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ENHANCING LEAN MANUFACTURING THROUGH DIGITAL E-KANBAN INTEGRATION AND INDUSTRIAL AUTOMATION

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Abstract

The traditional Kanban system has long served as a cornerstone in lean manufacturing for managing inventory and production flow. However, its limitations in real-time tracking, responsiveness, and data visibility make it less effective. This research presents the design and implementation of an Electronic Kanban (E-Kanban) system integrated with a programmable logic controller (PLC), infrared (IR) sensors, and real-time data visualization via Siemens S7-200 and OPC Expert. The system was deployed on a simulated assembly line with clearly defined workstations to evaluate improvements in throughput, cycle time, and work-in-process (WIP). Results indicate a 17% reduction in cycle time and a 21% increase in throughput, demonstrating the effectiveness of the proposed E-Kanban system. The integration of automation and digital tracking significantly reduced manual errors and enhanced decision-making. Future extensions include the integration of artificial intelligence (AI) and predictive analytics for proactive inventory management

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Introduction

In today's rapidly evolving industries, implementing an efficient and effective inventory control and information flow system is essential for the success of any organization. The traditional Kanban system has been used for decades to manage the inventory and material flow in an assembly line [1]. However, in the era of Industry 4.0, a digital Kanban system, known as E-Kanban, has emerged as a more advanced and effective solution.

Kanban is a lean manufacturing system developed by Taiichi Ohno [4] at Toyota in the late 1940s [2]. The Kanban system works on the principles of "pull" manufacturing, where the production process is initiated by customer demand. Traditional Kanban systems rely on physical cards flow between different departments such as production cell, assembly line, and Kanban board signaling the material and information [3].

The development of E-Kanban system has major concern with the industry 4.0, [5] and it is the step towards the fourth industrial revolution. The applications in developing E-Kanban system includes [6], Driving industrial growth by increased efficiency and productivity, Align with Industry 4.0 by integrating digital technologies in assembly processes, and Real-time data tracking and traceability enabling better decision-making. Prior works have highlighted the potential of digital Kanban for enhancing operational performance. However, empirical studies with actual data capturing improvements in throughput, WIP, and bottlenecks remain limited. This study aims to fill this gap by demonstrating a practical, low-cost, and replicable implementation of E-Kanban in a controlled environment.

Methodology

This section outlines the design and implementation stages of the E-Kanban system. The process includes development of a physical assembly line, automation using sensors and PLCs, data communication, and creation of a real-time E-Kanban board.

Developing an Assembly Line

The mechanical design of conveyor system with a sheet as a conveyor belt, which has a dimension of 126x26 inches. This conveyor has been developed after carefully considering the workstation requirements and the worker space at the conveyor. The work-stations for this assembly line have been identified through line balancing technique.

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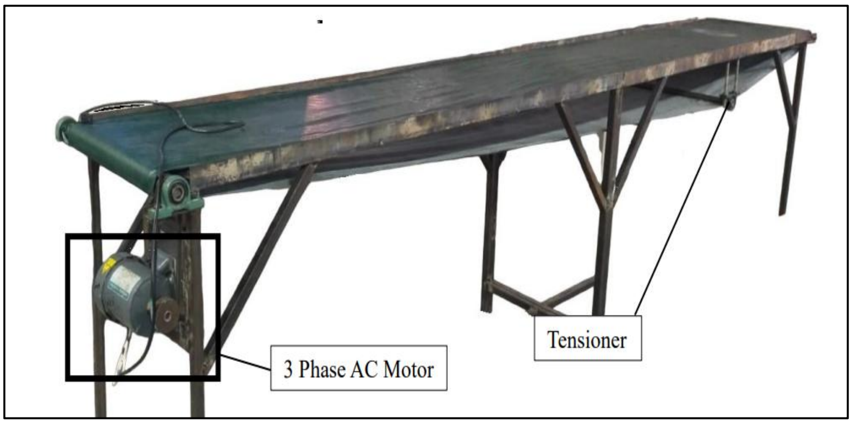
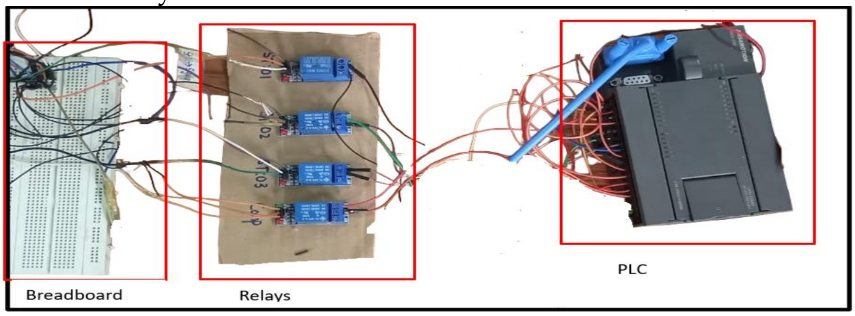


Figure 1: Developed Assembly Line

Automating Assembly Line

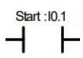
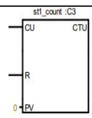
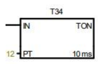
To automate the assembly line, we used AMX-200 Asmamotion PLC to automate the conveyor.



Infrared (IR) sensors are integrated at each station to automatically start/stop the con-veyor at each station when part arrives/leaves. The signal wire of IR sensors is con-nected to input terminal of relays, operating it to activate PLC accordingly. PLC ladder logic is created, to record or communicate this data to computer.

Table 1

PLC modules used in Ladder Logic

Normally Open Switch.	
Normally Closed Switch.	
Counter	
Comparator	
Time delay	

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Data Acquisition

Data collected from each workstation is communicated via PLC to computer (E-Kanban Board Display). To do this, we used Siemens S7-200 PC Access software and OPC Expert to create a bridge between PLC and Excel display.

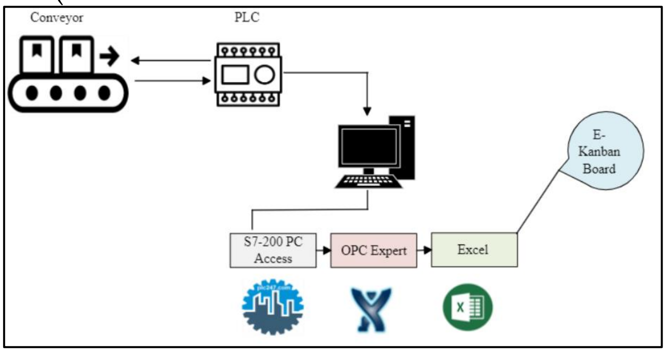

Figure 3. Schematic for the data communication

Creating E-Kanban Board Display

To create E-Kanban Board, we used Excel in which the following information is displayed. Kanban Board: Displaying buffer inventory, WIP and Completed at each workstation. Order Display Area: Production cell where the Sub-assemblies are produced for assembly area, and Assembly Area: Where assembly operations proceed to produce finished product.

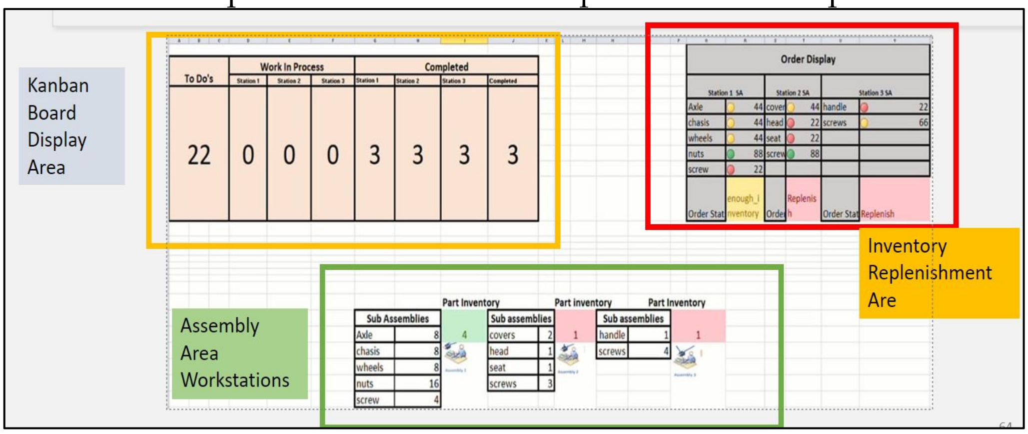

Figure 4 E-Kanban Display

Results and Discussion

The system was evaluated based on metrics such as cycle time, throughput, and work-in-process (WIP). Performance data was recorded over 20 production cycles be-fore and after implementing the E-Kanban system.

Table 2

Results

Metric	Before E-Kanban	After E-Kanban	Improvement
Avg. Cycle Time (sec)	48	39.8	17% decrease
Throughput	75	91	21% increase

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(units/hr)			
Avg. WIP (units)	12	8	33% reduction
Bottleneck Station	Assembly	None	Eliminated

Implementation of E-Kanban led to clear improvements. Cycle time reduced by 17%, throughput increased by 21%, and average WIP levels dropped by one-third. The visual WIP tracking helped resolve assembly line bottlenecks, especially at the assembly station, through better load distribution.

Moreover, human errors due to manual recording were eliminated, and in-ter-department communication improved through centralized data visibility. These outcomes align with lean manufacturing goals of waste reduction and continuous improvement.

The developed E-Kanban system is a digital solution designed to streamline the material and information flow within the organization through incorporating key features such as automated data capture, real-time inventory tracking, automatic replenishment triggers, and improved communication channels. The system seamlessly integrates with existing processes and systems, ensuring a smooth transition and minimizing disruptions.

Before developing E-Kanban, the following inefficiencies and challenges were identified in material and information flow in assembly line operations. These include Manual data entry, Delays in inventory replenishment, and Limited visibility. The key findings of implementing E-Kanban includes Automated data capture, Real-time tracking for Inventory, Inventory replenishment, Improved visibility into material availability, Communication between stakeholders, and Streamlined material flow.

We can say that E-Kanban Implementations have resulted in increased throughput in the assembly line operations. The following benefits of E-Kanban system observed while implementing in organizations, which include, Increased Throughput, Reduced Cycle Times, Minimized Bottlenecks, Improved Resource Allocation, and Enhanced Operational Efficiency.

In future implementations, predictive analytics using Artificial Intelligence (AI) models such as artificial neural networks (ANN) can be integrated. By analyzing historical WIP trends and demand variability, the system can preemptively adjust replenishment rates, avoiding overstock or stockouts. Such meta heuristic algorithms integration represents a crucial step toward Smart Factory realization under Industry 4.0

Conclusion

In conclusion, the developed E-Kanban system effectively digitizes lean inventory control by integrating PLC automation, IR sensors, and real-time data tracking. This implementation led to measurable improvements in key production metrics, including a 21% increase in throughput and a 17% reduction in cycle time, validating the system's effectiveness. The E-Kanban system delivers substantial benefits in terms of productivity, operational efficiency, cost reduction, and optimized resource utilization. By stream-lining material and information flow, automating data capture, and providing real-time inventory visibility, it addresses common challenges such as manual entry errors, lack of transparency, and poor interdepartmental coordination.

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