benefits. This study addresses that gap by proposing a low-cost digitization solution focused on tray cleaning in semiconductor manufacturing, a critical yet manually executed process. In collaboration with Sony Device Technology Thailand, an Excel VBA-based application was developed to automate real-time recording of tray movements and manpower data. The system incorporates inventory tracking, productivity monitoring, and an interactive dashboard that enhances operational visibility and eliminates the need for manual checks. Quantitative evaluation revealed a 50% reduction in input processing time and a 74.07% decrease in output processing time per transaction. Qualitative improvements include increased cross-functional collaboration, more transparent workforce evaluation, and data-driven decision-making. This study contributes a scalable, practical model for affordable digitization that integrates seamlessly with existing workflows, offering an effective path toward digital transformation in labor-intensive manufacturing environments.**

Index Terms—**Industry 4.0, Digitization, Excel VBA-based Application, Data Visualization, Semiconductor Manufacturing**

I. Introduction

The rapid evolution of the Fourth Industrial Revolution is reshaping manufacturing industries worldwide. Smart factories, intelligent inventory systems, and automated supply chains are becoming the standard, driven by advancements in artificial intelligence, machine learning, and data analytics [1]. At the core of this transformation lies digitization—the process of converting analog operations into digital formats to enhance efficiency and decision-making [2]. However, while large-scale digitization projects offer significant benefits, the high implementation costs pose a challenge.

In manufacturing, data is a fundamental requirement for process optimization. Every company needs reliable, real-time data to enhance efficiency, minimize waste, and optimize operations [3]. Despite the growing adoption of Industry 4.0, not every manufacturing step can be fully automated. Some processes, particularly those involving human operators, remain difficult to digitize using automated sensor-based tracking systems due to cost constraints. This gap highlights the need for practical, low-cost digitization solutions that can integrate with existing workflows without requiring substantial financial investment [4].

The semiconductor industry, a critical driver of modern technology, is a prime example of this challenge. Semiconductors power everything from smartphones to advanced computing systems, making their production efficiency crucial to meeting global demand [1]. In Thailand, the semiconductor sector is expanding rapidly, supported by increased investments aimed at enhancing production capacity and operational efficiency. Tray cleaning is a critical but often underappreciated process in semiconductor manufacturing, as it plays a key role in handling and protecting delicate wafers during transport and storage. Clean trays help prevent contamination, maintain yield quality, and reduce production loss, especially in high-volume production environments.

However, despite its importance, tray cleaning operations remain heavily reliant on manual labor, primarily due to the complexity of the task and the high cost of automation [2]. As a result, this process often lacks digital monitoring and is excluded from broader Industry 4.0 initiatives, even among large manufacturers. Ensuring accurate data recording and real-time monitoring for these operations at a low cost is vital for improving efficiency without disrupting existing workflows.

This paper presents a case study on low-cost digitization in semiconductor manufacturing, focusing on tray cleaning operations. By collaborating with Sony Device Technology Thailand, this research develops an Excel VBA-based application that enables real-time data recording and visualization of manpower and inventory movement. This approach provides an affordable alternative to high-cost automation systems, allowing manufacturers to enhance process tracking and decision-making without significant infrastructure changes.

To sum up, this study highlights the potential of low-cost digitization as a practical solution for bridging the gap between manual operations and Industry 4.0. By leveraging simple yet effective digital tools, manufacturers can optimize their processes, improve inventory management, and enhance operational efficiency with minimal investment. As industries continue to evolve, accessible digitization strategies will play a crucial role in ensuring sustainable growth and competitiveness in the global market.

II. Objective

This research develops an Excel VBA-based data collection tool to track manpower, automate productivity calculations, enable real-time data monitoring for informed decision-making, and reduce redundant manual verification processes.

III. Related Work

Industry 4.0 has significantly reshaped manufacturing with automation, AI, and IoT, offering advanced solutions to optimize operations. These innovations, including smart factories and automated supply chains, have greatly enhanced operational efficiency in developed economies [1], [2]. However, the high costs of automation pose significant challenges for small enterprises and developing nations. While automation benefits large-scale operations, many industries in emerging economies, including Thailand, continue to rely on manual labor due to the prohibitive costs associated with full automation [3], [4].

In sectors like semiconductor manufacturing, tasks such as tray cleaning remain heavily manual due to the complexity and high costs of automating these processes [2]. Despite the growth of Industry 4.0, there is a notable gap in providing affordable digitization solutions for industries that still rely on manual workflows. Most existing research focuses on high-tech automation tools, leaving small-scale manual operations largely overlooked [4]. This gap underscores the need for practical, low-cost alternatives that can seamlessly integrate with existing manual processes, making digitization accessible even for companies with limited financial resources.

The importance of low-cost digitization tools is further emphasized by the need for affordable alternatives in sectors that still rely heavily on manual labor, as highlighted by studies on semiconductor industries [5] and logistics management [6]. Existing research has also indicated that high financial costs, capital-intensive spending, and lack of incentives are among the most critical barriers across multiple industries when adopting new technological or circular models [7]. In parallel, cost-effectiveness has been identified as a decisive factor in other technological domains, such as renewable energy transitions, where improving efficiency and lowering Levelized Costs is essential for widespread adoption [8]. By leveraging Excel VBA applications, this paper demonstrates how businesses can achieve significant improvements in efficiency and accuracy without requiring large capital investments typically associated with high-tech solutions [9].

In addition to optimizing manual workflows, the integration of simple digital tools plays a key role in the digital transformation of small-scale operations, particularly within Thailand's manufacturing sector, where many businesses still rely on human labor [10]. This project highlights the potential impact of affordable digital solutions that bridge the gap between manual labor and Industry 4.0, providing businesses with the chance to enhance their competitiveness on a global scale without bearing the heavy financial burden of traditional automation systems [11]. The solution developed in this project has already been applied in the real semiconductor industry, demonstrating its practical value in enhancing operational efficiency and improving tracking systems without requiring costly automation. In summary, by introducing an accessible, scalable solution to improve manual operations, this paper contributes to the broader effort of modernizing industries in developing economies. The proposed solution could significantly enhance operational efficiency in smaller, labor-intensive operations, positioning them to better compete in an increasingly digital global marketplace. Moreover, this solution has already been successfully implemented in the real semiconductor industry, demonstrating its practical value in optimizing workflows and improving operational tracking in a real-world setting.

IV. Methodology

This section comprises two main parts: the generalized concept of a proposed system and a case study.

A. Proposed System

The proposed system, illustrated in Fig. 1, is designed to achieve three key objectives: recording tray movement, tracking manpower, and providing a real-time dashboard for comprehensive monitoring. The system is intended to manage the cleaning and storage processes within a designated room, where trays undergo a series of operations, including counting, inspection, cleaning, and if necessary, repair. The movement of each tray through these stages is systematically recorded in the application, ensuring that every action is logged for accuracy and traceability. Additionally, workers are required to input their manpower details at each stage, enabling the system to track the allocation of human resources alongside the physical movement of trays. Upon completion of all tasks, a real-time dashboard is provided to offer an integrated view of both tray and worker activities, ensuring full visibility into the operational process. This dashboard enables real-time monitoring, allowing managers to oversee the status of trays and workers, and thus enhancing efficiency and accountability. The system's design is adaptable, making it applicable to various industries that require the management of assets and labor, ensuring seamless integration into different workflows. By capturing and presenting data in an accessible format, this system offers potential for broad implementation, contributing to the optimization of operational processes across various sectors.

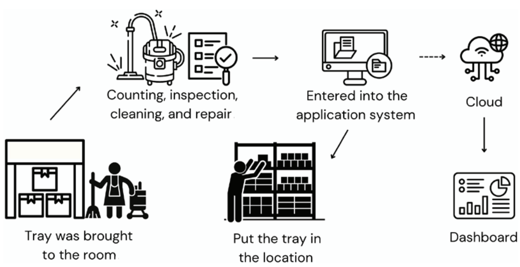

Fig. 1. Tray management process flow

B. Case Study

In this case study, the application was developed in collaboration with Sony Device Technology Thailand following interviews to identify inefficiencies in the manual tray tracking process. Through iterative prototyping and user feedback, a low-cost Excel-based system was developed and deployed in the tray cleaning area, as shown in Fig. 2. The tool integrates VBA and PivotTables to support real-time recording of manpower and inventory with minimal disruption to existing workflows.

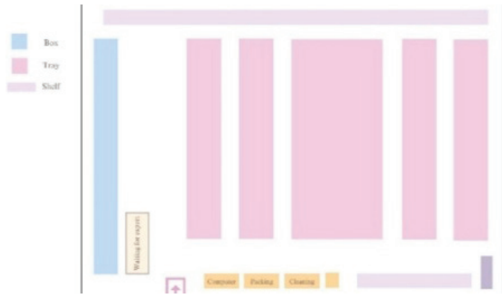

Fig. 2. Tray storage and workflow room layout example

1) Database

The database design was guided by an iterative development process rather than a technical specification. First, requirements were gathered through short interviews with operators and supervisors, which revealed frequent errors in manual logging of operator IDs and tray details. Based on these findings, two simple databases were designed: one for operator information (numeric ID and name) and another for tray information (tray ID, name, pieces per pack, business unit, and location).

Prototype versions were then tested with actual barcode scans in the workplace. User feedback highlighted the need for automatic validation and additional fields, such as tray location. These refinements were incorporated into the final design. The resulting databases thus reflect both technical considerations and user-driven adjustments, ensuring accuracy and ease of adoption.

2) Recording Tray Movement (Tray Inventory)

This feature was developed using a VBA-based user form to enable structured and consistent recording of tray quantities and related operational data. Upon entering key identifiers, such as part code and operator ID, the system performs input validation against the existing database and retrieves relevant information as shown in Fig. 3. Users then input the total quantity, after which the system automatically computes the number of packs and any remainder using the formulas: Pack Quantity = Total Quantity / Pack Size and Remainder = Total Quantity mod Pack Size. To reflect operational contexts, users can also select the appropriate transaction type. The interface and logic were refined through iterative feedback from operators, with particular attention to usability and error reduction as shown in Fig. 4.

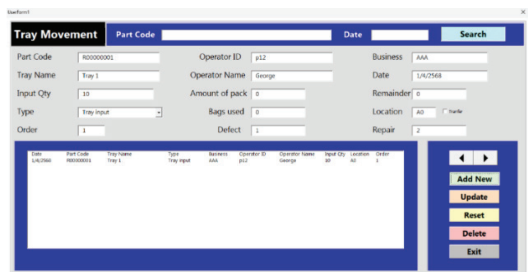

Fig. 3. The recording tray movement system

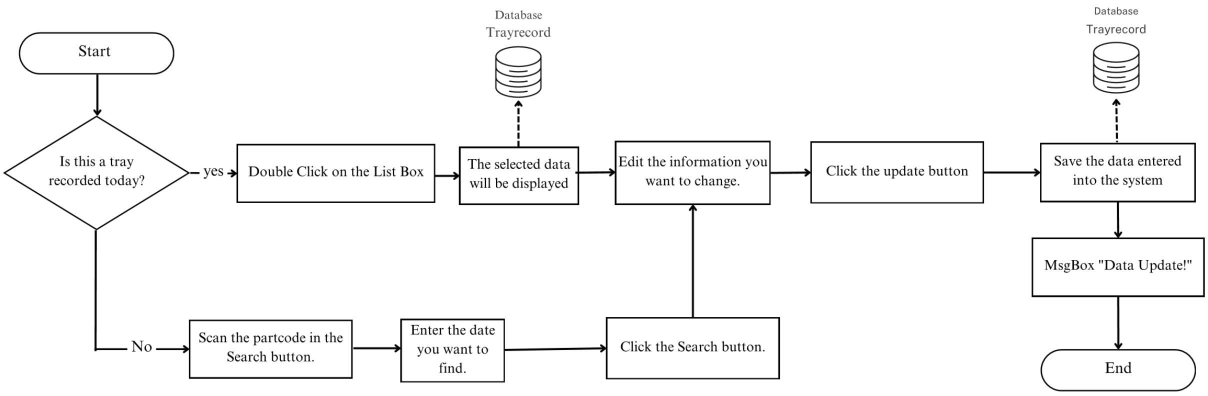

Fig. 4. The recording tray movement process chart

3) Recording Manpower

This feature, developed using Microsoft Excel VBA, offers an efficient system for tracking manpower and evaluating productivity. When the user clicks the "Manpower Record" button, a userform prompts them to input the necessary information, as shown in Fig. 5. The system then validates and processes the inputs according to the steps outlined in Fig. 6, ensuring that only accurate data—such as text, numbers, and dates—is saved to the manpower file. The application automatically records the time spent on each task. The recorded data is subsequently analyzed to monitor manpower usage, assess workloads, and improve productivity through automated task duration calculations. Productivity is determined using the formula: Productivity = units of output/ labor hours worked.

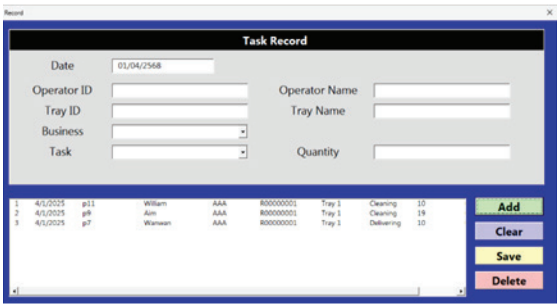

Fig. 5. The recording manpower system

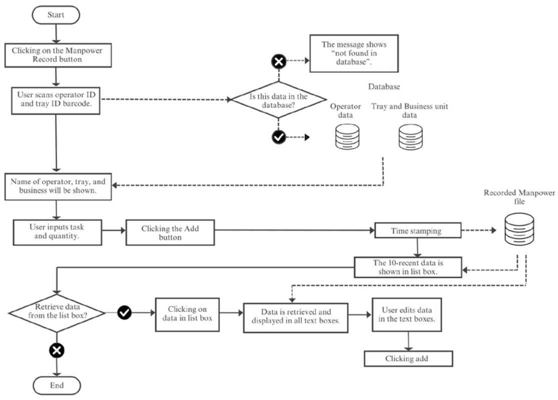

Fig. 6. Manpower record process chart

4) Dashboard Analyzation

To analyze the recorded data, the system retrieves both the manpower and tray quantity files and imports them into the main file. The command then generates an Excel PivotTable as an analysis tool to summarize productivity and inventory stock, following the process outlined in the chart, as shown in Fig. 7. To analyze available space, the system applies a weighted-average method since each pallet row does not have a fixed quantity. The analyzed data is then displayed as a percentage, making it easier to support decision-making. The results are displayed as an interactive graph with slicers, enabling managers to sort and filter the data according to their specific needs.

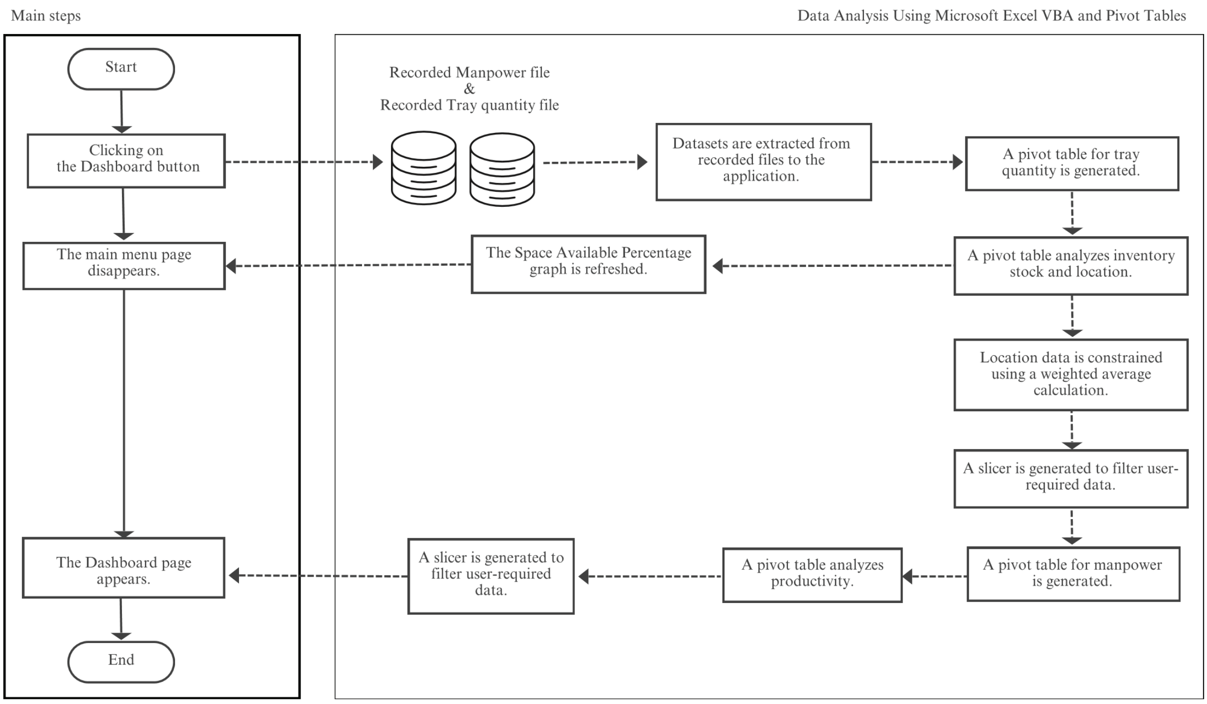

Fig. 7. Dashboard analysis process chart

V. Results and Discussion

For evaluating the performance of the demonstration set, reliability and accuracy have been tested.

A) Real-Time Interactive Monitoring Dashboard

To facilitate data visualization, an interactive dashboard with slicer functionality, as shown in Fig. 8, consolidates essential information on a single page, enabling users to make informed decisions quickly. The dashboard dynamically retrieves and presents data, eliminating the need for up to a week of manual effort previously required to summarize tray quantity and manpower productivity. Operators can now check tray inventory levels on a computer instead of performing manual counts, other departments can access the system in real time, reducing delays from phone inquiries. The dashboard enables managers to summarize tray quantities by month, date, and business unit using the left-hand slicer, and track productivity by month, date, and operator name using the right-hand slicer. The interactive graph separates data into manpower and tray quantity sections. A quick search feature and tray quantity summary further streamline inventory management by providing users with in-stock quantities based on scanned barcodes, improving efficiency in checking, and reducing time spent on counting and searching. It also enhances cross-department collaboration by making information accessible without informal inquiries. Thus, the dashboard reshapes both work habits and communication patterns.

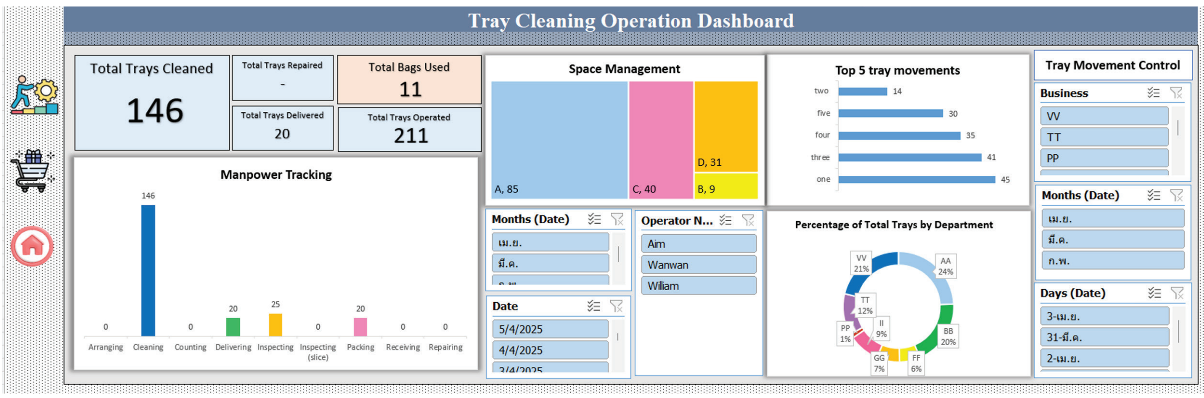

Fig. 8. The Dashboard analysis

B) Evaluation of Time Reduction in the Data Recording Process

The new application enhances efficiency by eliminating redundant tasks such as manual data entry and phone inquiries. With built-in data analysis and a real-time dashboard, it streamlines workflows, reduces errors, and enables faster, more accurate tracking of progress.

When comparing the traditional process and the newly developed process in terms of Input, as shown in Table I, and Output, as shown in Table II, the new process has significantly improved by removing unnecessary steps. In the Input section, the traditional process takes 1 minute and 40 seconds per transaction, while the new process only takes 50 seconds, reducing the time by 50 seconds or 50%. This time reduction is due to direct data entry into the application instead of manual writing and the removal of redundant steps, such as cleaning and arranging, which can now be done more efficiently. In the Output section, the traditional process takes 2 minutes and 15 seconds, whereas the new process only takes 1 minute and 4 seconds, saving 1 minute and 11 seconds or 74.07%. This reduction is achieved by eliminating phone calls for inquiries and enabling instant data entry within the application. These improvements in both sections make the overall process faster and more efficient, significantly reducing transaction time and increasing productivity.

Time savings reduce manual effort and can improve fairness and accountability, yet require employees to adapt to more structured workflows. The process redesign affects routines and staff interactions beyond mere efficiency.

C) Manpower Productivity Monitoring

This system introduces a new approach to track manpower in an area where no previous tracking or recorded data existed. The implemented system fills this gap by recording each operator's start time and task details, enabling accurate productivity assessments, as shown in Table III. Although this analysis uses data from a single operator, it originates from the cleaning data system and serves as a representative example. The system is scalable and can accommodate multiple operators based on each company's size and operational needs.

This data-driven approach replaces verbal reporting with measurable evidence, enabling managers to make informed workforce adjustments to prevent tray shortages, balance workloads, and reduce idle time. By recording detailed manpower data, the system ensures performance evaluations are objective and transparent. This not only enhances operational efficiency but also supports a structured, evidence-based method for managing workforce and inventory in previously untracked areas.

TABLE I
INPUT COMPARISON FOR 1 TRANSACTION

Input	**Present Steps for a Transaction**		
Order	**Activity**	**Action**	**Time/Transaction (avg.)**
1	Tray/Box for Delivery	Recorded Manually	0:00:29
2	Tray Cleaning	Clean, Count, Repair, and Pack	Depending on theAmount of Tray
3	Tray Placement on Shelf	Arranging	0:00:21
4	Data Entry in Traditional Application	Data Entry in Traditional Application	0:00:50
	Total		**0:01:40**

The recorded processing time is expressed in hours, minutes, and seconds (hh:mm:ss).

Input	**Proposed Steps for a Transaction**		
Order	**Activity**	**Action**	**Time/Transaction (avg.)**
1	Tray/Box for Delivery	Clean, Count, Repair, and Pack	Depending on the Amount of Tray
2	Data Entry in New Application	Input Data into the New Application	0:00:29
3	Tray Placement on Shelf	Arranging	0:00:21
	Total		**0:00:50**

The recorded processing time is expressed in hours, minutes, and seconds (hh: mm: ss).

TABLE II
OUTPUT COMPARISON FOR 1 TRANSACTION

Output	Present steps for a transaction		
Order	**Activity**	**Action**	**Time/Transaction (avg.)**
1	Call to Request/Ask	Communicate with Another Department	0:00:56
2	Save initial order data	Manually recorded	0:00:29
3	Retrieve Tray	Pick up the tray from the shelf	Depending on the amount of tray
4	Issues from the Traditional Application	Issues from the Traditional Application	0:00:50
	Total		**0:02:15**

The recorded processing time is expressed in hours, minutes, and seconds (hh: mm: ss).

Output	Proposed steps for a transaction		
Order	**Activity**	**Action**	**Time/Transaction (avg.)**
1	Receive the Report	Check if there is a tray in the Application	0:00:06
2	Retrieve Tray	Clean, Count, Repair, and Pack	Depending on the Amount of Tray
3	The Output Tray from the New Application	The Output Tray from the New Application	0:00:29
	Total		**0:00:35**

The recorded processing time is expressed in hours, minutes, and seconds (hh:mm:ss).

TABLE III
EXAMPLE OF MANPOWER PRODUCTIVITY CALCULATION

No.	Date	ID	Name	Product	Task	Quantity (Piece)	Time Record	Duration (hh: mm: ss)	Productivity (Pieces Per Hour)
1	19/2/2025	R01	Employee 1	Z	Cleaning	50	1:57:33 PM	0:07:42	390
2	19/2/2025	R01	Employee 1	Z	Inspecting	50	2:05:15 PM	0:03:50	783
3	19/2/2025	R01	Employee 1	Z	Packing	50	2:09:05 PM	0:01:29	2022
4	19/2/2025	R01	Employee 1	Z	Arranging	50	2:10:34 PM	0:03:20	900

The recorded processing time is expressed in hours, minutes, and seconds (hh:mm:ss).

VI. CONCLUSION

This study aims to develop a low-cost digitization method for semiconductor manufacturing, focusing on tracking tray movements and recording employee activities. The approach utilizes an Excel VBA-based application, offering a more affordable alternative to expensive automation systems. This method helps record and visualize data related to labor and inventory movements in real-time, without requiring significant changes to the existing infrastructure. The development of the new application reduces the time by 50% in the Input Tray process and 74.07% in the Output Tray process. The proposed system integrates seamlessly with existing processes, allowing manufacturers to track operations and make better decisions. While accuracy improvements in data accuracy are needed, the low-cost digitization approach demonstrates strong potential for enhancing operational efficiency and process monitoring.

VII. FUTURE WORK

Previously, the company relied on manual record-keeping, repeatedly entering data into a computer without the ability to export files for further analysis. With the implementation of this application, data is automatically calculated and recorded in an Excel file. Additionally, the files are retrieved and summarized in a one-page, real-time interactive dashboard. However, due to the coding limitations of Microsoft Excel VBA, the current application lacks flexibility in automatically tracking manpower and updating tray inventory. Privacy concerns within the collaborating company also pose challenges in integrating outsourced cameras. To address these limitations, future improvements should focus on leveraging computer vision and machine learning to automate quantity tracking and manpower productivity monitoring, reducing reliance on manual data entry.

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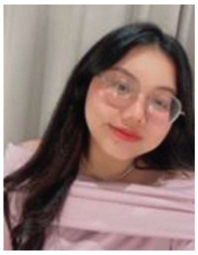

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