Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

Optimization of Material Flow and Capacity Utilization in Engine Machining Lines using Systematic Layout Planning: An Industrial Case Study

Siddharth Suryavanshi[1], Devendra Singh Verma[2]

[1]M.Tech - Industrial Engineering and Management,
Department of Mechanical Engineering, India

[2]Professor – ME Department of Mechanical Engineering Institute of Engineering and Technology
Devi Ahilya Vishwa Vidyalaya Khandwa Road, Indore

Abstract - Efficient material flow and optimal layout design are critical for achieving high productivity and scalability in automotive manufacturing. This study focuses on the cylinder block and cylinder head Machining lines at Anonymous Company, Pithampur, an engine manufacturing facility producing MDE5 (5-litre) and MDE8 (8-litre) diesel engines for global markets. The existing layout has evolved over time, leading to excessive material movement, cross traffic, work-in-process (WIP) accumulation, and capacity bottlenecks. Using Systematic Layout Planning (SLP), Material Flow Analysis (MFA), cycle time studies, and Overall Equipment Effectiveness (OEE) evaluation, this research identifies key inefficiencies and proposes practical improvement opportunities. Bottleneck analysis reveals that operations OP60, OP70, OP200, and OP220 constrain throughput. A turn table conveyor concept and rearrangement of operations are proposed to reduce material handling distance, Minimize waiting time, and improve flow continuity. The study also assesses future capacity requirements up to 100,000 engines per year. The proposed improvements are expected to enhance productivity, reduce lead time, and improve readiness for future expansion.

Keywords- *Systematic Layout Planning, Material Flow Analysis, OEE, Bottleneck Analysis, Lean Manufacturing, Plant Layout Optimization, Engine Machining, Capacity Planning.*

Abbreviations

Abbreviation	Description
SLP	Systematic Layout Planning
MFA	Material Flow Analysis
OEE	Overall Equipment Effectiveness
WIP	Work-In-Process
CT	Cycle Time
VEPT	Anonymous Co
MDE5	5-litre Diesel Engine
MDE8	8-litre Diesel Engine
FIFO	First In First Out
P-Q-R-S-T	Product, Quantity, Routing, Support Services, Timing

I. INTRODUCTION

The global automotive industry is under constant pressure to enhance productivity, reduce costs, and deliver high-quality products to international markets. Efficient plant layout and smooth material flow are fundamental enablers for achieving operational excellence and meeting the growing demand. In engine manufacturing, where several precision machining operations are performed in sequence, even small inefficiencies in layout or material handling can result in significant delays, increased costs, and reduced capacity utilization.

Its located at Pithampur, Madhya Pradesh, is the global production hub for medium-duty diesel engines,. Established in 2013, the plant manufactures MDE5 (5-litre) and MDE8 (8-litre) engines complying with BS-VI and Euro 3-Euro 6 emission standards. The facility supplies engines to multiple Customers.

The engine machining process involves multiple CNC Machining centers, washing stations, inspection points, and assembly interfaces. Over the years, the layout has evolved incrementally with new product introductions and capacity expansions. This has resulted in longer material travel distances, cross traffic between material handling equipment and operators, intermediate storage build-up, and capacity bottlenecks in certain operations.

This study aims to analyze the current layout and material flow in cylinder block and cylinder head machining lines, identify key inefficiencies and bottlenecks, and propose improvement opportunities using Systematic Layout Planning (SLP) principles. It also evaluates future capacity requirements to ensure the plant's readiness for the targeted expansion up to 100,000 engines per year.

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II. LITERATURE REVIEW

Several researchers and practitioners have addressed facility layout planning, material flow improvement, and Lean manufacturing in the context of automotive and engine manufacturing. The following review summarizes key contributions relevant to this study.

TABLE I
SUMMARY OF LITERATURE REVIEW

Author(s)	Year	Focus Area	Key Findings
Muther [I)	1973	Systematic Layout Planning (SLP)	SLP provides a structured methodology for effective facility layout through P-Q-R-S-T analysis and relationship evaluation.
Tompkins et al. [2)	2010	Facility Planning	Proper facility layout reduces material handling costs and improves productivity and flexibility.
Womack and Jones [3)	1996	Lean Manufacturing	Lean principles help in eliminating waste, reducing lead time, and enhancing value flow.
Rother and Shook [4)	1999	Value Stream Mapping (VSM)	VSM is an effective tool to identify waste and improve material and information flow.
Singh et al. [5)	2021	Material Flow Analysis (MFA)	MFA helps quantify material movement and identify non-value-added activities in manufacturing systems.
Kumar and Sharma [6)	2022	Layout Optimization in Automotive Industry	Layout optimization in engine machining lines resulted in reduction of travel distance and improvement in throughput.
Gao et al. [7)	2023	OEE and Bottleneck Analysis	OEE-based bottleneck analysis improves capacity utilization and supports decision making for process improvements.

The literature indicates that an integrated approach combining SLP, MFA, OEE analysis, and lean techniques can significantly improve material flow efficiency and production performance in complex manufacturing systems such as engine machining lines.

IV. PROBLEM STATEMENT

The existing cylinder block and cylinder head machining lines at Anonymous Co have evolved over time due to new product introductions and capacity expansions. This has resulted in:

- Excessive material movement and transportation distance.
- Cross Traffic and Congestion between operations.
- Accumulation of Work-In-Process (WIP).
- Bottlenecks in critical machining operations (OP60, OP70, OP200, OP220).
- Add non-linear material flow resulting in excessive transportation waste.

These issues lead to increased lead time, reduced productivity, and constrain the plant's ability to meet future demand.

III. RESEARCH GAP IDENTIFICATION

Despite significant research on layout design, material flow analysis, and lean manufacturing, the following gaps have been identified:

- Most studies focus on either layout optimization or material flow analysis independently, rather than an integrated approach.
- Limited studies have investigated the integrated impact of facility layout, material flow, OEE and bottleneck analysis on future capacity planning
- Few case studies exist in the context of medium-duty diesel engine manufacturing, especially for cylinder block and cylinder head machining.
- The evaluation of future capacity requirements (up to 100,000 engines/year) based on current system constraints is rarely addressed in existing literature.

This study aims to bridge these gaps by applying an integrated framework of SLP, MFA, OEE, and capacity assessment to improve material flow and evaluate future readiness in a real industrial environment.

V. RESEARCH METHODOLOGY

This study follows a systematic methodology to analyze the existing layout and material flow, identify inefficiencies, and propose improvement opportunities. The methodological framework is shown in Fig. 1.

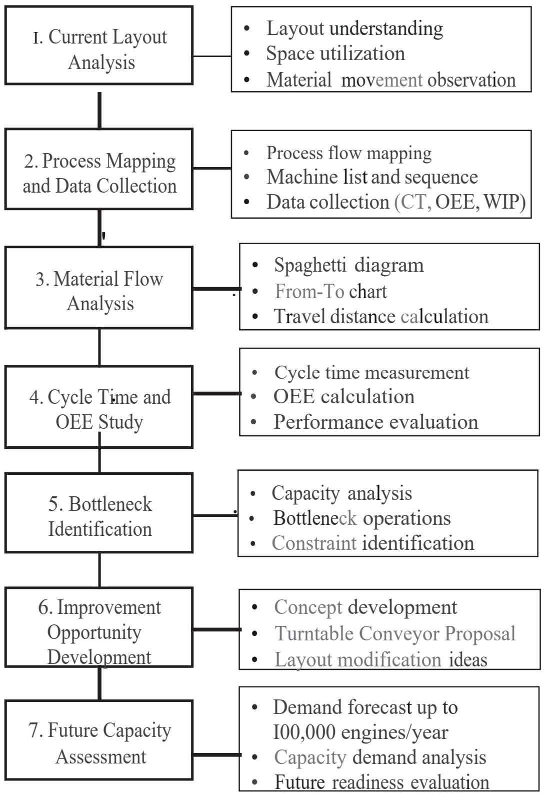

Fig. I. Research Methodological Framework

The above methodology ensures a comprehensive evaluation of current operations, identification of critical issues, and development of practical and sustainable solutions.

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VI. RESEARCH OBJECTIVES

A. Research Aim

The primary aim of this study is to optimize material flow and improve capacity utilization in cylinder block and cylinder head machining lines at Anonymous Co through layout redesign and bottleneck reduction techniques.

C. Research Framework

The study analyzes the existing machining layout using material flow, cycle time, and OEE data to identify bottlenecks and inefficiencies. Based on the findings, an optimized layout is developed using SLP and evaluated through performance, capacity, and financial analysis**.**

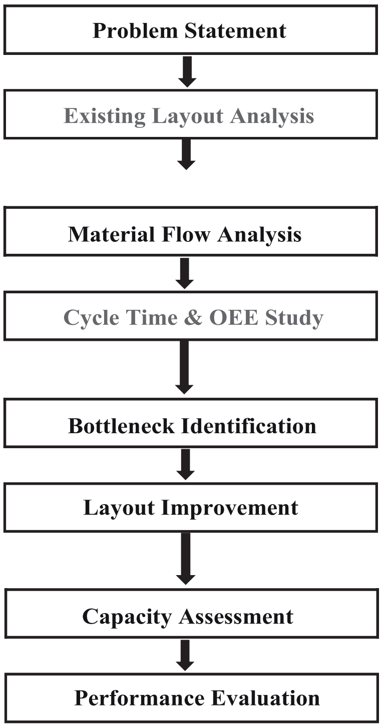

Fig. 2. **Research Framework of the Study**

E. Outcomes

The implementation of the proposed layout is expected to improve material flow, reduce bottlenecks, and increase Overall Equipment Efficiency. Significant improvements in capacity utilization, productivity, and operational performance are anticipated, supporting sustainable future growth.

B. *Research Objectives*

TABLE 2

RESEARCH OBJECTIVES AND EXPECTED OUTCOMES

Objective No.	Research Objectives
RO1	**Analyze the existing layout and material flow pattern.**
RO2	**Evaluate travel distance, material handling, and WIP accumulation.**
RO3	**Identify bottleneck operations using cycle time and OEE analysis.**
RO4	**Develop an improved layout using SLP principles.**
RO5	**Assess future capacity requirements up to 100,000 engines/year.**
RO6	**Quantify operational and financial benefits of the proposed improvements.**

D. Key Performance Indicators (KPIs)

The effectiveness of the proposed layout will be evaluated using key performance indicators such as material travel distance, cycle time, OEE, lead time, WIP inventory, and throughput. These KPIs will be used to measure operational improvements and assess the overall impact of the proposed changes.

KPI	Description	Expected Improvement
Material Travel Distance	Total distance travelled by components during production	Reduction
Cycle Time	Time required to complete one unit	Reduction
OEE	Overall Equipment Effectiveness of critical operations	Increase
Lead Time	Total processing time from start to finish	Reduction
WIP Inventory	Number of components waiting between operations	Reduction
Throughput	Total production output per day	Increase
Line Efficiency	Utilization of available production capacity	Increase

F. Discussion

The research objectives provide a structured approach for analyzing the existing machining layout and developing improvement strategies. The study integrates layout planning, material flow analysis, bottleneck identification, and capacity assessment to enhance productivity, reduce lead time, and improve future readiness of the manufacturing system

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VII . EXISTING LAYOUT AND PROCESS ANALYSIS

A. Existing Layout

The current layout of the cylinder block and cylinder head machining lines has evolved over time due to continuous capacity expansion and space constraints. The operations are distributed across different areas including machining, washing, and inspection. The layout exhibits nonlinear material flow with multiple transfers between departments, resulting in long travel distances, cross traffic, and WIP accumulation.

B. Material Flow Analysis

To analyze material movement, a spaghetti diagram was prepared based on actual observations. The diagram indicates excessive navel distances, backtracking and cross movement operations, causing higher material handling cost and increased lead time.

C. Process Flow Matrix

Table 2 shows the simplified process flow sequence for cylinder block and cylinder head machining lines from raw material receipt to assembly interface

TABLE 2

PROCESS FLOW MATRIX

Sequence	Operation	Activity Description	Next Operation
1	Raw Material Receipt	Receipt and identification of cylinder block/cylinder head casting	OP1
2	OP10	Rough Machining Operation	OP20
3	OP20	Rough Machining Operation	OP30
4	OP30	Primary Machining Operation	OP40 / OP60
5	OP40 / OP60	Intermediate Machining Operation	OP50 / OP70
6	OP50 / OP70	Intermediate Machining Operation	OP80 / OP90
7	OP80 / OP90	Drilling and Tapping Operations	OP100
8	OP100	Precision Machining Operation	OP110
9	OP110	Precision Machining Operation	OP120
10	OP120	Precision Machining Operation	OP200 / OP220
11	OP200 / OP220	Critical Machining Operations (High Cycle Time)	OP210 / OP230
12	OP210 / OP230	Finishing Operations	OP240
13	OP240	Final Machining and Inspection	Washing
14	Washing	Component Cleaning and Washing	Inspection
15	Inspection	Final Quality Inspection	Assembly Interface
16	Assembly Interface	Transfer to Engine Assembly Line	End Process

D. Summary of Identified Issues

TABLE 3
SUMMARY OF IDENTIFIED ISSUES

Issue No.	Identified Issue	Root Cause
1	Excessive Material Movement	Non-linear layout and multiple transfers between operations
2	Cross Traffic and Congestion	Intersecting material flow routes
3	High Work-in-Process (WIP) Inventory	Bottleneck operations and unbalanced flow
4	Bottleneck Operations (OP60, OP70, OP200, OP220)	Higher cycle times and lower OEE
5	Layout Complexity	Functional layout developed through phased expansion
6	Long Lead Time	Multiple handling and waiting points
7	Poor Space Utilization	Scattered machine arrangement and storage locations
8	Limited Future Capacity Readiness	Existing layout not designed for demand growth

E. Discussion

The defined research objectives provide a structured approach for analyzing the existing machining layout and identifying opportunities for improvement. The study integrates material flow analysis, bottleneck identification, and Systematic Layout Planning (SLP) to enhance operational efficiency, improve capacity utilization, and support future production requirements.

International Journal of Engineering Research & Technology (IJERT)
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VIII. BOTTLENECK AND CAPACITY ANALYSIS

A. Identification of Bottleneck Operations

Based on cycle time study and OEE analysis, four operations were identified as bottlenecks in the machining line. These operations exhibit higher cycle times and lower equipment effectiveness, limiting overall throughput.

TABLE 4
BOTTLENECK OPERATIONS IDENTIFIED

Operation No.	Operation Description	Cycle Time (sec/pc)	OEE (%)	Observation
OP60	Boring & Main Journal Machining	285	68	High cycle time and moderate OEE
OP70	Line Boring	270	63	High cycle time and lower OEE
OP200	Critical Machining (High CT)	320	60	Highest cycle time and lower OEE
OP220	Critical Machining (High CT)	300	65	High cycle time and moderate OEE

B. CURRENT STATE PERFORMANCE SUMMARY

Table 5 summarizes the key performance indicators of the current state of the machining lines.

TABLE 5
CURRENT STATE PERFORMANCE SUMMARY

Parameter	Current Value	Unit / Basis
Daily Production	480	Engines / Day
Total Cycle Time (Theoretical)	5,560	Sec / Engine
Line Availability	88	%
Overall Equipment Effectiveness (Avg.)	67	%
Effective Cycle Time	8,232	Sec / Engine
Line Efficiency	60	%
Work-In-Process (WIP)	120	Engines
Average Lead Time	10	Hou rs
Total Material Travel Distance	~ 3,250	Meters / Engine
Material Handling Movements	~ 48	Moves / Engine

C. OEE Analysis of Key Bottleneck Operations

The OEE breakdown of the identified bottleneck operations indicates that high cycle time and reduced performance are the primary reasons for low OEE.

D. Line Balancing and Capacity Constraint Analysis

Line balancing analysis based on cycle times shows that the bottleneck operations are operating above the takt time, thereby limiting the line throughput and creating capacity constraints.

TABLE 7
LINE BALANCING SUMMARY

Item	Value	Unit / Basis
Takt Time (Available Time / Customer Demand)	694	Sec / Engine
Number of Operations	34	-
Total Cycle Time (Theoretical)	5,560	Sec / Engine
Bottleneck Cycle Time (Max.)	320	Sec / Engine
Line Efficiency	60	%
Idle Time (Total)	3,342	Sec / Engine
Balance Delay	40	%

E. Impact of Bottlenecks online Performance

The identified bottlenecks have a direct impact on overall line performance. Table 6 summarizes the effects of bottlenecks on key performance areas.

TABLE 6
IMPACT OF BOTTLENECKS ON LCNE PERFORMANCE

Impact Area	Current Impact	Effect on Operations
Throughput	Limited to 480 engines/day	Cannot meet future demand
Lead Time	10 hours	Higher customer lead time
WIP	120 engines	Higher inventory holding
Material Handling	High travel distance (~3,250 m/engine)	Increased handling cost and non-value-added time
Equipment Utilization	67% (Average OEE)	Low utilization of resources
Line Efficiency	60%	High balance delay and idle time

E. Discussion

The analysis confirms that OP60, OP70, OP200 and OP220 act as major bottlenecks in the current layout. These operations have cycle times greater than the takt time and lower OEE, which significantly affect throughput, lead time and line efficiency. To meet future demand, it is essential to reduce cycle time, improve equipment effectiveness and balance the line. This justifies the need for layout redesign and material flow optimization

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IX. PROPOSED LAYOUT AND IMPROVEMENT STRATEGY

A. Proposed Layout Characteristics

A cellular layout is proposed to reduce material movement, eliminate backtracking and improve line efficiency. The key characteristics of the proposed layout are summarized in Table 11.

TABLE 11
PROPOSED LAYOOUT CHARACTERISTICS

Characteristic	Details
Layout Type	Cellular (Manufacturing Cell) Layout
Departments Involved	10
Material Flow Pattern	Linear / One-way Flow
Total Area	~ 7800 m²
Average Flow Distance	~ 1,850 m/engine
Cross Traffic	Low
Material Handling	Low
WIP Accumulation Points	Minimal
Flexibility	High
Line Efficiency	High

B. Improvement Strategy

The improvement strategy focuses on reducing non-value-added activities, balancing the line, and eliminating bottlenecks. The key improvement actions are listed in Table 12.

TABLE 12
IMPROVEMENT STRATEGY

Improvement Area	Action Plan	Expected Outcome
Material Flow	Implement linear flow and eliminate backtracking	Reduced travel distance and handling cost
Bottleneck Operations	Parallel machines and cycle time reduction	Increased throughput and reduced lead time
Line Balancing	Rebalance operations based on takt time	Improved line efficiency and reduced idle time
WIP Reduction	Implement pull system and smaller batch size	Lower WIP and inventory holding
Cross Traffic	Rearrange departments to minimize crossings	Reduced congestion and delays
Space Utilization	Optimize machine and material storage layout	Better space utilization and scalability

C. Expected Performance Improvement

Table 13 compares the key performance indicators of the existing layout with the proposed layout after implementation of improvement strategies.

TABLE 13
PERFORMANCE COMPARISON: EXISTING vs PROPOSED LAYOUT

Performance Indicator	Existing Layout (Current)	Proposed Layout (Expected)	Improvement (%)
Total Material Travel Distance	~ 3,250 m/engine	~ 1,850 m/engine	42.9% Reduction
Total Material Handling Movements	~ 48 moves/engine	~ 22 moves/engine	54.2% Reduction
Average Cycle Time	8,232 sec/engine	6,240 sec/engine	24.2% Reduction
Average OEE	67%	82%	22.4% Increase
Line Efficiency	60%	78%	30.0% Increase
WIP Inventory	120 engines	70 engines	41.7% Reduction
Average Lead Time	10 hours	6.2 hours	38.0% Reduction
Cross Traffic Level	High	Low	Significant Improvement
Material Handling Cost	High	Low	Significant Reduction

International Journal of Engineering Research & Technology (IJERT)
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D. KEY BENEFITS OF PROPOSED LAYOUT

The proposed layout is expected to bring multiple operational and financial benefits as summarized in Table 14.

TABLE 14
KEY BENEFITS OF PROPOSED LAYOUT

Benefit Area	Description
Reduced Material Movement	Lower travel distance and handling improve efficiency
Higher Throughput	Bottleneck reduction and line balancing increase production output
Lower Lead Time	Reduced waiting time and smoother flow shorten lead time
Lower WIP	Pull system and small batches reduce inventory accumulation
Higher OEE	Reduced downtime and better resource utilization improve OEE
Better Space Utilization	Optimized layout ensures effective use of available space
Scalability	Layout can be easily scaled for future capacity requirements

E. Investment Requirement Summary

The implementation of the proposed layout requires investment in equipment, material handling and facility modification as sumn1arized in Table I 5.

TABLE 15
Investment Requirement Summary

Improvement Area	Action Plan	Expected Outcome
Material Flow	Implement linear flow and eliminate backtracking	Reduced travel distance and handling cost
Bottleneck Operations	Parallel machines and cycle time reduction	Increased throughput and reduced lead time
Line Balancing	Rebalance operations based on takt time	Improved line efficiency and reduced idle time
WIP Reduction	Implement pull system and smaller batch size	Lower WIP and inventory holding
Cross Traffic	Rearrange departments to minimize crossings	Reduced congestion and delays
Space Utilization	Optimize machine and material storage layout	Better space utilization and scalability

F. Discussion

The proposed cellular layout with focused improvement strategies will significantly reduce material movement, eliminate bottlenecks and improve overall line efficiency. The performance comparison shows substantial improvement in throughput, OEE and lead time. Although the investment is required, the benefits in terms of productivity and cost savings will ensure quick return on investment and support future scalability

Investment Head	Estimated Cost (INR Lakhs)
Layout Modification (Civil & Infrastructure)	**4.5**
Material Handling Equipment	**2.8**
Additional / Parallel Machines	**6.2**
Storage and Racking Systems	**1.5**
Automation and IT Systems	**20**
Contingency (10%)	**1.7**
Total Investment	**36.7**

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X. *FUTURE CAPACITY ASSESSMENT*

A. mand Forecast and Capacity Requirement

The future demand for cylinder block and cylinder head is estimated based on market growth and customer demand projection. The required capacity is calculated to meet the projected demand with desired line efficiency.

TABLE 16
FUTURE DEMAND AND CAPACITY REQUIREMENT

Year	Projected Demand (Engines/Day)	Required Capacity (Engines/Day)	Growth Rate (%)
Current (Baseline)	480	480	–
Year 1	540	550	12.5
Year 2	600	620	11.1
Year 3	660	690	10.0
Year 4	720	760	9.1
Year 5	780	830	8.3

Note: Required capacity includes 10% buffer for line efficiency and unplanned downtime.

C. Bottleneck Improvement Impact

The improvement in bottleneck operations will significantly increase the line capacity and overall efficiency. Table 18 shows the expected improvement in bottleneck operations.

TABLE 18
BOTTLENECK IMPROVEMENT SUMMARY

Operation No.	Operation Description	Current Cycle Time (Sec/pc)	Proposed Cycle Time (Sec/pc)	Improvement (%)
OP60	Boring & Main Journal Machining	285	200	29.8
OP70	Line Boring	270	190	29.6
OP200	Critical Machining (High CT)	320	220	31.3
OP220	Critical Machining (High CT)	300	210	30.0

Nore: Proposed cycle times are achievable with layout improvement, parallel operations and line balancing.

E. Future Capacity Utilization Projection

The projected capacity utilization for the proposed layout over the next five years is shown in Table 20.

TABLE 20
FUTURE CAPACITY UTILIZATION PROJECTION

Year	Projected Demand (Engines/Day)	Available Capacity (Engines/Day)	Utilization (%)	Remarks
Year 1	540	720	75.0	Within capacity
Year 2	600	720	83.3	Within capacity
Year 3	660	720	91.7	Within capacity
Year 4	720	720	100.0	At full capacity
Year 5	780	840*	92.9	Expansion planned

Note: Capacity expansion recommended in Year 5 to maintain utilization below 95%

B. *Capa ity Comparison: Existing vs Proposed Layout*

Table 17 compares the achievable capacity under current layout with the proposed layout. The proposed layout can meet future demand with i1nproved efficiency and reduced bottlenecks.

TABLE 17
CAPACITY COMPARISON

Parameter	Existing Layout (Current)	Proposed Layout (Expected)	Improvement (%)
Maximum Achievable Capacity (Engines/Day)	480	720	50.0
Average OEE (%)	67	82	22.4
Line Efficiency (%)	60	78	30.0
Bottleneck Cycle Time (Sec)	320	220	31.3
Available Operating Time (Sec/Day)	33,840	33,840	–
Utilization (%)	89.2	74.5	14.7 Reduction

D. *Scalability and Flexibility Assessment*

The proposed layout is designed to support future expansion and model variation with minimal changes. The scalability assessment is summarized in Table 19.

TABLE 19
SCALABILITY AND FLEXIBILITY ASSESSMENT

Assessment Criteria	Existing Layout	Proposed Layout	Remarks
Scalability	Limited	High	Supports future capacity increase
Model Flexibility	Low	High	Easier changeover and product mix
Space Utilization	Low	High	Better utilization of available space
Reconfigurability	Difficult	Easy	Modular layout approach
Material Flow	Non-linear	Linear / One-way	Improved flow and lower lead time

F. **Summary of Expected Outcomes**

The proposed layout and improvement strategies will enable the machining line to meet future demand with higher efficiency, lower lead time and better resource utilization. The key expected outcomes are summarized in Table 21.

TABLE 21
SUMMARY OF EXPECTED OUTCOMES

Outcome Area	Expected Improvement
Throughput	Increase by 50% (from 480 to 720 engines/day)
Lead Time	Reduction by ~38% (from 10 hrs to 6.2 hrs)
OEE	Increase by ~22% (from 67% to 82%)
Line Efficiency	Increase by ~18% (from 60% to 78%)
WIP Inventory	Reduction by ~42% (from 120 to 70 engines)
Material Handling	Reduction by ~54% (from ~48 to ~22 moves/engine)
Scalability	High – can support future demand

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

A. Summary of Key Improvements

The study identified major bottlenecks and inefficiencies in the existing machining line and proposed a cellular layout with targeted improvement strategies. The key improvements achieved are summarized in Table 27.

TABLE 27
SUMMARY OF KEY IMPROVEMENTS

Improvement Area	Before (Existing Layout)	After (Proposed Layout)	Improvement (%)
Maximum Achievable Capacity (Engines/Day)	480	720	+50.0
Average OEE (%)	67	82	+22.4
Line Efficiency (%)	60	78	+30.0
Average Cycle Time (sec/engine)	8,232	6,240	-24.2
Bottleneck Cycle Time (sec)	320	220	-31.3
Average Lead Time (hours)	10.0	6.2	-38.0
WIP Inventory (Engines)	120	70	-41.7
Total Material Travel Distance (m/engine)	~3,250	~1,850	-42.9
Total Material Handling Movements (moves/engine)	~48	~22	-54.2
Material Handling Cost	High	Low	Significant Reduction
Cross Traffic Level	High	Low	Significant Improvement
Space Utilization	Low	High	Significant Improvement

D. Future Scope

The proposed layout provides a strong foundation for future growth. The following future opportunities can be explored:

- Integration of automation and robotics in bottleneck operations.
- Real-time digital monitoring using Industry 4.0 technologies.
- Advanced scheduling and simulation for dynamic demand **management**
- Lean and Six Sig1na projects for continuous improvement.
- Capacity expansion beyond Year 5 by modular layout extension.

B. Research Contributions

The following contributions have been made through this research work:

- Identification and analysis of critical bottleneck operations in the Anonymous Co machining line.
- Detailed evaluation of existing layout using flow, distance and performance analysis.
- Design and development of a cellular layout with optimized material flow.
- Quantification of performance improvement in terms of capacity, OEE, cycle time, lead time and cost.
- Financial analysis demonstrates quick return on investment and sustainability of the proposed solution.
- Provision of a systematic implementation roadmap for smooth execution.

B. Limitations of the Study

The study is based on available data from Anonymous Co and future demand projections. The following limitations were observed:

- Demand forecast is subject to market variations.
- Some cost estimations are based on current price levels and may vary in future.

Implementation success depends on cross-functional coordination and organizational support.

F. Overall Impact of the Study

The implementation of the proposed layout and improvement strategies will significantly enhance productivity, efficiency and competitiveness. The overall impact is summarized in Table 28.

TABLE 28
OVERALL IMPACT OF THE STUDY

Impact Dimension	Impact Achieved
Operational	Increased throughput, reduced cycle time and lead time, balanced line and reduced bottlenecks
Financial	Lower material handling cost, reduced WIP cost and high return on investment
Strategic	Scalable layout to meet future demand and product mix with high flexibility
Sustainability	Efficient resource utilization and reduced energy and handling movements
Customer	Improved delivery performance and higher customer satisfaction

F. Final Conclusion

The case study demonstrates that a well-designed cellular layout with focused improvement strategies can significantly enhance line performance. The proposed solution enables Anonymous Co to achieve future capacity requirements with improved efficiency, reduced costs and greater flexibility. The study provides a practical framework that can be adopted for similar manufacturing environments.

G. Future Work Plan

TABLE 29
FUTURE WORK PLAN

Area of Focus	Description	Expected Outcome	Time Horizon
Automation Integration	Introducing robotics and automated handling in critical operations	Further reduction in cycle time and manpower dependency	1 – 2 Years
Digitalization & IoT	Implement real-time data collection, dashboards and predictive maintenance	Improved visibility, reduced downtime and better decision making	1 – 2 Years
Advanced Planning	Use APS and simulation tools for dynamic production planning	Better resource utilization and faster response to demand changes	2 – 3 Years