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IMPROVEMENT OF FUEL CONTROL UNIT PRODUCTION EFFICIENCY: A VALUE STREAM MAPPING AND SIMULATION APPROACH FOR BOTTLENECK IDENTIFICATION AND OEE ENHANCEMENT

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Abstract - *This journal paper improves FCU manufacturing at ABC Company, doubling production from 35,000 to 50,000 units/month by maximizing OEE and removing bottlenecks in die casting, trimming, and leak testing. VSM and simulation uncover inefficiencies, which direct improvements in machine availability, performance, and quality. Reducing processes ensures scalable, high-quality manufacturing to meet demand cost-effectively.*

Key Words: **FCU, OEE Optimization, Bottleneck Elimination, Process Efficiency, Throughput Improvement**

1.INTRODUCTION

Efficiency is paramount in the sketch of FCUs. ABC Company, which produces 35,000 units/month through die casting, blends VSM and simulation in real-time optimization. (Z. DeVries. Et al., 2021) This forecast method improves manufacturing, optimizes operations, and guarantees long-term viability.

Figure 1.1 Sketch of FCU product

1.1 PROBLEM STATEMENT

The FCU part is manufactured at 70 parts/hour, for a total of 35,000 units per month. Optimizing to achieve 50,000 units requires improvement in machine performance, availability, and quality, as well as eliminating bottlenecks in die casting, trimming, and leak testing. (A. Gupta, et.al., 2019)

1.2 LITERATURE REVIEW

A surgical database comparing F1-score and area under the curve. Although health-focused, their methodology can be beneficial to FCU production through enhanced defect prediction and quality testing.

Gupta, Jain & Mehta (2019) showed how simulation and lean implementation improve manufacturing performance, i.e., enhance OEE and VSM. Their research directly supports improving FCU production efficiency.

Johnson, Brown & Jones (2018) reviewed VSM's effect on lean manufacturing and proved its efficiency in minimizing waste, cycle time, and resource usage. This technique is advantageous to high-output industries such as FCU production.

Kareem, Benin & Mohammed (2022) combined VSM and simulation for lean manufacturing to achieve notable OEE enhancements. Their approach is transferable to FCU manufacturing for better process effectiveness.

Kumar, Narayan & Gupta (2020) highlighted VSM's contribution to efficiency in production by minimizing cycle time and maximizing productivity. Their findings find themselves in great harmony with FCU production optimization.

2. METHODOLOGY

2.1 OBJECTIVE

Increasing FCU Production to 50,000 Units/Month involves cutting bottlenecks through automation of die casting, optimized post-casting flow, and upgrading leak testing. Scaling involves efforts on resource deployment, technology upgrades, and workflow optimization for continued efficiency. (V. Kumar. Et al., 2021)

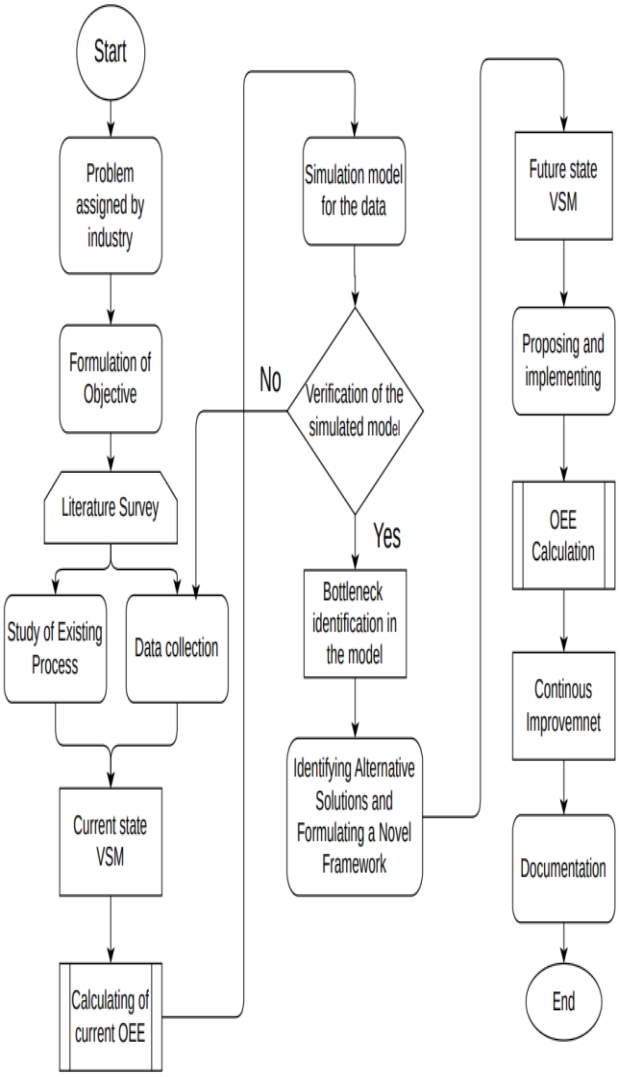

Figure 2.1 Flow chart of general methodology

3. DATA COLLECTION AND INTERPRETATION

The Fuel Control Unit (FCU) controls the supply of fuel to achieve maximum engine power, efficiency, to control emissions performance. In the automotive sector, it cooperates with sensors and ECUs to control fuel injection, whereas in aerospace, it guarantees accurate fuel flow for safety and fuel efficiency. It is made more durable through enhanced materials, high-precision production, and periodic maintenance. Production starts with material choice and die design, followed by melting, alloy preparation, and die casting. Upon cooling and solidification, runner cutting, trimming, and fettling finish the casting of FCU. Machining and surface finishing improve accuracy, while leak testing guarantees integrity. The part is then assembled, inspected, and packed for dispatch. Ongoing improvements maximize efficiency, guaranteeing high quality, performance, and reliability. (H. Y. Kwan., et al., 2017)

3.1 FCU PRODUCTION TIME STUDY SUMMARY

The 400-ton PDC machine runs at 43 sec/shot (70 shots/hour), including die changes (2–3 hrs) and shift restarts (15 min). Furnace refills require 15 min, then trimming (30.8 sec) and runner cutting (31.2 sec).

Vibro polish (20 min) consists of loading/unloading (11/16 min), cleaning, stripping caps (2 min/pallet), and stamping (4 min/pallet). Impregnation comprises loading (10 min), cycles (dry: 15 min, wet: 6 min, pressure: 22 min), washing (each 2 min), and striping (20 min).

Machining (394.4 sec/2 parts) consists of cutting, trimming, deburring (15 min/pallet), cleaning, and quality inspections (±13 microns). Leak testing requires 153.9 sec (double/single fixer) and 85.9 sec (manual fixer).

Final inspection (1–2 min/part) is then completed by packing with prep (3–5 min), pallet loading (8–10 min), labelling (2 min), and shipment checks (1–2 min).

And Key bottlenecks in casting, machining, and inspection need cycle/setup time reduction and workflow optimization to boost FCU production. (R. Martinelli, et al., 2022)

CURRENT STATE

CURRENT STATE VALUE STREAM MAPPING

Value Stream Map (VSM) describes the process of production from supplier to consumer, including material flow, processing time, and inventory. The information is described in the figure 5.1 current state value stream map. Raw materials received through truck shipments and are transported using forklifts. Pressure Die Casting has a Cycle Time (C/T) of 44s, Changeover Time (C/O) of 10 min, and 82.5% uptime, followed by Trimming (C/T: 30.8s, C/O: 10 min, 80% uptime) and Runner Cutting (C/T: 31.1s, C/O: 10 min, 82% uptime). Vibro Polishing is completed in 3600s per cycle, Machining in 453s, Leak Testing in 170s, and Impregnation in 12,000s. Final Inspection (50s) and Packing (35s) finish the process [8]. The total time for inventory is 33,400s (556.68 min), whereas the processing time is 18,864.2s (316.07 min). A Kaizen burst emphasizes areas for improvement to eliminate bottlenecks and increase efficiency. M. C. May,2023)

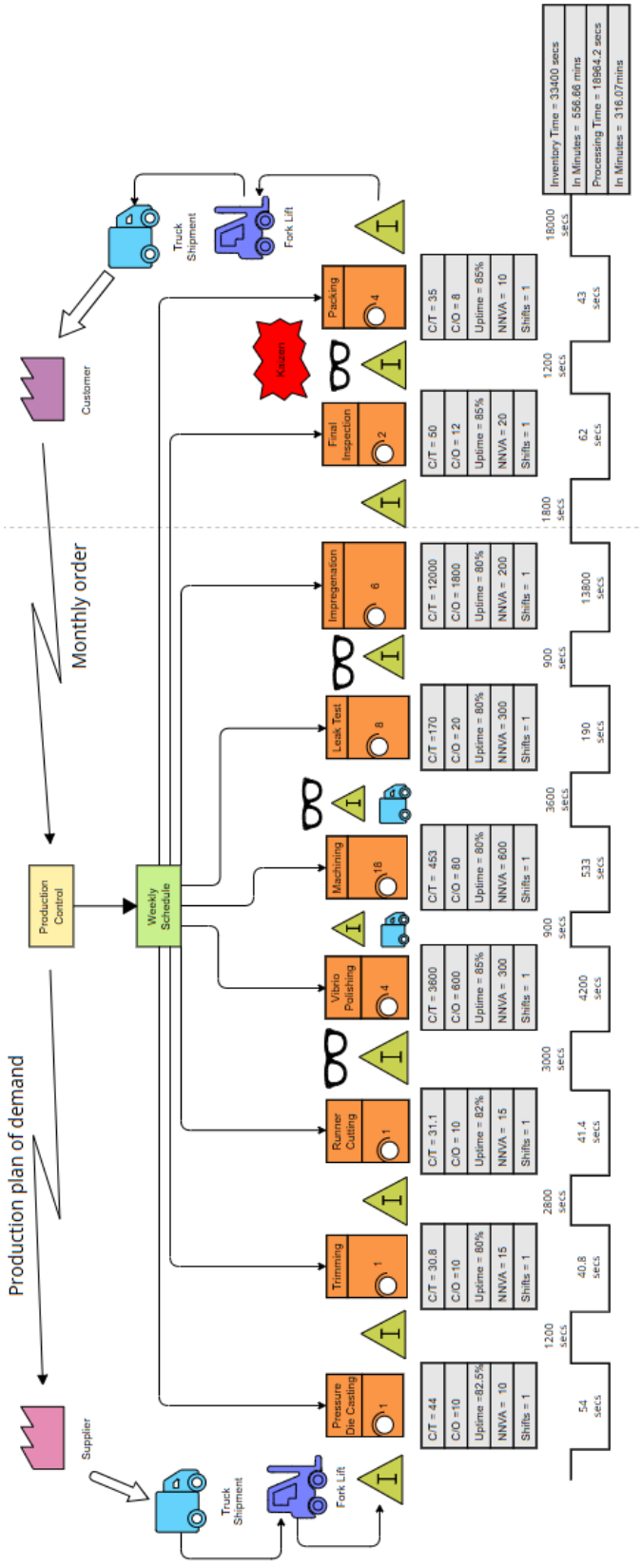

Figure 3.1 Current state Value Stream Mapping

SIMULATION ANALYSIS

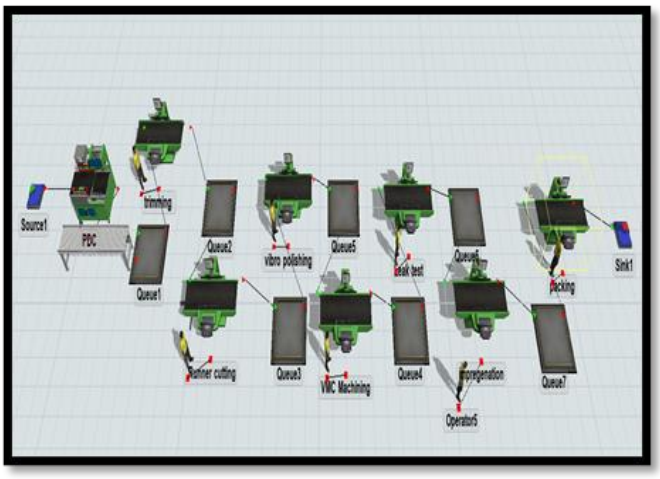

Figure 3.2 Model of Simulation Analysis

After running of current state of Process in simulation

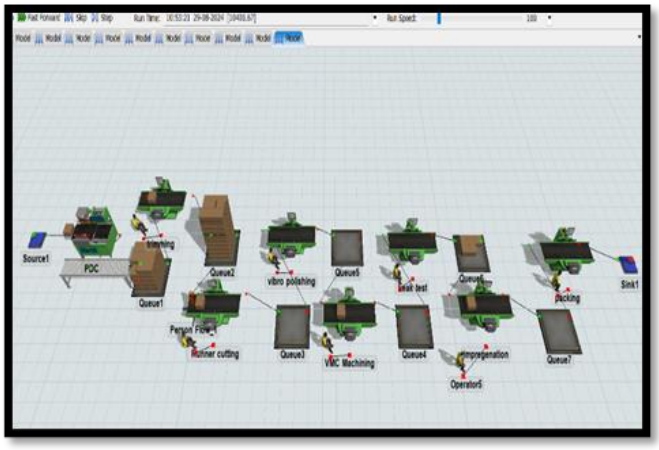

Figure 3.3 Running of simulation (current state)

RESULT OF CURRENT STATE SIMULATION

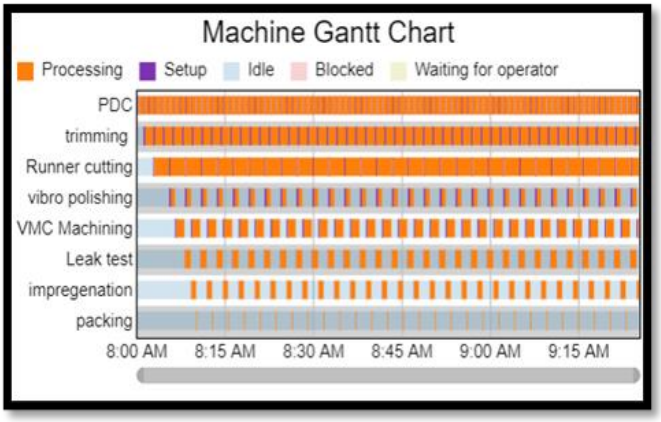

Figure 3.4 Machine Gantt chart

Figure 3.4 Machine Gantt Chart monitors schedules between 8:00–9:45 AM. The X-axis shows time, and the Y-axis enumerates machines/processes (PDC, Trimming, Runner Cutting, Vibro Polishing, VMC Machining, Leak Test, Impregnation, Packing). Colored bars represent status: Orange (Processing), Purple (Setup), Light Blue (Idle), Pink (Blocked), and Light Yellow (Waiting for Operator).

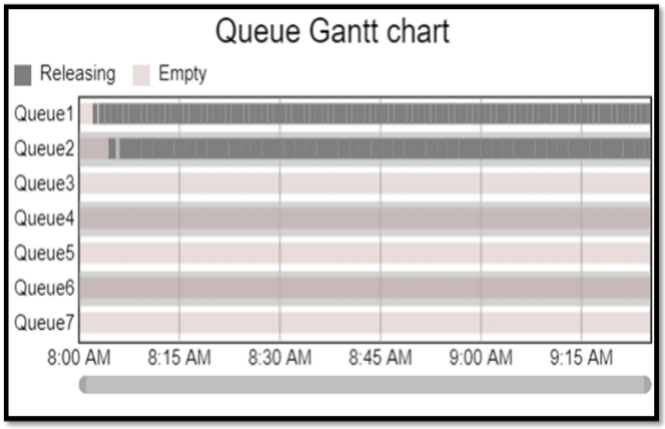

Figure 3.5 Queue Gantt Chart

The Figure 3.5 Queue Gantt Chart tracks queue status from 8:00-9:15 AM over seven queues. The X-axis is time and the Y-axis contains queue names (Queue1–Queue7). Coloured bars denote status: Gray (Releasing) and White (Empty). (J. Neira, et al., 2023)

BOTTLENECK ANALYSIS AND OPTIMIZATION IN TRIMMING & RUNNER CUTTING

Excessive queue lengths in trimming and runner cutting reflect inefficiencies due to machine idleness, low productivity of workers, and obsolete equipment. Figure 3.4 has lengthy setup and heating times, slow operations, and low-capacity machines are the causes of delays.[11] For maximum efficiency, batch production can enhance throughput, adding machines can minimize congestion, and equipment upgrading can increase reliability. Simplifying setups reduces downtime, establishing performance goals enhances productivity, and purchasing high-capacity equipment raises output. These enhancements reduce bottlenecks, providing a smoother flow and increased production efficiency.

CURRENT STATE OVERALL EQUIPMENT EFFICIENCY (OEE) CALCULATION

S. No.	OEE Factor	Data
1.	Planned Production Time	480 mins
2.	Unplanned Downtime	96 mins
3.	Ideal Cycle Time	4.5 mins/part
4.	Actual Cycle Time	4.9 mins/part
5.	Total Parts Produced	35000 Parts
6.	Good Parts Produced	35000 Parts

Table 3.1 Data for ABC OEE calculation

Calculating of the OEE from Table 3.1 are Availability is 80%, Performance is 91.8%, Quality is 100% and Final calculation of OEE is 73.44%

CURRENT OEE OF THE FCU COMPONENT = 73.44% ≈ 74.

BOTTLENECK IDENTIFIED IN THE PRODUCTION PROCESS

In ABC Production, the problem was traced to inefficiencies in the runner cutting process and not worker laziness or unavailability. To counter this, employees are given daily work sheets detailing target tasks so that the department can measure their efficiency. (G. Papadopoulos. Et al., 2020) If daily logs indicate satisfactory performance and targets are achieved, the firm can offer incentives as rewards for their efforts.

DAILY WORK LOG FOR OPERATORS

		Daily Work Log for Operators (Pressure Die Casting)				
Date:		Layman name with ID no:			Supervisor name with ID no:	
S.No.	Material In time	Downtime if any	Material out time	How many pallets	Signature of layman	Signature of Supervisor
1).						
2).						
3).						
4).						
5).						
6).						
7).						
8).						
9).						
10).						
Total:						
Daily Production Target						
Signature of Supervisor		Signature of production Head:		Signature of Production manager:	Date:	
					Department:	

Table 3.2 Daily Work log for operator's

FUTURE STATE

Future state VSM of both ABC production and Machining

This future state is a theoretical values and assumptions [13].

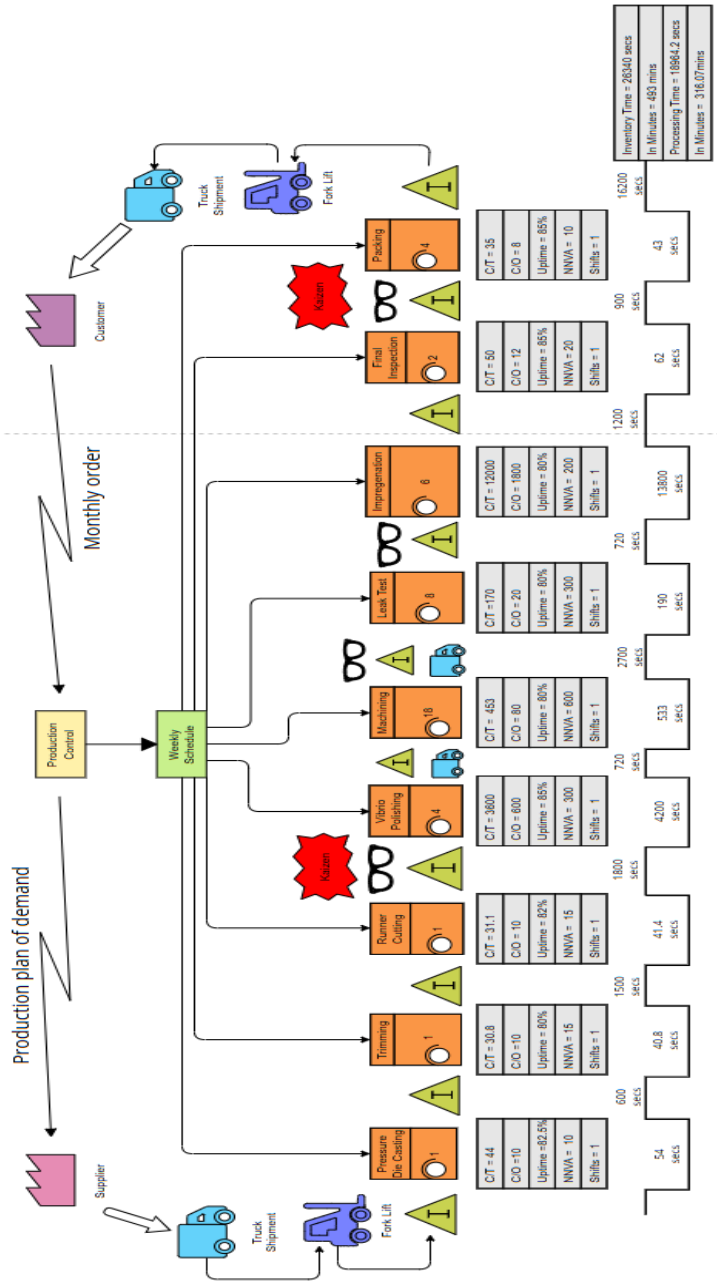

Figure 3.6 Future State Value Stream Mapping

The Figure 3.6 Future State Value Stream Map (VSM) depicts an optimized production process flow from customer to supplier, with reduced lead time, improved efficiency, and waste minimization. Raw materials are shipped by truck and are moved inside the company with the use of forklifts. Pressure Die Casting has 44s Cycle Time (C/T), 10 min Changeover (C/O), and 82.5% uptime, with subsequent Trimming (C/T: 30.8s, C/O: 10 min, 80% uptime) and Runner Cutting (C/T: 31.1s, C/O: 10 min, 82% uptime) with optimized material flow. Vibro Polishing (3600s), Machining (453s), Leak Testing (170s), and Impregnation (12,000s) are optimized to enhance uptime and minimize non-value-added activities (NNVA). Final Inspection (50s) and Packing (35s) guarantee quality and readiness for shipment. Kaizen initiatives reduce total inventory time to 26,840s (493 min) and processing time to 18,864.2s (316.07 min) while maintaining the same level of processing time, thus improving overall productivity as well as meeting customer demand more effectively. (A. Rastogi, et al., 2022)

SIMULATION ANALYSIS OF THE FUTURE STATE

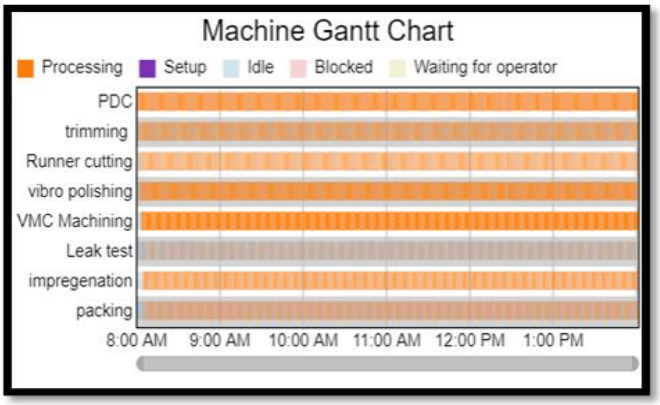

Figure 3.7 ABC Production Machining Gantt chart

The Figure 3.7 machine Gantt chart (8:00–9:15 AM) shows task flow between processes such as PDC, trimming, and machining but doesn't reflect inefficiencies. the above starting chart. The chart (8:00 AM–1:00 PM) adds setup, idle, and waiting time, providing insights into machine use and process constraints. (T. Roosefert Mohan, et al., 2021)

The chart facilitates the identification of inefficiencies such as operator delays and idle time.

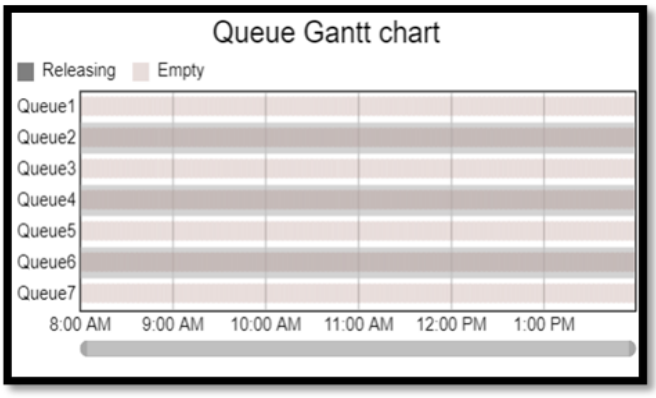

Figure 3.8 ABC Production Queue Gantt chart

Figure 3.5 gives an overall picture of queue patterns between 8:00 AM and 1:00 PM, indicating trends over time, whereas Figure 3.8 gives a close-up view of queue activity over a shorter 8:00 AM to 9:15 AM interval. The former indicates long-term trends, whereas the latter identifies particular bottlenecks, which helps in queue behaviour analysis.

FUTURE STATE OVERALL EQUIPMENT EFFICIENCY (OEE) CALCULATION

Table 3.3 Data for ABC Production OEE calculation

S. No.	OEE Factor	Data
1.	Planned Production Time	480 mins
2.	Unplanned Downtime	80 mins
3.	Ideal Cycle Time	4.5 mins/part
4.	Actual Cycle Time	4.7 mins/part
5.	Total Parts Produced	45000 parts
6.	Good Parts Produced	45000 parts

Calculating of the OEE from Table 3.3 are Availability is 83.33%, Performance is 95.74%, Quality is 100% and Final calculation of OEE is 79.80%.

FUTURE STATE OEE OF THE FCU COMPONENT = 79.80 %

4. RESULTS AND DISCUSSION

COMPARISON OF VALUE STREAM MAPPING (VSM)

Table 4.1 VSM Comparison

Current State and Future state comparsion of Value stream Mapping (VSM)							All Timinings are in Seconds	
S.No	Current State		Future State		Improvement		status of performance	
	Processing Time	Inventory Time	Processing Time	Inventory Time	Processing Time	Inventory Time	Processing Time	Inventory Time
1	54	1200	54	600	0	50%	same	Redused
2	40.8	2800	40.8	1500	0	46.43%	same	Redused
3	41.4	3000	41.4	1800	0	40%	same	Redused
4	4200	900	4200	720	0	20%	same	Redused
5	533	3600	533	2700	0	25%	same	Redused
6	190	900	190	720	0	20%	same	Redused
7	13800	1800	13800	1200	0	33.33%	same	Redused
8	62	1200	62	900	0	25%	same	Redused
9	43	18000	43	16200	0	10%	same	Redused
Total in secs	18964.2 secs	33400 secs	18964.2 secs	26340 secs				
Total in minutes	315.56 mins	556.66 mins	315.56 mins	439 mins				
Total in Hours	5.25 hrs	9.27hrs	5.25 hrs	7.31 hrs				

By comparing Table 4.1, VSM compares efficiency analysis indicating a 16.5% decrease in cycle time (13.99 to 12.58 hours) and a 21.07% decrease in inventory time. With the same processing time at 5.27 hours, efficient workflow, less waiting time, and more effective inventory control reduce delays

SIMULATION ANALYSIS COMPARISON

In ABC Production:

Future state simulation reduces the idle time of machines and queuing to a minimum. And Gantt chart clearly depicts the difference between future and current states.

COMPARISON OF CURRENT AND FUTURE STATE OVERALL EQUIPMENT EFFICIENCY (OEE)

Table 4.2 Comparison of current and future state OEE of ABC Production

S. NO.	OEE Factor	current state OEE calculation	Future state OEE calculation	status of performance
1).	Planned Production Time	480 mins	480mins	same
2).	Unplanned Downtime	96 mins	80 mins	Redused
3).	Ideal Cycle Time	4.5 mins/parts	4.5 mins/parts	same
4).	Actual Cycle Time	4.9 mins/parts	4.7 mins/parts	Redused
5).	Total Parts Poduced	35000 parts	45000 parts	Improved
6).	Good Parts Produced	35000 parts	45000 parts	Improved
7).	Availability	80%	83.33%	Improved
8).	Performance	91.80%	95.74%	Improved
9).	Quality	100%	100%	same
10).	Overall Equipment Effectiveness	73.44%	79.80%	Improved

Based on Table 4.2 Current and future state OEE comparison of ABC Production. The unplanned downtime falls to 80 minutes in the future state, cycle time to 4.7 minutes, and production to 45,000 units. The availability improves to 83.33%, performance to 95.74%, and OEE to 79.80%, increasing efficiency and productivity

4. CONCLUSIONS

Through the rise of OEE from 73.44% to 79.80%, ABC Production significantly improves to the level of producing 45,000 units. Machining OEE increased from 68.75% to 73.96%, while the inventory holding time decreased by 117.66 minutes, promoting efficiency. These enhancements facilitate increased productivity, quality, and waste minimization toward sustainable development. (J. Tanaka, et al., 2021)

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