Int. J. Nonlinear Anal. Appl.
Volume 12, Special Issue, Winter and Spring 2021, 1761-1774
ISSN: 2008-6822 (electronic)
http://dx.doi.org/10.22075/ijnaa.2021.5883

Development of IIoT based parts replenishment system for MSME

V. Vijayanand[a,*], R. Jayachitra[a], P. Guhapranav[a]

[a] PSG College of Technology, Coimbatore, India

(Communicated by Madjid Eshaghi Gordji)

Abstract

Productivity improvement is vital to sustaining in the market. This work outlines the significance of productivity improvement encompassing quick changeovers, fixture design modifications and improved material handling thereby meeting the demand requirements. There is the total of 10 component varieties such as D88 U1, D88 L1, D110 U2, D110 L2, D132 U3, D132 L3, D150 U4, D150 L4, D168 U5 and D168 L5. D88 contributes to 82% of part production and hence termed as high-volume components whereas D110, D132, D150 and D168 components are termed as low volume components. In the current state, there were totally 7 machines but in the future state, there would be only 4 machines. Out of 4 machines, 2 machines will be delivering the same output of 220 D88 parts per day as of Mar-2021 and the other 2 machines will be satisfying fluctuating order arrivals at low volume production line. Apart from effective utilization of resources, deploying the latest technologies is equally important in this competitive environment. Industries needs to incorporate the growing technologies to sustain in the market. Internet of Things (IoT) connects the physical world with the digital word and makes life simple by automating a wide variety of processes across diverse environments available. This work highlights the usage of the Industrial Internet of Things (IIoT) for replenishment systems in a small-scale industry environment and outlines the effect of productivity improvement. This idea will be beneficial if done at a low cost, unlike the inventory management software which is priced quite higher and seems unaffordable to small-scale industries.

Keywords: IIoT, Productivity improvement, Cycle time, Capacity plan, Order quantity, Safety stock, Replenishment plan

*Corresponding author

Email addresses: vij.mech@psgtech.ac.in (V. Vijayanand), rjayachitra@psgtech.ac.in (R. Jayachitra), pguhapranav.psg@gmail.com (P. Guhapranav)

Received: August 2021 *Accepted:* November 2021

1. Introduction

Process improvement involves the business practice of identifying, analyzing and improving business processes to optimize performance, meet best practice standards or simply improve the quality and the user experience for end users. Inventory management is the process of handling stocks as and when required for production and regulated by means of demand and supply pattern. Inventory management in large scale industries is maintained by means of software packages but small-scale industries maintain inventory by means of Kanban systems. Kanban systems communicates and create visibility to workers regarding current inventory levels. So that when the bin reaches the reorder level, the purchase order is triggered to the supplier. Until the goods arrive the safety stock will be utilized to carry out the production.

2. Problem definition

Due to manual replenishment of raw materials, there are a few occurrences wherein maintaining optimal inventory is a challenge. As humans, keeping track of the goods focusing its accurate count and corresponding supplier would be tedious and prone to errors.

Accumulation of excess raw materials and work in process inventory has added up to their inventory cost thereby affecting cash flows. On the other hand, very low inventory count would affect resource utilization and customer delivery times. In addition to problems faced at inventory management, lack of continuous process improvement in the company has led to a situation wherein the cycle time is 228 seconds for lower split ring and 188 seconds for upper split ring. There is a need to streamline the replenishment cycles and construct a feasible production plan after carrying out the necessary process improvements.

3. Literature survey

Abdul Talib Bon et al., [2] explains the evaluation of improvement activities done to improve the productivity of the manufacturing process by reducing the number of workstations wherein the analysis is carried out in ARENA simulation.

Keivanpour et al., [4] describes the role of RFID at MRO department. This depicts the role of IoT in sending real time data information to data analysis module for updating the estimation of remaining lifetime of parts and send the required notifications to maintenance department to take necessary actions.

Muchaendepi et al., [6] identified a problem wherein SME incurred higher than necessary operating costs in order to satisfy their customer service by holding excessive stocks. The reason behind this was poor inventory planning and failure in creating a balance between efficiency and responsiveness explaining the role of inventory costs.

Tejesh et al., [7] addresses the difficulties in monitoring the stock. The author explains how RFID suits here because of low cost and robust such that it could be integrated into any field of application. The author has chosen Raspberry Pi as central server for monitoring information and the webpage has been created to monitor the process entirely.

Yerpude et al., [8] briefs the interoperability requirements of IoT to work with heterogenous devices wherein it is achieved with Service Oriented Architecture (SOA). Four layers in SOA comprises of sensing layer, networking layer, service layer and the interfacing layer.

From the past works surveyed, it is evident that warehouse management can be automated using IoT [1, 3] which may be helpful to MSME when done in a cost-effective manner. Inventory planning is crucial to them as they play a major role in balancing inventory holding cost and customer service.

The process improvements must be simulated using software prior to shop floor implementations for better risk assessments [5].

4. Methodology

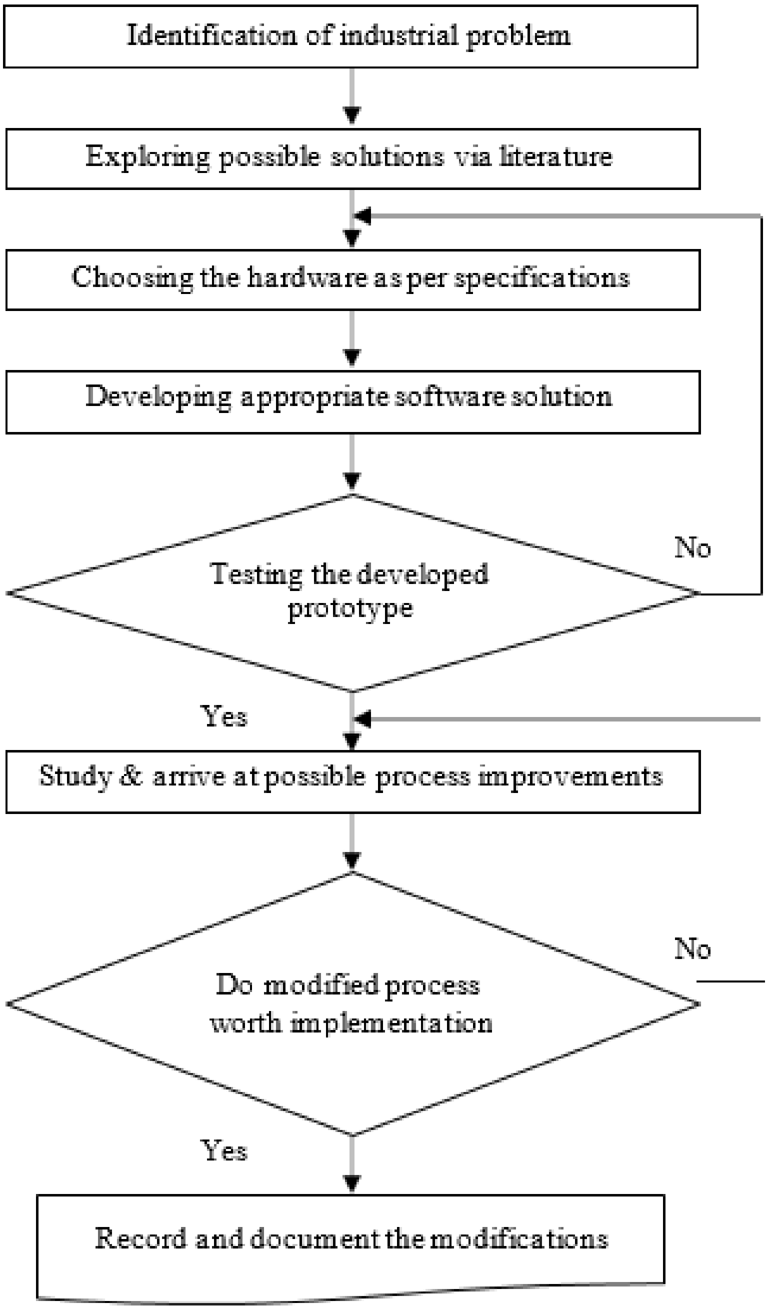


Figure 1: Workflow

The industrial problem, exploration of possible solutions and formulation of objectives has been stated before. The next task is to arrive at a proper prototype to the proposed problem afterwhich it should be tested. Once the IoT prototype is successful, look for any other process improvements after observing and analyzing the industry. If the found solution is worth implementation, suggest it in the form of kaizen else keep iterating as in Fig 1. Finally document the modifications applicable to the industry.

5. System design

A. Hardware selection

The We-Mos D1 R2 WiFi ESP 8266 Development board is used for programming in Arduino IDE. The problem defined can be sorted out only if there is a communication that could be triggered back to the supplier. We also need to incorporate an inductive proximity sensor whose operating voltage is 3.3 V, then Wemos-D1 R2 Wi-Fi ESP 8266 is the apt one as it allows 3.3 V unlike Node-MCU. D1 R2 has a micro-USB for auto programming. It can also be programmed using OTA. All I/O works at 3.3 V. Arduino IDE is easy to use for beginners yet flexible enough for advanced users to take advantage of as well and so it is preferred here as well.

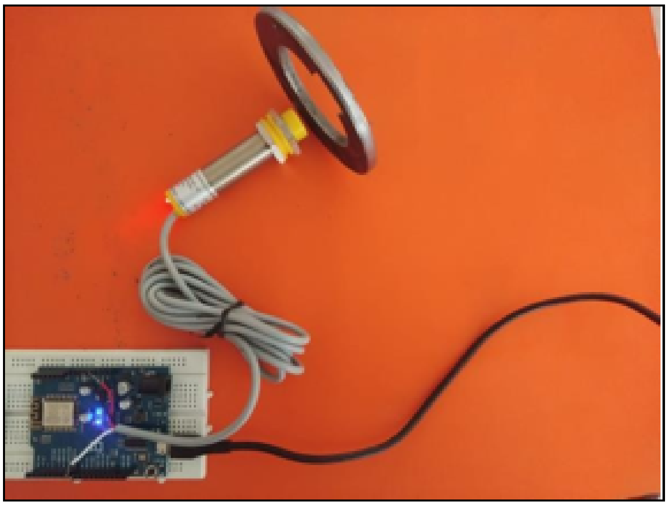


Figure 2: Hardware setup

Inductive proximity sensors are used for non-contact detection of metallic objects.Thus, Arduino We Mos D1 R2 board is purchased and connected to an inductive proximity sensor according to the circuit diagram. This is done to take account whether the reorder level is reached in the bin. The red color is live wire and connected to 3.3 V pin and black color is neutral wire connected to GND pin which is next to 3.3 V pin. The white color is the signal wire connected to pin D7 (GPIO 13) which receives the sensor data and Fig 2 picturizes this connection.

B. Software solution

The software solution is arrived in three phases and integrating them. Three phases are as listed below as follows

1. Database creation at PhpMyAdmin using XAMPP
2. Main program code at Arduino IDE
3. Customizing IFTTT platform

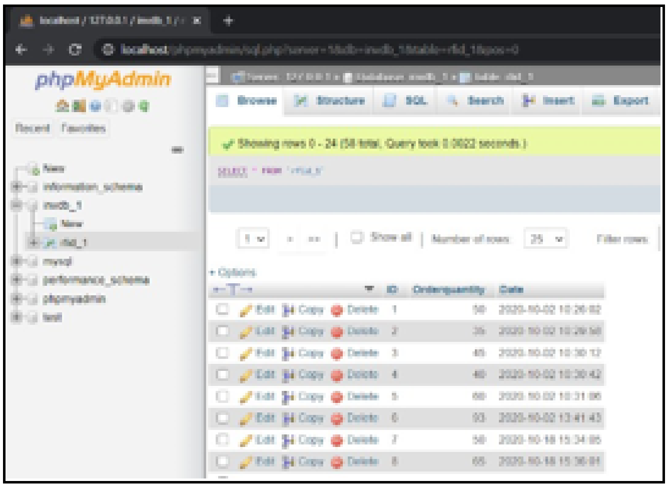


Figure 3: Database creation

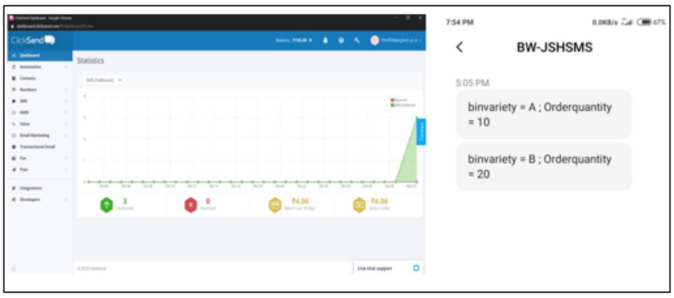


Figure 4: ClickSend SMS

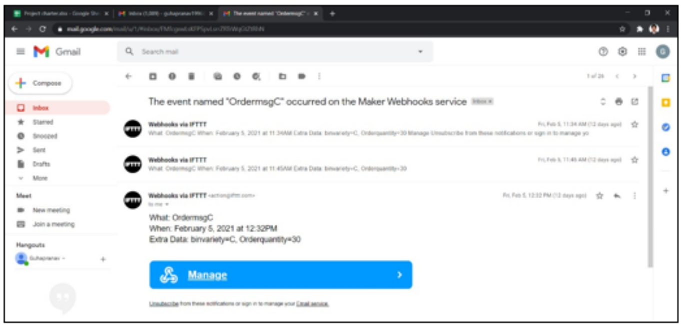


Figure 5: Gmail notification

First the XAMPP control panel needs to be downloaded in the computer. Then php script to update order quantity as and when triggered has been written in Notepad++ and stored in the appropriate path directory. The order trigger trial was carried out by triggering manually at different times and verified as in Fig 3.

The second phase involves the core logic fed into the Arduino IDE. Some of the important logics involved in the program are described here. This program logic aims to monitor the inventory levels and send an email to the supplier when the reorder level is reached in the bin. This is done

capturing the current quantity in the bin by means of a proximity sensor and sending it through a local server. The third phase involves the communication of message or mail to supplier as in Fig 4 and Fig 5. The serial monitor and html pages are represented in Fig 6 and Fig 7.

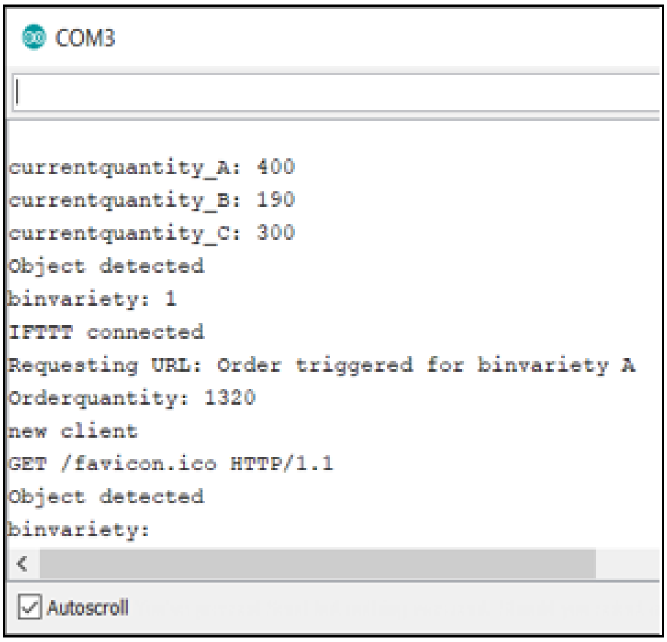


Figure 6: Serial monitor

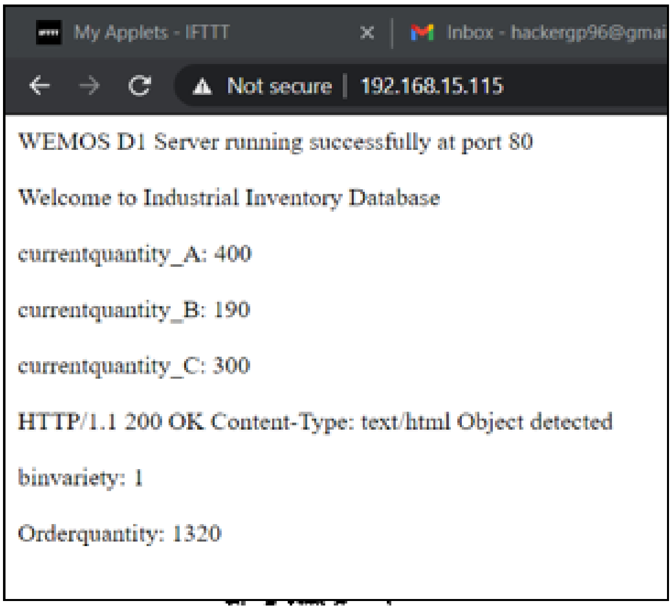


Figure 7: HTML webpage

6. Industrial observation

A. Existing scenario

There are totally 10 component varieties such as D88 U1, D88 L1, D110 U2, D110 L2, D132 U3, D132 L3, D150 U4, D150 L4, D168 U5 and D168 L5. Their geometric dimensions, demand values and existing resource information have been collected from them. D88 component contributes to 82% of part production and hence termed as high-volume components whereas D110, D132, D150 and D168 components are termed as low volume components.

Initially their monthly demand values have been closely observed for previous two years and this year forecast values for the first quarter have been estimated by winters method in Minitab software. Their result interval accommodated the March demand results correctly. This is done to have an idea on demand and supply patterns thereby deciding the order quantity, replenishment interval and safety stock values currently followed by the industry.

A micromotion analysis has been performed for both high and low demand parts consisting of upper and lower stud rings separately using video taken in the premises. The machining operations involved were drilling, reaming and tapping. The upper stud ring had 3 holes whereas the lower had 4 holes for which separate videos were taken. The cycle time estimates for upper and lower stud rings irrespective of outer diameter variations were 188 seconds and 228 seconds respectively.

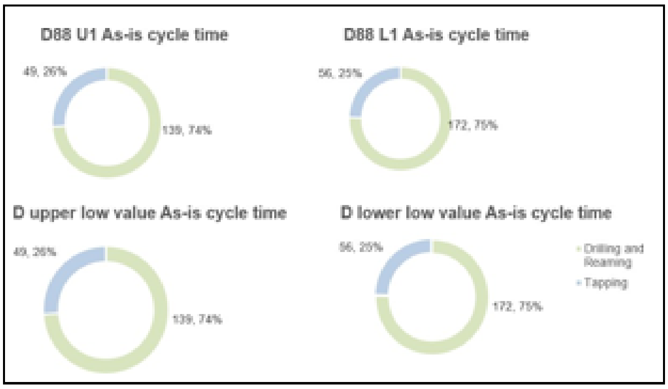


Figure 8: As-is cycle time

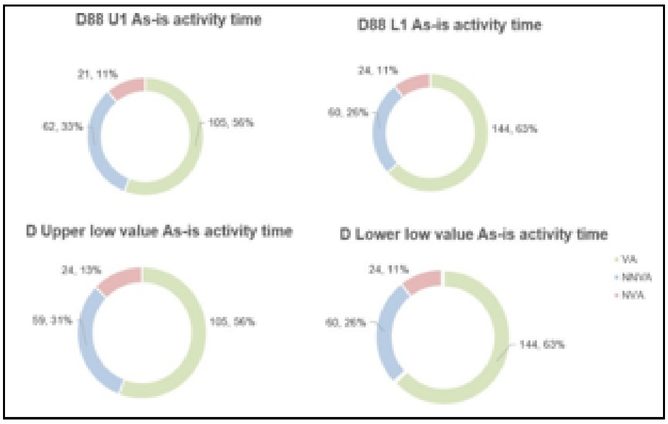


Figure 9: Activity time

Their respective process time values are shown in Fig 8 as per the operations performed.

Each operation involves different activities which was classified based on Value Added (VA), Non-Value Added (NVA) and Necessary Non-Value Added (NNVA) activities. Their results are represented in doughnut charts in Fig 9.

B. Observations from existing scenario

1. The community members know that they are its i. The worker movements can be reduced by mapping the process flow with the machine arrangements accordingly

2. The reorders can be executed with part-based replenishment system and notifying the suppliers through mail as and when reorder level is reached

3. The worker should be placed ergonomically so that he can stand and operate those machines. The bin could be replaced by a tray which could also be elevated to a comfortable height for the worker

4. The production schedule and the machine for high demand items (D88 U1 and D88 L1) to be given a dedicated line setup and low demand items to be produced on a different machine to avoid clash and improve the product deliverability

5. For high demand items (D88 U1 and D88 L1), the drilling operation could be done in a re-designed fixture wherein it can hold two components at a single setup. Moreover, incorporating drill com reamer setup at drilling machines would complete save the reaming process and the corresponding operation times

C. Scope for improving productivity

1. The worker movements can be reduced by mapping the process flow with the machine arrangements accordingly

2. The reorders can be executed with part-based replenishment system and notifying the suppliers through mail as and when reorder level is reached

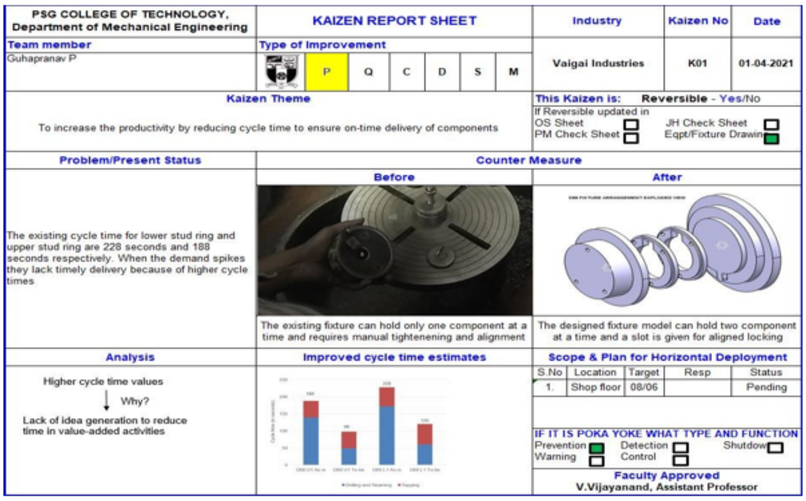
3. The worker should be placed ergonomically so that he can stand and operate those machines. The bin could be replaced by a tray which could also be elevated to a comfortable height for the worker

4. The production schedule and the machine for high demand items (D88 U1 and D88 L1) to be given a dedicated line setup and low demand items to be produced on a different machine to avoid clash and improve the product deliverability

5. For high demand items (D88 U1 and D88 L1), the drilling operation could be done in a re-designed fixture wherein it can hold two components at a single setup. Moreover, incorporating drill com reamer setup at drilling machines would complete save the reaming process and the corresponding operation times

7. Suggestions

The following suggestions have been proposed in the form of kaizen sheets as in Fig 10 and Fig 11 for industrial approval.

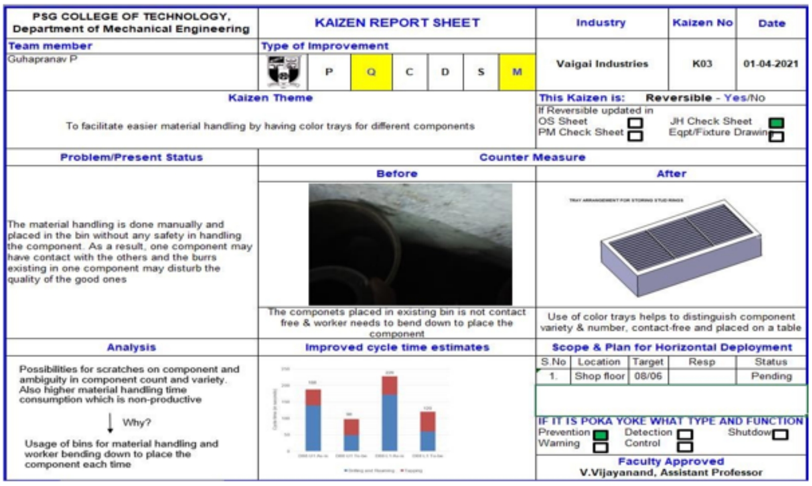


PSG COLLEGE OF TECHNOLOGY, Department of Mechanical Engineering
KAIZEN REPORT SHEET
Industry: Vaigai Industries
Kaizen No: K01
Date: 01-04-2021
Team member: Guhapranav P
Type of Improvement: P Q C D S M
Kaizen Theme: To increase the productivity by reducing cycle time to ensure on-time delivery of components
This Kaizen is: Reversible - Yes/No
If Reversible updated in: OS Sheet, PM Check Sheet, JH Check Sheet, Eqpt/Fixture Drawing
Problem/Present Status: The existing cycle time for lower stud ring and upper stud ring are 228 seconds and 188 seconds respectively. When the demand spikes they lack timely delivery because of higher cycle times
Counter Measure
Before: The existing fixture can hold only one component at a time and requires manual tightening and alignment
After: The designed fixture model can hold two component at a time and a slot is given for aligned locking
Analysis: Higher cycle time values
Why?
Lack of idea generation to reduce time in value-added activities
Improved cycle time estimates
Scope & Plan for Horizontal Deployment

S.No	Location	Target	Resp	Status
1.	Shop floor	08/06		Pending

IF IT IS POKA YOKE WHAT TYPE AND FUNCTION: Prevention, Warning, Detection, Control, Shutdown
Faculty Approved: V.Vijayanand, Assistant Professor

Figure 10: Fixture design modification



PSG COLLEGE OF TECHNOLOGY, Department of Mechanical Engineering
KAIZEN REPORT SHEET
Industry: Vaigai Industries
Kaizen No: K03
Date: 01-04-2021
Team member: Guhapranav P
Type of Improvement: P Q C D S M
Kaizen Theme: To facilitate easier material handling by having color trays for different components
This Kaizen is: Reversible - Yes/No
If Reversible updated in: OS Sheet, PM Check Sheet, JH Check Sheet, Eqpt/Fixture Drawing
Problem/Present Status: The material handling is done manually and placed in the bin without any safety in handling the component. As a result, one component may have contact with the others and the burrs existing in one component may disturb the quality of the good ones
Counter Measure
Before: The componets placed in existing bin is not contact free & worker needs to bend down to place the component
After: Use of color trays helps to distinguish component variety & number, contact-free and placed on a table
Analysis: Possibilities for scratches on component and ambiguity in component count and variety. Also higher material handling time consumption which is non-productive
Why?
Usage of bins for material handling and worker bending down to place the component each time
Improved cycle time estimates
Scope & Plan for Horizontal Deployment

S.No	Location	Target	Resp	Status
1.	Shop floor	08/06		Pending

IF IT IS POKA YOKE WHAT TYPE AND FUNCTION: Prevention, Warning, Detection, Control, Shutdown
Faculty Approved: V.Vijayanand, Assistant Professor

Figure 11: Modified material handling equipment

8. Future state

Once the existing industrial scenario has been studied and analyzed thorougly and mapped with problem statement, it is clear that the capacity plan and replenishment cycle needs to be formulated for improved cycle time estimate values after the kaizen has been implemented in the industry. The capacity plan for high demand item has been displayed in Table 1 and Table 2 whereas the capacity plan for low demand items are displayed in Table 3 and Table 4. The order quanity for high volume items are 1320 components per week whereas for low volume item it is 375 component for D110 and 300 component for D132, D150 and D168. The safety stock for D88 is kept as 2 day production count which is 440 compones whereas for low volume item irrespective of demand fluctuations as to 375 and 300 components the safety stock is kept as 1 day production count which turns out to be 200 numbers. These vaules are arrived by a systemantic approach which is discussed below. The main assumption is that the delivery takes place once in a week and all low volume items need not be produced daily. There are 4 weeks in a month and 4 low volume varieties. So, it is produced one variety per week basis whereas high volume parts are produced daily and delivered weekly once.

From the Table 1 and Table 2, it is evident that estimated monthly production times sum up

Table 1: Capacity plan of high demand item for drill com reaming operation

S No	**Part No**	**Drill + Ream cycle time (sec)**	**Monthly demand (Nos)**	**Estimated monthly production time (hours)**	**Available monthly production time (hours)**
1	D88 U1	49	5500	74.86	170
2	D88 L1	60	5500	91.67	

Table 2: Capacity plan of high demand item for tapping operation

S No	**Part No**	**Tap cycle time (sec)**	**Monthly demand (Nos)**	**Estimated monthly production time (hours)**	**Available monthly production time (hours)**
1	D88 U1	49	5500	74.86	170
2	D88 L1	60	5500	91.67	

Table 3: Capacity plan of low demand item for drill com reaming operation

S No	**Part No**	**Tap cycle time (sec)**	**Monthly demand (Nos)**	**Estimated monthly production time (hours)**	**Available monthly production time (hours)**
1	D110 U2	100	375	10.42	170
2	D110 L2	120	375	12.50	
3	D132 U3	100	300	8.33	
4	D132 L3	120	300	10.00	
5	D150 U4	100	300	8.33	
6	D150 L4	120	300	10.00	
7	D168 U5	100	300	8.33	
8	D168 L5	120	300	10.00	

to 166.53 hours out of 170 hours which amounts to machine utilization of 97.96% for high demand production line. Extending the similar observations to Table 3 and Table 4, it is evident that drill com reaming operation and tapping operations incur machine utilization of 45.83% and 27.07% for low demand production line. Another observation is that since the cycle time of both drilling and tapping process are balanced in high demand production line, their machine utilization values remain the same irrespective of the operation.

Table 4: Capacity plan of low demand item for tapping operation

S No	**Part No**	**Tap cycle time (sec)**	**Monthly demand (Nos)**	**Estimated monthly production time (hours)**	**Available monthly production time (hours)**
1	D110 U2	60	375	6.25	170
2	D110 L2	70	375	7.29	
3	D132 U3	60	300	5.00	
4	D132 L3	70	300	5.83	
5	D150 U4	60	300	5.00	
6	D150 L4	70	300	5.83	
7	D168 U5	60	300	5.00	
8	D168 L5	70	300	5.83	

The next step is to evaluate maximum capacity as per the demand forecasts obtained from the industrial observation. It is observed that all components follow a unique seasonal trend. The trend analysis for D88 is shown in Fig 12.

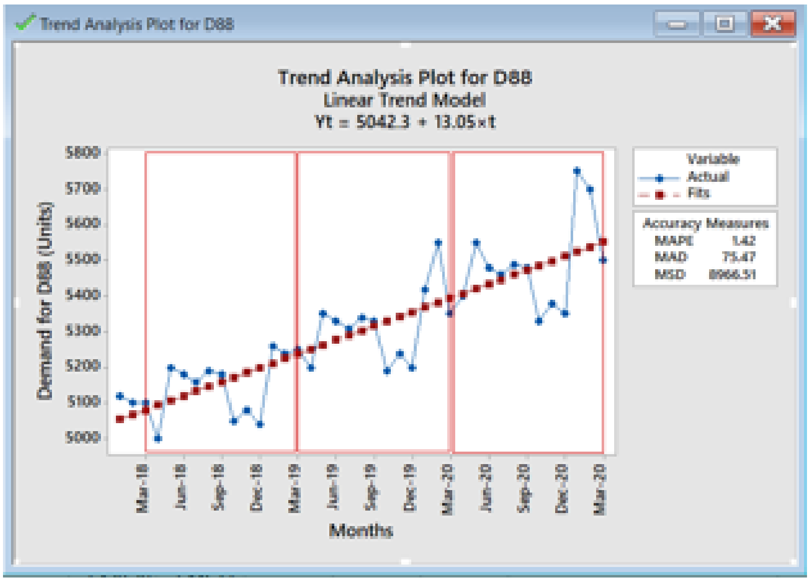


Figure 12: Trend analysis for D88

This conveys an increasing trend across the time horizon with demand peaks in the months of January and February in contrast to demand drop in the months of November and December. So, the capacity plan must accommodate the demand in the months of January and February to be a successful and feasible one. Now the maximum monthly demand to be accommodated is calculated as shown in (1).

$$\frac{49 \times monthly\ demand}{3600} + \frac{60 \times monthly\ demand}{3600} = 170 \tag{1}$$

Solving (1), the maximum monthly demand will be 5614 components. In case their monthly demand goes beyond this value then the industry needs to manufacture in advance and store it. For example, in the month of Jan-2021 and Feb-2021 their demand values crossed 5750 and 5700 but their demand values in the month of Nov-2020 and Dec-2020 were 5380 and 5350 respectively. the start of Oct-2020 they should have performed a three-month forecast wherein the Demand hike in Jan-2021 would have been known. So that they could have produced 5614 units instead of 5380 in Nov-2020. So, 234 excess numbers can be stored in inventory anticipating a demand hike.

Once the maximum capacity is calculated, arriving at appropriate replenishment plans is the next task. The available production time is observed from industry. The industry 25 working days per month at 8 hours a day with labor efficiency of 85%. The monthly demand value for Mar-2021 is 5500. So daily requirement (2) will be 220 D88 stud rings. The corresponding weekly demand will be 1320 stud rings which is the order quantity provided the number of working days in a week is taken to be 6. The supplier expects a weekly delivery and so the order quantity is taken to be weekly demand requirement (3). The safety stock (4) is taken to be 440 components. This is because the supplier usually takes 1 day to pool and deliver the blank. So, it is safe to have 2-day inventory in order to avoid stock out scenario.

$$Daily\ demand = \frac{Monthly\ demand\ value}{No.\ of\ working\ days} \tag{2}$$

$$Order\ quantity = weekly\ demand\ requirement \tag{3}$$

$$Safety\ stock = 2\ day\ inventory \tag{4}$$

Since there is a fluctuating demand in low volume items there will be machine hours available to load the component even when there is a sudden increase in demand. But the high-volume line would also remain undisturbed if this new improvements and modifications are implemented.

While planning for low volume items, the production plan must be according to machine utilization hours than focusing on demand pattern as the demand can be easily accommodated in the production schedule. The replenishment plan must be spelled out for low volume items as well.

$$Safety\ stock = 1\ day\ inventory \tag{5}$$

Considering 85% worker efficiency, No. of productive working seconds available per day = 28800 x 0.85 = 24,480 sec

Time taken to produce 1 D110 U2 component = 100 sec

No. of components that can be produced per day = $\frac{24480}{100}$ = 244 components (approx.)

Safety stock for D110 U2 = 244

Time taken to produce 1 D110 L2 component = 120 sec

No. of components that can be produced per day = $\frac{24480}{100}$ = 204components (approx.)

Safety stock for D110 L2 = 204

Safety stock for low demand components is 200 (approx.) as per (5) for the month of March 2021. But this can vary depending on monthly orders.

Moreover since this is low volume component with high part variety, the supplier needs to make proper replenishment arrangements to collect the processed orders. So, having low inventory count would be sufficient for low volume and high variety parts in the industry. In case there is surplus time, they can start to capture other orders and expand their business or utilize the existing resources more efficiently.

9. Conclusion

This work illustrates the productivity improvement estimates as a result of process improvement activities. The development of Industrial Internet of Things based parts replenishment system is also a type of process improvement. The overall improved cycle time estimates are shown below in Fig 13.

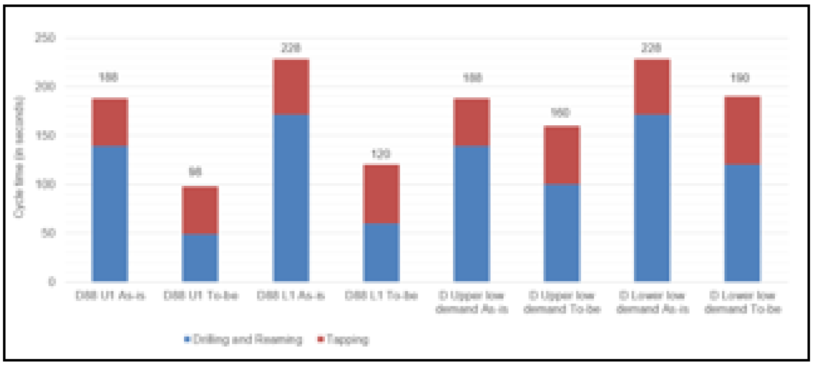


Figure 13: Overall improved cycle time estimates

The cycle time reduction is quite high in high volume parts because of setup time reduction by fixture modification and drill com reamer setup. But for low volume parts only drill com reamer setup is suggested. This is because of current demand pattern for that part in the market. Incase their demand picks up then both the suggested modification can be implemented for further reduction in cycle time estimates.

10. Future work

Some of the areas of improvement are using conveyers for material handling system and pneumatic machines for easy movement of drilling arms with less application of manual effort. Integrating several ERP modules like part replenishment in inventory, order procurement etc., under warehouse management and performing the same across different departments like CRM, SCM etc. thereby transforming the company to factory 4.0 by incorporating automation systems.

Acknowledgement

My sincere thanks to the MSME industry for permitting in their premises. I would also like to thank my professors for persistently monitoring and providing their valuable inputs for the successful completion of this work.

References

[1] A.M. Atieh, H. Kaylani, Y. Al-abdallat, A. Qaderi, L. Ghoul, L. Jaradat and I. Hdairis, *Performance improvement of inventory management system processes by an automated warehouse management system*, Procedia Cirp. 41 (2016) 568–572.

[2] A.T. Bon and N.N. Shahrin, *Assembly line optimization using Arena simulation*, Proc. Int. Conf. Ind. Eng. Oper. Manag. Kuala Lumpur, Malaysia (2016) 2225–2232.

[3] J. Chen, O. Gusikhin, W. Finkenstaedt and Y.N. Liu, *Maintenance, repair, and operations parts inventory management in the era of industry 4.0*, IFAC- PapersOnLine 52(13) (2019) 171–176.

[4] S. Keivanpour and D. A. Kadi, *The effect of "internet of things" on aircraft spare Parts inventory management*, IFAC-PapersOnLine 52(13) (2019) 2343–2347.
[5] S. Kumar and P. Phrommathed, *Improving a manufacturing process by mapping and simulation of critical operations*, J. Manuf. Technol. Manag. 17(1) (2006).
[6] W. Muchaendepi, C. Mbohwa, T. Hamandishe and J. Kanyepe, *Inventory management and performance of SMEs in the manufacturing sector of harare*, Procedia Manuf. 33 (2019) 454–461.
[7] B.S. Tejesh and S. Neeraja, *Warehouse inventory management system using IoT and open-source framework*, Alex. Eng. J. 57(4) (2018) 3817–3823.
[8] S. Yerpude and T. K. Singhal, *SMART warehouse with internet of things supported inventory management system*, Int. J. Pure Appl. Math. 118(24) (2018) 1–15.