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Real-Time WIP Shelf-Life Tracking with Barcode Technology for Defects Reduction

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Abstract. *Manual labeling of product information in the wafer production line at PT XYZ failed to meet secure tracking and tracing requirements, resulting in increased defects. To solve this problem, the author used the Gemba Kaizen approach as a tool companies use for continuous improvement achieved through low-cost steps. Our main idea is to introduce alternative technologies by developing real-time applications to track WIP (Work-in-process) movement information in production. This barcode technology uses low-cost technology and has proven effective in helping production supervisors speed up decision-making of WIP management and minimize the risk of process failure in production that causes an increase in the number of defects. The results showed that the real-time system can reduce the number of defects from 2.6% to 1.6%. This can optimize overall inventory management and provide valuable insights for manufacturing companies looking to improve their operational efficiency through low-cost technology and real-time monitoring.*

Keywords: *inventory; gemba kaizen; real-time monitoring; shelf life; work in process*

I. Introduction

Inventory management is an operation to monitors and tracks the flow of stock of goods within an organization. In this transformative era, the efficient management of warehouse inventory holds paramount importance for the seamless functioning of production and supply chains (M. G. Khan et al., 2022) Effective Inventory management is important for manufacturing plants. It balances holding too little or too much stock to improve efficiency (M. Khan et al., 2023). A production-inventory system includes finished goods inventory managed by inventory strategy and restocking mechanisms that play vital roles in the structure of a stock-to-fulfill inventory control framework (de la Cruz & Daduna, 2023). High inventory levels directly impact financial results and reduce plant efficiency (Al Barrak et al., 2017). The ineffective management of inventory can result in excess inventory, which may be deemed wasteful from a lean philosophy perspective (Zhu et al., 2023).

To avoid running out of stock, it is essential to maintain good inventory management (Leung et al., 2016). Examining an inventory system aims to comprehend the systematic progression of goods or WIP across various stages within a manufacturing cycle (Mahapatra et al., 2021). Ensuring WIP is properly maintained is crucial to achieving production plan targets. In managing inventory flow, when problems occur that require tracking, WIP monitoring requires close supervision aimed at output tracking, status monitoring, quality control, defects reduction, capacity feedback, delivery time reduction, and cost minimization. This crucial element must be maintained in manufacturing companies with a competitive advantage to improve lead time, WIP efficiency, productivity, and delivery time (Gebeyehu et al., 2022; Manuel et al., 2019). According to Paschko et al. (2023) to achieve maximum throughput and minimum WIP, inventory management is used to balance uncertainties and minimize costs to achieve optimum productivity and worker utilization.

Wafer products with a short shelf life can easily deteriorate if their WIP stage is improperly handled. Because a wafer is a perishable food, the duration of travel and storage conditions are critical for food quality and safety and for

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extending shelf life (Bimpizas-Pinis et al., 2022; Cevoli et al., 2023). The system monitoring for a wafer as a fast-moving WIP can be more complex due to its short shelf life. Monitoring the food product's shelf life during distribution is important because its quality can deteriorate physiologically, chemically, and physically over time (Fadiji et al., 2023). This systematic approach is crucial as deterioration rates or defect percentages tend to increase with a larger WIP (Mandal et al., 2021).

Product quality can be affected by variations (defects) in raw material, production conditions, and operator behavior (Simegnaw Ahmmed & Ayele, 2020) as different factors, such as breakdowns, misplacements, process errors, human error (Zhou & Piramuthu, 2015), high levels of non-conformity, lack of planning, or long preparation times (Quiroz-Flores & Vega-Alvites, 2022) which cause inventory inaccuracies. Many research papers have identified the need for innovative solutions to improve product quality and delivery time and reduce defects (Rathi et al., 2021).

In production, when a process or machine failure (breakdown) occurs, it is an urgent matter to have a successful traceability system. The aim of smoothing the process flow is to ensure proper traceability of materials in the WIP process (Benmoussa, 2022). Implementing traceability involves storing and communicating product information to support documentation (Islam et al., 2022). In an ideal traceability system, product labels should tag each product securely (Agrawal et al., 2018).

Product labels can provide product information on WIP to track if there are affected products that have problems. Research in food science has yielded mixed results on how labeling affects consumer choices (Folwarczny et al., 2024). This is particularly challenging for labeling solutions in the fast-moving consumer goods industry, which must meet strict track and trace requirements (Isohanni, 2022). However, manual product labeling systems are not recommended because they are less efficient and error-prone in providing such information.

Alternative technologies can replace manual paper-based labeling systems to increase efficiency in handling WIP. The implementation of Barcode as an alternative technology has been discussed in selected papers. Research conducted by Hlongwane et al. (2019) found that Barcode labels have evolved to the point where they can seamlessly trace products from manufacturing facilities across worldwide distribution networks. Barcodes are the most popular identifiers in retail stores, and they are undoubtedly the easiest and fastest method available to share financial statement information (Ning & Yu, 2021). Barcode technology ensures that data collection can be repeated and verified by others, increasing the transparency and reproducibility of published research, and it is an open-source tool to document data wrangling and analysis (Copp et al., 2014; Wu et al., 2020). *Barcodes* are a useful technology that can help businesses automate tasks like inventory management and product tracing, which can be repetitive and time-consuming if done manually. Barcodes have revolutionized inventory management in industrial settings by improving speed and accuracy compared to traditional manual identification methods. Producing barcode labels costs significantly less due to the requirement of only specific software and a printer (Fernández-Caramés et al., 2019).

PT XYZ is implementing a Kaizen improvement program with a low-cost approach company policy by delivering high-quality products while increasing productivity and driving innovation at low costs. One of the key strategies for achieving this is implementing Gemba Kaizen, a continuous improvement process applied to all operations within the company. According to Kumar et al. (2018), the Gemba Kaizen workshop is a Lean Kaizen approach that directly influences processes and management systems. Aizen makes production processes more efficient and standardized, particularly in quality, cost, transportation, management, safety, and working conditions. His approach begins with small changes and low costs to achieve complete and continuous improvement of conditions (Androniceanu et al., 2023). The Kaizen

Figure 1. Product Information Label (Wafer Line)

management model is widely used in global corporations and focuses on continuously improving processes to reduce costs and enhance the quality of goods and services (Kozhabayev et al., 2023).

As a leading publicly traded world-class food manufacturer, PT XYZ is listed on the Singapore Stock Exchange with its affiliated company in Indonesia. One of the problems in PT XYZ's wafer production department was the use of paper-based manual inventory management methods to record all information about WIP. All WIP containers were labeled with small labels bearing product information entirely written by hand, making them vulnerable to misinformation or a high risk of inaccurate tracking information in case of problems on the production line. These have contributed to the increasing number of defects. This issue can damage the company's reputation and lead to significant future losses. Figure 1 is the manual product labeling system at PT XYZ.

To overcome these problems, a new systematic approach using the Gemba Kaizen concept is needed to identify the cause of the increase in production defects with data capture techniques to integrate material and product information flows on the production floor.

II. Research Method

This research uses the experimental Kaizen management technique, especially in inventory. The research approach depicted in Figure 2 guided the development of the research methodology concept (Cherrafi et al., 2019; García-Alcaraz et al., 2022).

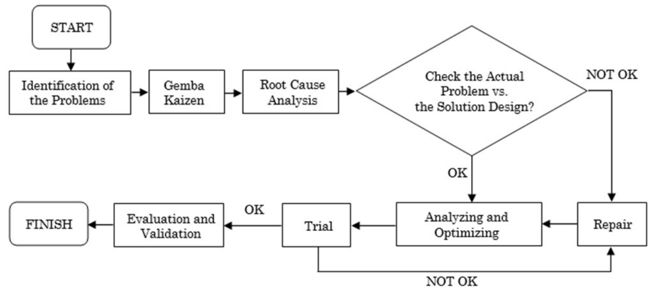

Figure 2. Research Method

The stages of Gemba Kaizen are as follows:

2.1 Identification of the Problems

Data collection of defects in wafer production lines was the first step in this study. By elucidating the input and output mechanism, it becomes simpler to identify the requisites and limitations pertinent to creating an inventory management system. This is illustrated in Figure 3 through the depiction in the system flow diagram.

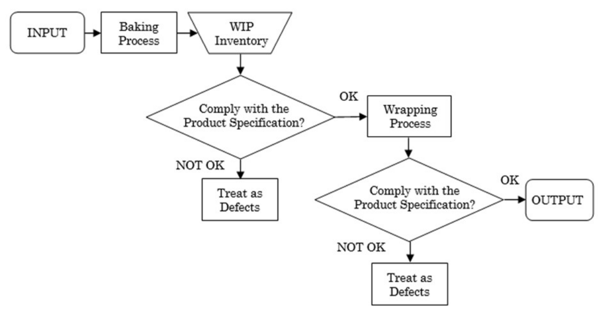

Figure 3. Wafer Line Flow Diagram

The movement of product material from input to output goes through a series of processes from the Oven machine (Baking process) to the Wrapping machine (Wrapping process), which should comply with the product specifications. This flow diagram identified that the manual label system was not accurate enough to trace material flow and information when there was a problem with the machine or production process, so the manual label system was ineffective in minimizing products affected (defects) by the problem. Operational data will be collected through systematic records (Garza-Reyes et al., 2022), including data on monitoring time information related to WIP age and the number of defects produced before and after implementing the Barcode application system in production.

2.2 Gemba Kaizen and Root Cause Analysis

It is recommended that Gemba be performed after identifying the problem. Gemba's objective is to directly witness and address production floor issues without dependence on intermediaries. Direct site examination facilitates the prompt identification of deviations from the established procedures (Cherrafi et al., 2019). The production supervisor, QC staff, and head conducted Gemba to understand the issue comprehensively.

2.3 Check the Actual Problem vs. the Solution Design

It is important to place design problems and solutions side by side to compare the problem and the proposed design solution. This paper proposes real-time monitoring of the WIP movement toward the finished product with secure system access through user authentication on the Use Case Diagram of User 1 and User 2 (Figure 4).

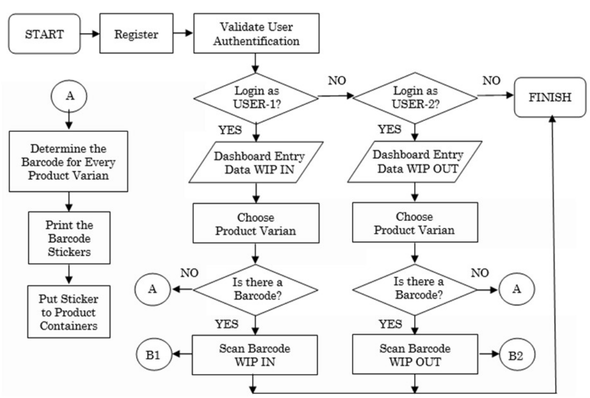

Figure 4. Conceptual Framework of WIP Entry Data System (IN – OUT)

Utilizing the gathered information, we constructed The Use Case diagram to outline the interactions between the user and the envisioned system (Pradana et al., 2023). The Use Case SPV (Supervisor) (Figure 5) controls the application usage and monitors WIP in real time through the application dashboard.

2.4 Analyzing and Optimizing

Once the design and appropriate tools have been established, following this pivotal stage, the subsequent essential action involves scrutinizing and enhancing the design or process. Records of production are useful in aiding process design and optimization, particularly in simulating applications. However, if the design and application differ, necessary improvements must be made to achieve the primary objective.

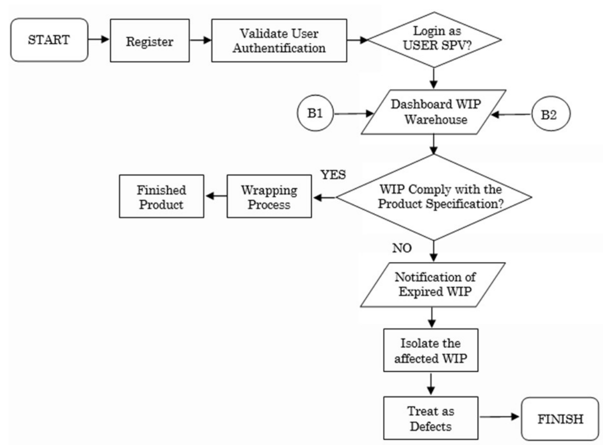

Figure 5. Conceptual Framework of WIP Warehouse System

2.5 Trial

Trials are conducted to achieve a successful simulation of the application. The decision-making trial is a technique that is used to visualize cause-and-effect relationships (Tseng et al., 2023).

2.6 Evaluation and Validation

After implementing a real-time application that tracks the movement of work-in-progress (WIP) to the finished product, we will assess its effectiveness in reducing defects in the wafer production line. This evaluation and validation will be conducted using linear regression statistical tests to measure the effectiveness of the application.

III. RESULT AND DISCUSSION

3.1 Result

The Gemba test was conducted, and it has the following results. In identifying the root cause of defects sources, the Pareto Analysis is used to prioritize and identify critical sub-defects (Wassan et al., 2022). The results of the Pareto chart analysis on the wafer production line (Figure 6) showed the highest number of defects caused by WIP that did not comply with product specifications. Some of the causes were machine breakdown, product changes, and overproduction, which resulted in expired WIP so that it could not be packaged into finished products. In quality Inspection, samples are defective sources that cannot be avoided in production. The number of defects in the wafer line in January-July 2023 (Figure 7) exceeds the predetermined maximum target of 2%. This was related to the difficulty in managing data manually, which was the main trigger for the problem of increasing the number of defects.

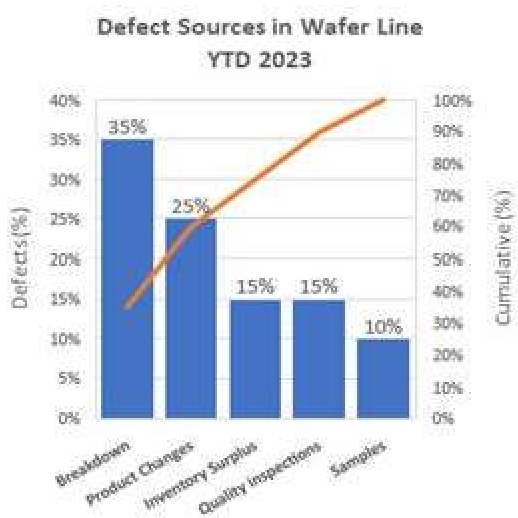

Figure 6. Pareto Chart of Defect Sources

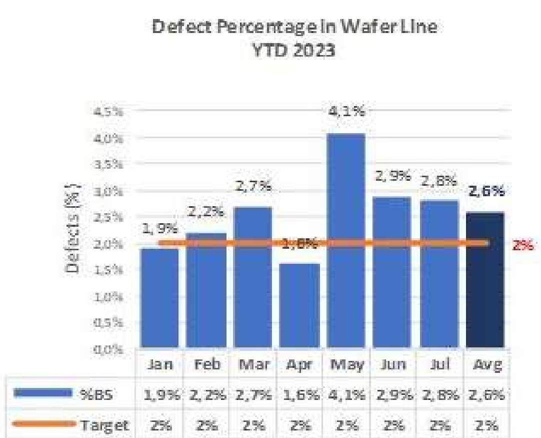

Figure 7. Defect Percentage Chart

The study describes the system design of the application, implementation and collects data to prove its effectiveness. The barcode scanner application is designed to generate a unique barcode attached to each WIP container. This sticker only needs to be attached to the container once until it is damaged (Figure 8). These codes will be translated as real-time information about the production date and WIP travel hours from the Oven Machine to the Wrapping machine. Scanning QR codes can determine real-time temperature and freshness, predicting the real shelf life of food (Zhang et al., 2023).

Figure 8. Determining Barcode Number

The user interface is implemented in a WEB-based application and the Laravel framework, as depicted in Figure 9. You must register and create a login system to access the application using an Android smartphone. The login system authorizes users to manage the inventory management system content. User 1 is responsible for entering incoming WIP data, while User 2 is inputting outgoing WIP data. The system employs barcode scanning to gather data and track work-in-progress inventory in real time. The information is gathered and housed in a central repository, accessible via mobile phones, laptops, or desktop devices. The database is implemented using MySQL software, just like in the research of Shukran et al. (Shukran et al., 2017) as shown in

Figure 10. The system transmits data over the internet network to the warehouse management system application server on the main computer in real time.

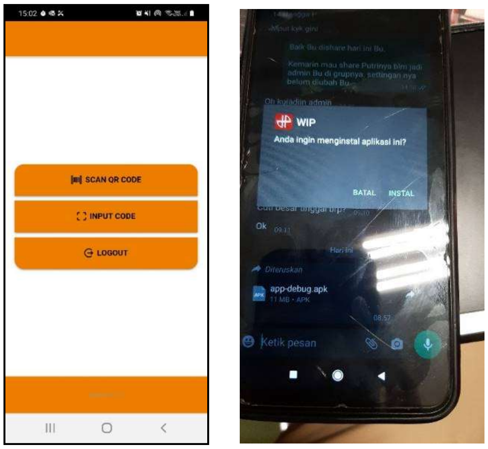

Figure 9. WIP Application Dashboard for User 1 and User 2

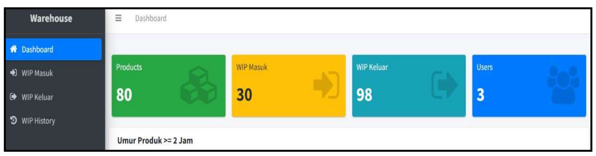

Figure 10. WIP Warehouse Application Dashboard for User SPV

This application can send reminders to users when WIP has been stored for over 2 hours. A red signal appears on the dashboard of the WIP Warehouse System (Figure 11) to alert users. This helps prevent defects from being packaged as finished products. It also provides supervisors feedback to recalculate production capacity, consider the new bottleneck, and enable them to replan alternative strategies to ensure target achievement(Fragapane et al., 2023).

Furthermore, the finished product packaged in the wrapping machine is given production information such as the production date, time, and expiration date (Figure 12). Effective product packaging is crucial for communicating vital details about its contents to the consumer (Isohanni, 2022). It helps track finished products with quality problems through product information on individual package packaging. This allows easy identification if any issues arise related to the quality of the packaged WIP. Information loss issues will hinder traceability relationships between product lots, and this becomes important for legal compliance, certification, or standardization (Islam et al., 2022). Research by Pagliusi et al. (Pagliusi et al., 2023) shows that implementing data barcodes on vaccine labels and various packaging layers is essential for ensuring product traceability.

3.2 Statistical Analysis

To summarize, scanning barcode information into items is currently underway. A computer is connected to the barcode scanner, which decodes the information through a network to the server. The results showed that after the use of real-time

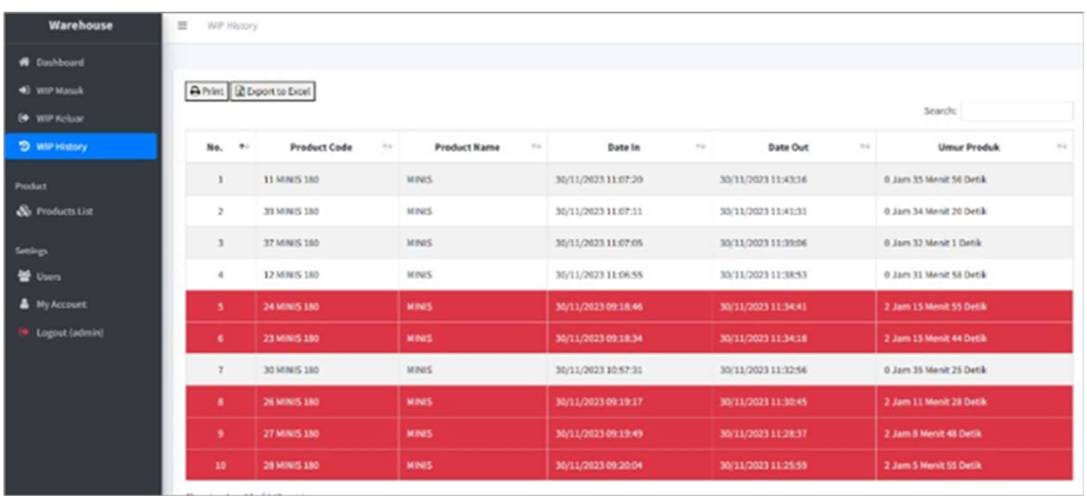

Figure 11. Red Signals for Defect

Figure 12. Individual Pack

wafer WIP monitoring applications, there was a reduction in the average number of production defects from 2.6% to 1.6% (Figure 13).

The logistic model used measures error frequency and employed a linear regression model to determine current performance (Küng et al., 2021). In the analysis result using linear regression, a significant relationship was found between implementing a barcode application to monitor the work in progress in real time and the level of defects. The positive regression coefficient indicates that an increase in application usage correlates with a decrease in the number of defects, suggesting that the application has the potential to reduce the product defect rate effectively. These findings support the hypothesis that the integration of the barcode application has a positive impact on product quality, endorsing the success of this research in designing a solution to reduce defects through monitoring the work in progress.

Real-time inventory management system with low-cost barcode technology through an integrated product information label system from WIP to individual pack product packaging. This will effectively reduce unnecessary losses caused by the human factor. The risk of higher products being exposed to WIP quality problems in production will also be reduced. We can use big data to create an advanced inventory optimization system, which can accurately forecast inventory needs, adapt to changing customer needs, minimize inventory costs, and provide a comprehensive understanding of inventory levels. Barcode technology can effectively and conveniently achieve identification and traceability, and consistently documenting and verifying information is vital in the logistics and traceability sectors (Chen et al., 2020). This can streamline the movement and storage of inventory and potentially reduce the need for safety stock (Fernández-Caramés et al., 2019). The barcode design captures real-time temperature and freshness data, enabling the prediction of the food's effective shelf life. Research has shown that implementing barcode technology and algorithms can effectively identify and classify defects in concrete structures (Naji et al., 2023). Barcode technology, especially barcode sequencing, is used to identify, classify, and

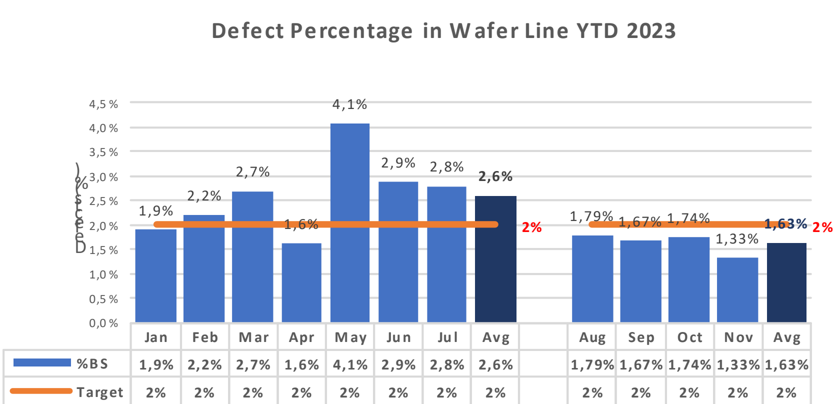

Figure 13. Defect Percentage Before – After Kaizen Implementation

analyze mutants to identify defects (Arjes et al., 2022). By employing automatic identification technologies like barcode systems, manufacturing companies can guarantee a comprehensive record of component process history, traceability, and tracking, thus mitigating the risk of product recalls and preventing costly downtime associated with defects (Segura Velandia et al., 2016). QR codes are widely used, but detecting defects is challenging. Our method is robust and efficient in identifying defects (Yanhua et al., 2017).

3.3 Limitation

The main concerns of implementing this system include installation, migrating data from the old database conventionally to the new database using Google Worksheets, practical monitoring, control, and operation configuration, and software security system. This barcode-based system is still traditional since it involves manual smartphone scanning to enter data. Sometimes, when an inventory item lacks a barcode label, inventory officers create their barcode to help monitor inventory more efficiently (Siaw-Yeboah et al., 2020). Therefore, there is still the potential for errors and missed data if the users do not scan product barcodes. Further research could propose improvements to scanning systems, such as using automated applications with sensor scanning that is automatically stored in production machines' IN and OUT areas. This will reduce user/operator workload and could be the focus of future research studies to improve overall production efficiency and productivity.

IV. CONCLUSION

The inquiry has determined that Gemba Kaizen is an efficient approach for recognizing issues on the production floor and minimizing the occurrence of defective products to levels below the established maximum standards. The investigation results show that the main cause of the increase in product defects is the manual labeling system in the production area's WIP journey. This problem must be solved immediately as it fails to implement the product traceability system, resulting in more defective products. An automatic labeling system using barcode technology is required to prevent the risk of failure or error from manual methods. This system can support supervisors to make quick decisions on segregating affected defective products and balancing production capacity to make the WIP journey smoother and more efficient. The system runs successfully, according to the desired design and conceptual model.

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