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Supply Chain Resilience in Industrial Manufacturing

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ABSTRACT:
Supply chain resilience has become a crucial factor for small-scale manufacturing industries, as disruptions from global crises, natural disasters, and market fluctuations expose vulnerabilities in traditional supply chains. This study explores strategies to enhance resilience in small-scale manufacturing by integrating Value Stream Mapping (VSM) to assess both current and future states, implementing One-Piece Flow and Batch Flow for efficiency, and adopting the 5S Principle for workplace organization. Key factors such as predictive analytics, supply chain visibility, and supplier collaboration are evaluated for their role in mitigating disruptions. The research demonstrates that small-scale firms adopting a proactive, structured approach can significantly minimize lead times, reduce waste, and maintain operational continuity in the face of unforeseen challenges. This paper provides a framework for integrating resilience-building practices tailored to small-scale manufacturers, encouraging industry stakeholders to invest in sustainable supply chain stability.

Keywords: **Supply Chain Resilience, Small-Scale Manufacturing, Value Stream Mapping (VSM), Lean Manufacturing, 5S Principle, Inventory Optimization, Technology Integration.**

1. INTRODUCTION

Supply chain resilience has emerged as a key priority for small-scale manufacturing firms manufacturers often operate with limited resources, making them more vulnerable to disruptions. The interconnected nature of supply chains means that even minor delays in material sourcing can lead to significant production setbacks. Therefore, adopting lean methodologies such as Value Stream Mapping (VSM), One-Piece Flow, Batch Flow, and the 5S Principle can help streamline operations and enhance resilience. This study explores the unique challenges faced by small-scale manufacturers, the objectives of resilience-building, and the scope of implementing lean techniques for supply chain improvement.

1.1 Problems Faced

Small-scale manufacturing supply chains encounter several challenges, including:

Global Disruptions: Events such as the COVID-19 pandemic, supply chain breakdowns, and regional instabilities have led to production halts and material shortages, increasing costs and affecting order fulfillment.

Dependency on Single Sources: Many small-scale firms rely on a limited number of suppliers, often concentrated in specific regions, making them highly susceptible to localized disruptions.

Lack of Visibility and Data Integration: Limited real-time tracking of inventory, production workflows, and supplier reliability can hinder effective decision-making during disruptions.

Demand Volatility: Rapid fluctuations in market demand require flexible production strategies, which traditional batch production alone may not efficiently address.

International Journal of Engineering Research & Technology (IJERT)
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1.2 Objectives of the Study

The primary objectives of this study are as follows:

Identify Key Strategies for Building Resilience: Examine various approaches, including risk assessment, diversified sourcing, and the use of lean principles, that enhance supply chain resilience for small-scale manufacturers.

Analyze the Role of Lean Tools and Technology: Investigate how digital tools such as predictive analytics, IoT, and AI, along with lean manufacturing techniques like VSM, One-Piece Flow, and the 5S Principle, can improve efficiency and responsiveness.

Develop a Framework for Resilient Small-Scale Manufacturing: Propose a comprehensive framework that small firms can adopt to strengthen their supply chains, minimize disruptions, and improve their adaptability to changing market conditions.

1.3 Scope of the Study

This study focuses on small-scale manufacturing industries, examining various sectors where supply chain resilience is essential for maintaining operational continuity. By using Value Stream Mapping (VSM) to analyze both current and future states, we assess how resilience strategies can be integrated at different stages of the supply chain, from raw material procurement to final product distribution. The research also emphasizes lean techniques such as One-Piece Flow, Batch Flow, and the 5S Principle, demonstrating their impact on waste reduction, efficiency improvement, and long-term sustainability. This study provides actionable insights for small manufacturers looking to build more reliable and resilient supply chains in response to future challenges.

2. LITERATURE REVIEW

Numerous academic journals have published extensive research addressing the importance of supply chain resilience. Notable journals include the Journal of Supply Chain Management, which focuses on strategies for resilience; Supply Chain Management: An International Journal, highlighting case studies and methodologies; and the International Journal of Production Economics, which explores operational strategies. Additional journals include the Transportation Research Part E, which addresses logistical challenges, and the Journal of Business Logistics, which examines practices that enhance resilience.

Further contributions come from the Supply Chain and Operations Management, the Journal of Operations Management, and the International Journal of Logistics Management, which investigate logistics strategies and their impact on resilience. The Journal of Purchasing and Supply Management discusses procurement strategies, while the Journal of Retailing and Consumer Services emphasizes consumer-centric supply chain strategies. The International Journal of Operations & Production Management offers insights into operational efficiency, and the Journal of Business Research* provides a broader perspective on how supply chain practices affect overall business outcomes. Other relevant journals include the European Journal of Operational Research, which analyses quantitative methods in supply chain management, and the International Journal of Physical Distribution & Logistics Management, focusing on the logistics aspects of supply chain resilience.

Several pivotal articles provide deeper insights into resilience strategies. For instance, "Supply Chain Resilience: A Review and Research Agenda" offers a comprehensive overview of resilience concepts, while "Building Resilience in Supply Chains: Strategies and Methods" discusses approaches like diversification and technology adoption. Articles such as "The Role of Information Technology in Supply Chain Resilience" explore how technological advancements bolster resilience, and "Agility and Resilience in Supply Chains: A Dual Perspective" analyses the interplay between agility and resilience. Furthermore, "Risk Management Strategies in Supply Chains: A Resilience Perspective" emphasises the necessity of integrating risk management into resilience frameworks. Collectively, this body of literature emphasises the multifaceted nature of supply chain resilience, incorporating elements of risk management, technology integration, and strategic planning.

International Journal of Engineering Research & Technology (IJERT)
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In addition to published research in key supply chain journals, various studies have highlighted the integration of lean manufacturing techniques such as Value Stream Mapping, One-Piece Flow, and 5S Principles in small-scale industries. These methodologies have proven effective in reducing lead time, improving productivity, and enhancing supply chain resilience.

3. STRATEGIES FOR BUILDING RESILIENCE

3.1 Value Stream Mapping (Vsm)

Value Stream Mapping (VSM) is a lean management tool used to visually represent the flow of materials and information throughout the entire production or service process. The primary goal of value stream mapping is to identify and eliminate waste, streamline processes, and enhance overall efficiency. It provides a detailed, end-to-end view of how products or services are delivered, from raw material acquisition to the final delivery to customers.

Here are the key elements and steps involved in value stream mapping:

Key Elements of Value Stream Mapping

Customer Demand: Represents the end customer's needs, including the desired product or service quantity and delivery timeline.

Information Flow: This shows how information flows throughout the value stream, including communication between different processes, departments, or external suppliers.

Material Flow: Indicates the movement of materials, raw goods, and semi-finished products from one stage to the next.

Process Steps: These represent each stage or activity in the production or service delivery process, such as assembly, inspection, or transportation.

Lead Time: The total time taken for a product to move through the value stream, from start to finish.

Cycle Time: The amount of time required to complete one unit of production or deliver one service.

Steps to Create a Value Stream Map

Select the Process or Product: Identify the specific product, service, or process to map. This should typically be one that represents a significant portion of your business or one that has improvement potential.

Define the Scope: Establish the boundaries of the value stream map by determining where the process begins (e.g., receiving raw materials) and ends (e.g., shipping the finished product to customers).

Gather Data: Collect data on each process step, such as cycle times, inventory levels, lead times, downtime, and any other relevant metrics.

Map the Current State: Draw the current state map, showing the flow of both materials and information. This map highlights the existing process flow and helps visualize inefficiencies, delays, and bottlenecks.

Identify Waste and Opportunities for Improvement: Analyze the current state map to identify areas where waste occurs, such as delays, excess inventory, or unnecessary steps. Look for opportunities to improve flow, reduce waste, and shorten lead times.

International Journal of Engineering Research & Technology (IJERT)
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Design the Future State: Develop a future state map that illustrates how the process should ideally function, with improvements that reduce waste and optimize flow. This might include implementing lean principles like 5S, reducing batch sizes, or improving communication.

Implement and Improve: Develop an action plan to implement the changes identified in the future state map. Once the changes are in place, continue to monitor performance, adjust, and refine the process to achieve sustained improvements.

Benefits of Value Stream Mapping
Improved Efficiency: By identifying and eliminating waste, VSM helps organizations streamline processes, improve throughput, and reduce lead times.

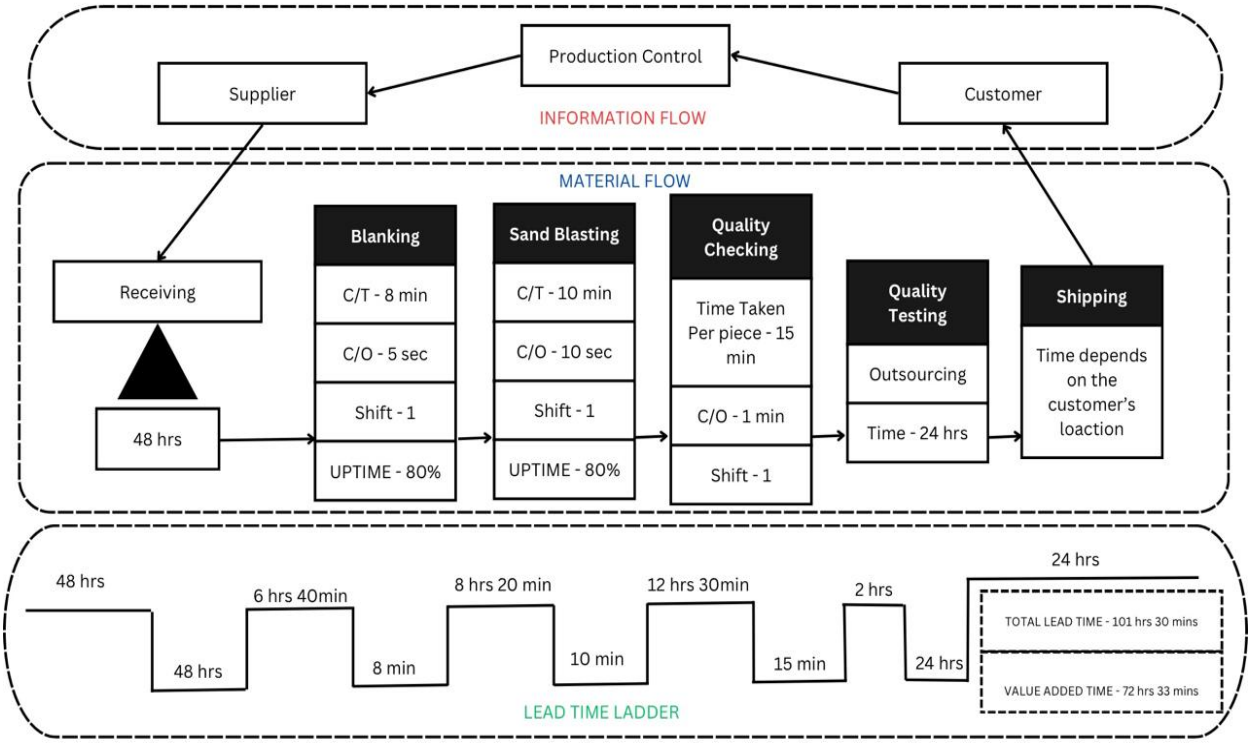
Enhanced Communication: It creates a shared understanding among teams by visualizing the entire process flow, making it easier to discuss areas for improvement.

Better Decision Making: Data gathered during VSM helps management make informed decisions on where to invest resources to improve processes.

Reduced Costs: Waste reduction, such as lower inventory levels and less waiting time, directly contributes to cost savings.

Continuous Improvement: VSM facilitates a culture of ongoing improvement, where processes are continually reassessed and optimized.

3.1.1 Current State Value Stream Mapping (Vsm)



3.2 Progress to Solution
To enhance supply chain resilience and efficiency, the following key steps are proposed:

Implementation of the 5S Principles for workplace organization and efficiency.

International Journal of Engineering Research & Technology (IJERT)
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Transitioning from Batch Processing to Single-Piece Flow to reduce lead time and improve flexibility.
Development of a Future State VSM to optimize processes and eliminate waste.

3.3 Implementation of 5S Principles

The 5S methodology enhances efficiency and productivity in small-scale manufacturing by creating a well-organized and sustainable work environment. The five steps are:

Sort (Seiri):

• The first step in 5S is to sort through all items and materials in the workplace, distinguishing between necessary items and unnecessary ones.
• Unnecessary items are removed or disposed of, freeing up space and reducing clutter.
• Sorting helps streamline processes, reduce waste, and improve efficiency by ensuring that only essential items are kept in the workplace.

Set in Order (Seiton):

• Once unnecessary items have been removed, the next step is to organize and arrange the remaining items in a logical and efficient manner.

• Each item is assigned a designated location based on frequency of use, accessibility, and workflow requirements.

• Clear labeling, signage, and visual aids are used to indicate storage locations and facilitate easy identification and retrieval of items.

• Setting items in order helps reduce search time, minimize errors, and enhance productivity by ensuring that everything has a designated place and can be easily found when needed.

Shine (Seiso):

• Seiso focuses on cleanliness and maintaining a clean and orderly workplace environment.

• Regular cleaning and inspection activities are performed to remove dirt, dust, debris, and other contaminants from work areas, equipment, and tools.

• Cleaning tasks are assigned to employees, who are responsible for keeping their own workspaces clean and organized.

• Regular maintenance and preventive measures are implemented to ensure that equipment and facilities are in good working condition.

• A clean and well-maintained workplace enhances safety, reduces the risk of accidents or injuries, and promotes a sense of pride and ownership among employees.

Standardize (Seiketsu):

• Standardization involves establishing clear guidelines, procedures, and standards for maintaining the 5S principles on an ongoing basis.

• Standardized processes and procedures are documented and communicated to all employees, ensuring consistency and uniformity in workplace organization and cleanliness.

• Visual management tools, such as checklists, standard operating procedures (SOPs), and color-coded labels, are used to reinforce standards and facilitate compliance.

• Regular audits and inspections are conducted to monitor adherence to standards and identify areas for improvement.

International Journal of Engineering Research & Technology (IJERT)
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• Standardization promotes accountability, reinforces good habits, and sustains the benefits of 5S over time.

Sustain (Shitsuke):
• The final step in 5S is to sustain and continuously improve the gains achieved through the previous steps.
• Sustaining 5S requires ongoing commitment, discipline, and participation from all employees at all levels of the organization.
• Training, education, and communication initiatives are implemented to foster a culture of 5S and promote employee engagement and ownership.
• Continuous improvement practices, such as Kaizen (continuous improvement) events, are used to identify opportunities for further optimization and refinement of processes.
• Sustaining 5S leads to long-term benefits, including improved efficiency, quality, safety, and employee morale, contributing to overall organizational success.
• By implementing the 5S Principles, organizations can create clean, organized, and efficient workplaces that support operational excellence, safety, and continuous improvement.
Implementing 5S in small-scale manufacturing requires commitment from all employees to ensure long-term sustainability, efficiency, and safety improvements. By following a structured approach to workplace organization, small manufacturers can significantly enhance productivity, minimize errors, and create a more streamlined and adaptable production environment.

4. COMPARISON BETWEEN BATCH PROCESSING AND SINGLE-PIECE FLOW PROCESSING

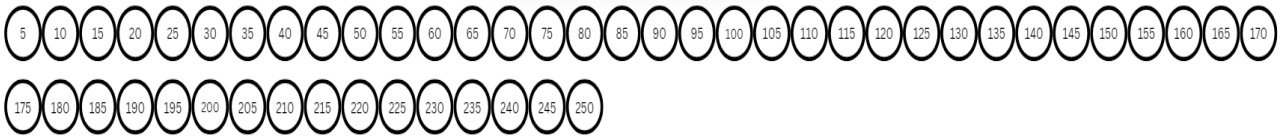
Batch processing and single-piece flow processing significantly impact the efficiency and responsiveness of small-scale manufacturers. A comparison of both approaches in a small scale industry which produces gear sprockets is given below,

4.1 Batch Processing:

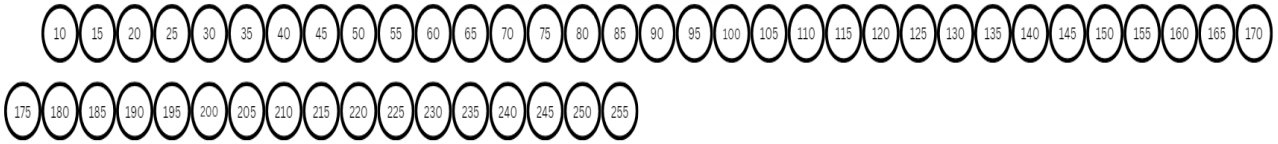
Blanking: Batch of 50 components = 8 × 50 = 400 min
Sand Blasting: Batch of 50 components = 10 × 50 = 500 min
Quality Checking: Batch of 50 components = 15 × 50 = 750 min
Total Time for 50 components: 400 + 500 + 750 = 1650 min (27 hr 30 min)

4.2 Single-Piece Flow Processing:

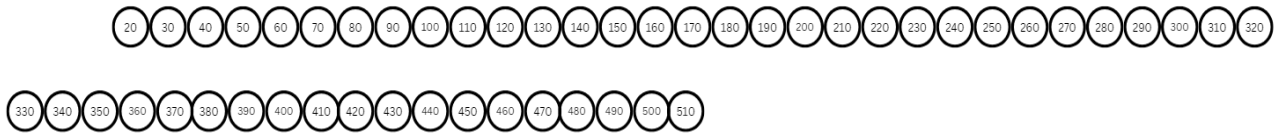
Blanking: Immediate processing of individual components reduces waiting time.



Sand Blasting: Components move directly to the next stage without waiting for batch completion.



Quality Checking: Continuous inspection prevents backlogs and enables real-time defect identification.



Overall Lead Time Reduction: Greater flexibility and responsiveness, reducing total processing time significantly.

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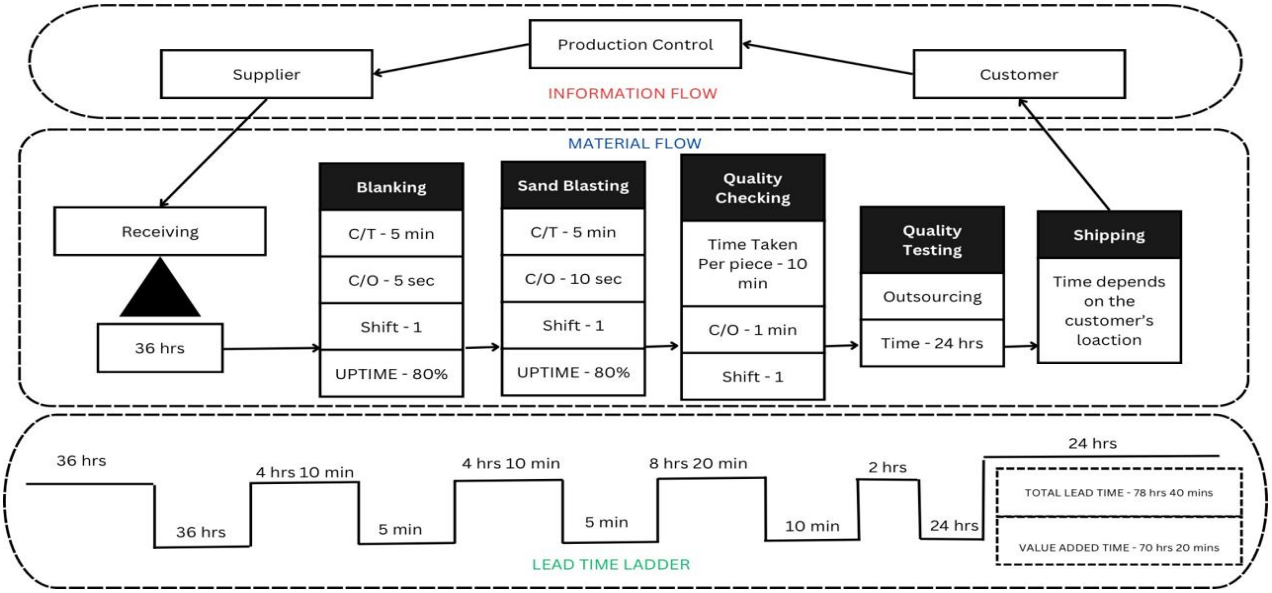
By transitioning from batch processing to single-piece flow, small manufacturers can improve efficiency, minimize inventory holding costs, and enhance production responsiveness, ensuring a more resilient supply chain.

5. FUTURE STATE VALUE STREAM MAPPING (VSM)

By transitioning from batch processing to single-piece flow and implementing lean principles, the future state of VSM demonstrates improved efficiency and lead time reductions.



LEAD TIME CALCULATION

Process	Current State	Future State	Percentage Reduction
Receiving	48 hrs	36 hrs	25%
Blanking	8 min	5 min	37.5%
Sand Blasting	10 min	5 min	50%
Quality Checking	15 min	10 min	33.3%
Quality Testing	24 hrs	24 hrs	0%

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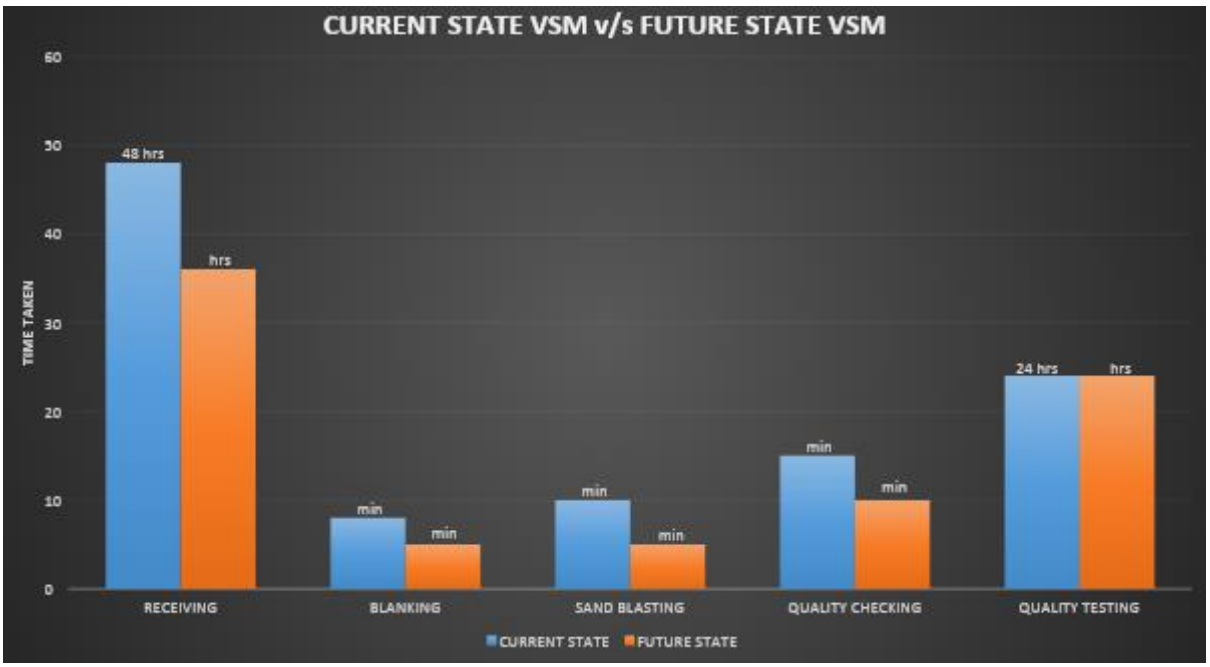
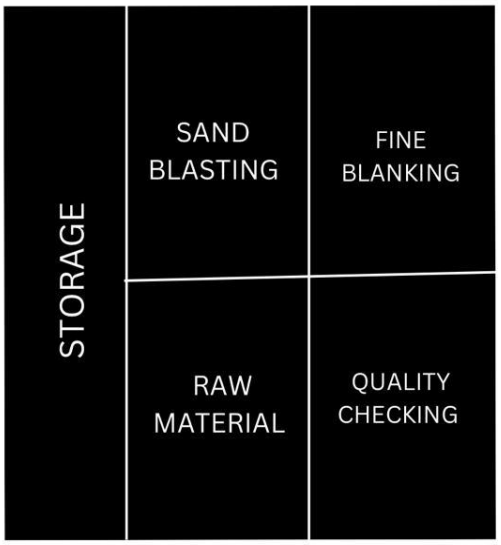
7.COMPARISON BETWEEN CURRENT STATE VSM V/S FUTURE STATE VSM



8. LAYOUT OPTIMIZATION



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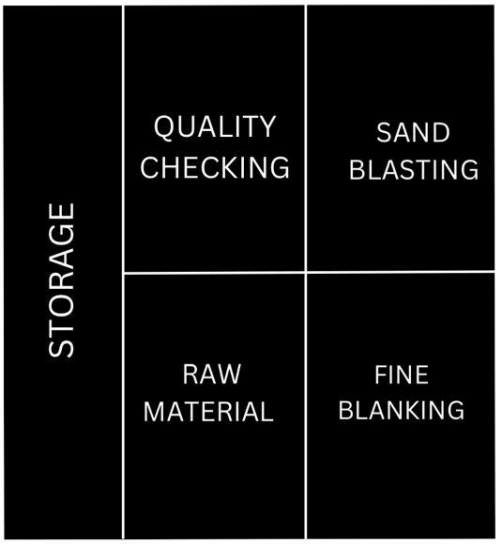

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PURPOSE OF LAYOUT OPTIMIZATION:

Layout optimization plays a significant role in enhancing the resilience of supply chains by improving operational efficiency, reducing lead times, and increasing flexibility in response to disruptions. In a supply chain, the layout refers to the physical arrangement of resources, such as production lines, storage areas, transportation routes, and suppliers within a facility or across a network of facilities.

The purpose of layout optimization in supply chain resilience can be understood through several key objectives:

1. Improved Operational Efficiency

Minimized Travel Time: Optimizing the layout minimizes the time spent moving materials, products, or components between different stages of the production or distribution process. This leads to faster throughput, reducing the time required to fulfill customer orders and improving overall operational performance.

Streamlined Flow of Goods: A well-organized layout ensures smoother material flow, which is crucial in maintaining consistent production levels. This reduces bottlenecks and ensures that production lines are not hindered by unnecessary delays or interruptions.

Reduction in Inventory Levels: By arranging resources and equipment efficiently, layout optimization can reduce the need for excess inventory, which reduces the costs associated with storage and stockouts.

2. Enhanced Flexibility and Adaptability

Quick Response to Disruptions: A flexible layout allows for quick reconfiguration of processes and workflows in response to disruptions, such as raw material shortages, transportation delays, or demand fluctuations. This adaptability is crucial for maintaining operations during unexpected events.

Capacity to Scale Operations: Layout optimization supports scalability by enabling easy expansion of production capacity or integration of new processes and technologies. This ability to scale operations quickly enhances resilience when dealing with changes in demand or new market conditions.

3. Improved Coordination and Communication

Centralized or Decentralized Operations: Optimized layouts can enhance communication and coordination between departments, suppliers, and customers. For example, bringing related activities (e.g., assembly and quality control) closer together can facilitate better coordination and reduce delays caused by information gaps.

Reduced Errors and Miscommunication: A well-organized space helps reduce errors caused by unclear communication, especially when different teams or shifts need to collaborate. With a clear layout, workers are more likely to understand their roles and where materials or products need to go.

4. Enhanced Safety and Risk Management

Clear Pathways and Designated Zones: Layout optimization helps minimize safety risks by ensuring clear walkways, designated areas for high-risk activities, and proper storage arrangements for hazardous materials. By preventing accidents or injuries, the supply chain remains more resilient to disruptions caused by safety-related issues.

Contingency Planning: Optimizing layout involves planning for contingencies (e.g., emergency exits, backup storage, and alternative transportation routes) that help the supply chain recover more quickly from disruptions such as natural disasters or equipment failures.

5. Cost Reduction and Resource Utilization

Efficient Use of Resources: Optimizing the layout ensures that resources—both human and material—are used efficiently. This reduces waste, maximizes throughput, and cuts down on unnecessary operational costs, all of which strengthen supply chain resilience.

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Lower Operational Costs: By reducing inefficiencies like unnecessary movement of goods, high energy consumption, and poor space utilization, a well-designed layout can significantly cut costs, thus allowing the company to better weather economic challenges or disruptions in the supply chain.

6. Better Inventory Management
Improved Stock Control: With an optimized layout, inventory can be organized in a way that minimizes stockouts and excess inventory, reducing the risk of product shortages or overstocking. This is particularly important for maintaining a resilient supply chain during demand fluctuations or supply disruptions.

Just-in-Time (JIT) Capabilities: A well-optimized layout supports JIT systems, where materials and products are available at the right time, in the right quantity. This minimizes delays and enhances the ability to quickly respond to changes in market conditions.

7. Support for Lean and Agile Practices
Lean Principles: Layout optimization supports lean practices by ensuring that processes flow smoothly, waste is reduced, and processes are standardized. A lean supply chain is more efficient and can adapt faster to changes.

Agility: A flexible layout allows companies to switch between different production volumes or product types, supporting agility in times of uncertainty, such as during sudden shifts in consumer preferences or changes in market conditions.

8. Improved Customer Satisfaction
Faster Response Times: A more efficient layout enables faster production and distribution, which leads to quicker response times to customer orders. This improves the company's ability to meet customer demands, even when there are supply chain disruptions.

Consistency in Delivery: With optimized layouts, there is less risk of delays or errors in fulfilling customer orders. This helps maintain consistent product availability and service levels, which are critical for customer retention and brand reputation.

9.CONCLUSION

Achieving more than a 25% improvement in all processes within the supply chain of a small-scale industry is a significant milestone that demonstrates the potential for enhanced operational efficiency, cost savings, and overall business performance. By focusing on key areas such as inventory management, production scheduling, supplier relationships, and logistics, small-scale industries can realize substantial gains in performance without the need for extensive capital investment.
This improvement is typically the result of implementing a combination of process optimization techniques, such as lean principles, better demand forecasting, and enhanced communication between stakeholders. Moreover, small-scale industries can adopt strategic measures like better layout optimization, embracing digital tools for real-time data tracking, and improving workforce training to reduce waste and increase productivity.
The outcome of such improvements is not only seen in reduced lead times, minimized costs, and higher-quality products but also in enhanced resilience, enabling the business to better withstand market disruptions, manage fluctuating demand, and adapt to new challenges. For small-scale industries, these changes contribute to a more agile and competitive business that is capable of sustaining growth and profitability over time.
Ultimately, achieving a 25% improvement across the entire supply chain underscores the importance of continuous improvement and adaptability, especially in the face of changing market conditions and increasing customer expectations. Small-scale industries that embrace this mindset will be well-positioned to thrive in a highly competitive landscape.

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