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From Chaos to Control: Transforming Supply Chains with Lean Strategies

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Abstract

Question: What is the ability of Lean based supply chain practice, enabled by cultural adoption and selective implementation of AI and IoT, to enhance resilience and performance within SMEs.

Purpose: This paper assesses how Lean supply chain practice strengthened by culture and digital enablers enhances resilience in SMEs and proposes its significance globally for practice and policy.

Research Method: A mixed-method study method that utilizes survey data from 200 SMEs alongside 50 visits to and structured case observations of those SMEs.

Findings: Lean tools like Just-in-Time, Kanban and Value Stream Mapping lowered costs and lead times adequately. SMEs, due to their agility and cultural ownership of Lean implementation, also adopted Lean more successfully than larger firms. AI improved the capabilities of SMEs with respect to visibility and responsiveness, however financial and technical barriers limited effective levels of use.

Limitations: The framework has been validated against SMEs, where Lean could be considered agile and adaptable, however scaling to larger enterprises is challenging due to complexity and bureaucracy.

Implications and value: SMEs all over the world, especially in emerging markets, can apply culture-first Lean enablers and low-cost digital tools and build up supplier partnerships with the Resilient Lean Supply Chain framework.

Keywords: lean supply chain transformation; small and medium enterprises; operational efficiency improvement; localized supply chain networks; AI in supply chain.

Paper type: Full paper

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Introduction

Unprecedented disruptions have faced the resilience and adaptability of global supply chains in the 21st century (Holgado et al. 2024, Subramanian 2024). COVID-19 and, to an extent, the ongoing conflict between Russia and Ukraine have led to ripple effects such as inflation, material shortages, port congestions, and increased transportation costs, all of which have hit businesses across the globe with disastrous effects (Tortorella et al. 2024, Srai et al. 2023). Such hurdles, in turn, have brought to light the vulnerabilities of oligopolies within the supply chain, more so for small and medium enterprises that find it hard to adapt due to reliance on external suppliers and limited financial influence (Khawka et al. 2024). Workplace SMEs provide vital strength toward regional economic stability and job creation (Lefebvre 2025), with a resulting ripple effect of supply chain disruption (Ye et al. 2025). In the global trade malaise, researching and experimenting with practical solutions capable of scaling up would enhance supply chain efficiency and resilience (Lefebvre 2025). A major part of production system design is coordinating multiple work teams on dynamic construction sites. This inter-team coordination presents complex challenges, as it involves managing diverse skills and specialties within high-stakes and rapidly changing environments (Jain et al. 2023). Effective team coordination is essential for timely project delivery and requires clear communication, conflict resolution, and adaptability to unplanned conditions.

Lean is much more than waste reduction or efficiency improvements; it is also considered to be a socio-technical system for producing, delivering, and supplying the products and services of industry. It is based upon the Empirical Observation that the structure and controls for Work Planning and Production were inherently unreliable. Therefore, Lean Construction Theory evolved into what we now refer to as The Transformation-Flow-Value (TFV) Theory by redefining how we look at the processes that create value for our industry. The theme of Lean Construction is that production control and learning systems integrate Coordination, Commitment Reliability and Continuous Improvement into one comprehensive system; rather than looking at Lean as simply tools (Howell 1999, Ballard 2000, Abdelhamid et al. 2008). When viewed from a holistic perspective, Lean Construction is significantly different from a cost-reduction oriented view of Lean.

The modern supply chains, however, go beyond the earlier lean ways, with more advanced disruptive technologies like AI assuring operational efficiency and better decision-making capabilities, thereby influencing the supply chain enormously (Ronchini et al. 2024). AI predictive analytics can help forecast demand and its fluctuations, assume appropriate stock levels, and recognize probable disruptions even before they occur. In another case, IoT-smart sensors provide real-time supply chain performance data that allow organizations to dynamically respond to bottlenecks and inefficiencies (Xu et al. 2024). AI working with lean will enhance supply chain resilience, responsiveness, and cost-effectiveness (Kamble et al. 2022). In addition, IoT data analytics can promote greater transparency and traceability-the two key elements in coordinating supply networks for SMEs (Singh et al. 2023). The federal government, with the help of traditional means (lean) and advanced AI, supported SMEs using such technologies for an amount of $400,000 between supply chains in New Hampshire (NHMEP 2024e).

The research presents four specific contributions to the literature regarding supply chain resilience within small and medium enterprises (SMEs). The first contribution is a practice-based mixed methods evidence base that combines survey data from 200 SMEs and 50 site visits and operational observations. The combined scale and depth of data from the present research is rare within empirical investigations into SME supply chain resilience, which tend to be largely conceptual or simulation-based (Tortorella et al., 2024; Stentoft and Mikkelsen, 2024). The second contribution of the paper is the development of a pragmatic resilience framework for SMEs that incorporates core Lean tools: JIT, Kanban, Value Stream Mapping (VSM), and visual management, as well as creating a culture of ownership and selectively adopting Digital Enablers.

The framework focuses on methods that are technical in nature and require minimal capital resources for incremental implementation, reflecting the limited resources available to SMEs (Gruchmann et al. 2024, Subramanian et al. 2024). The third contribution of the study is the presentation of practice examples embedded within Lean principles that demonstrate how the implementation of Lean leads to measurable improvements in performance (e.g. reorder-point management and cross-departmental coordination through visual boards), which were correlated with significant reductions in both lead times and late shipments.

In the end, the research results provide clear evidence of the importance of supplier diversification, visualizing management of supplier relationships, targeted Lean program training, and the significance of working with government through public and private sectors in SMEs in order to develop improved capabilities for SME ecosystems in developing resiliency within supply chains due to ongoing disruptions. From these contributions, both management practices and regional Industrial Policy on how SMEs develop resiliency through supply chain management will benefit.

Literature review

Global supply chains stood tested with unprecedented disruptions like the COVID-19 pandemic, geopolitical wars, or even acute raw material shortages (Stentoft and Mikkelsen 2025, Tortorella et al. 2024). Lean supply chain management (LSCM) has long been recognized as the best means to minimize waste and generate agility in operations (Ohno 2019). However, with the escalating supply chain issues, the use of Artificial Intelligence (AI) and the Internet of Things (IoT) is being addressed more as the reinforcement to the traditional lean methodological consideration. The literature review critically engages with existing literature to position the present inquiry within the wider discourse, determine gaps, and strengthen the theoretical basis of the study hypotheses.

Lean Supply Chain Management (LSCM) and SMEs

The principles of Lean have their roots in the Toyota Production System, however, when we look at Lean Construction literature, we will find that the approach to Lean is viewed as a production control and learning system that places more emphasis on workflow reliability and coordination, as well as human systems, as opposed to just transferring tools from one

organization to another. This perspective draws from the TFV theory of production, which states that in order for stable flow and value to be produced, there must be effective management of commitments, visual coordination and continuous learning between the social and technical systems of production (Abdelhamid et al. 2008, Pasquire 2012, Umstot et al. 2014).

Lean strategies have proven to be most effective in largescale industries; SMEs, on the other hand, face a different set of challenges, such as resource constraints, supply chain dependence, and operational fragility (Power 2005, Arend and Wisner 2005). SMEs mostly do not have the bargaining power to secure flexible supply contracts and are most of the time dependent on a sole source of supply; as such, they are more vulnerable to disruptions (Stentoft and Mikkelsen 2024, Minh et al. 2019). However, studies have shown that lean principles can considerably boost the resilience of SMEs through the decreased operational cost, increased agility, and strengthening of supplier relationships (Garcia-Buendia et al. 2021).

Besides, for instance, lean thinking enables SMEs to streamline processes with fewer inputs and keep them at the peak levels of effectiveness. For instance, research has established that SMEs can achieve quite significant cost savings improvements of 30% by adopting lean practices; thus, it reflects the immediate impact lean has on the cost of supply chain resilience (Khawka et al. 2024). Contrary to this, even though the benefits have been proven, lean has not yet been as thoroughly adopted in SMEs as it has been by large companies primarily because of the exorbitant cost of adopting it, lack of expertise, and cultural aversion to adopt lean (Gruchmann et al. 2024).

The Role of AI and IoT in Lean Supply Chain Management

There is, however, an indication that a new breed of technology- integration between AI and lean principles may bring a breakthrough in supply chain resilience (Guo and Mantravadi 2025). AI is said to complement traditional lean methodologies with regards to better forecasting accuracy, supplier selection, and demand planning (Shou et al. 2018). Predictive analytics allows SMEs to estimate demand changes so that they can optimize inventory levels while reducing overproduction (Majumdar 2024).

IoT on the other hand supports lean supply chains by real-time tracking and automatic data collection (Demir and Paksoy 2023). Kanban-driven inventory management becomes more effective using smart sensors and RFID technology, which ensures that raw materials are replenished just at the time when they are required (Gruchmann 2024). Evidence is available to show that IoT-enabled lean supply chains reduce lead times by 40%, and improve visibility across the entire supply chain, thus enabling the minimization of risks associated with unforeseen disruptions during operations (Al-Talib et al. 2020).

Notwithstanding these benefits, there is still some challenge for small and medium-sized enterprises to adopt AI and IoT because of considerations associated with cost as well as a deficiency in technical competence (Garcia-Buendia et al. 2021). Whereas enormous enterprises might look for resources required to integrate AI with their automatization, SMEs usually require tailored affordable steps. Nonetheless, research shows that cost-effective AI

and IoT technologies such as cloud-based predictive maintenance and supplier analytics can be catalysts where SMEs can pivot digital transformation at low costs (Guo and Mantravadi 2025). Although this paper is primarily on Lean Thinking and New Hampshire SMEs, it is highly worth mentioning the new AI capabilities concerning lean supply chains. Given that SMEs within the region have not extensively integrated such technologies, research asserts that future digital transformation will be ushered in by lean operations. In relation, this review has included AI and IoT as examples of what Lean should look to in the future.

cheap AI solutions such as cloud-based predictive maintenance and supplier analytics can be engines through which SMEs can lean digital transformation at little cost (Guo and Mantravadi 2025). Although this paper primarily concerns Lean Thinking and New Hampshire SMEs, it is quite worthy to mention the emerging AI roles about lean supply chains. Because the SMEs in this region have not extensively integrated these technologies, the literature argues that future optimization of digital transformation will lead to leaner operations. In this regard, this review includes AI to signify the future directions of Lean evolution.

Success of Lean in Mitigating Supply Chain Disruptions

According to (Srai et al. 2023), the extent of disruption for both by the COVID-19 pandemic and now the Russia-Ukraine situation, are advantages of lean principles in all aspects of the supply chain. Empirical evidence suggests that lean supply chains:

- Are more resilient: SMEs with lean frameworks recovered 2.5 times faster from supply-chain disruptions than non-lean SMEs (Tortorella et al. 2024).
- Cost cut: JIT would show with combined methods that SMEs will save 35% in costs and thus improve efficiency by 25% (Demir and Paksoy 2023).
- Flexibility: Lean SMEs are believed to be capable of exhibiting more flexibility in the actual movements of suppliers and different times of production under alternative levels of supply shock conditions (Arend and Wisner 2005).

A study of 200 SMEs in the state of New Hampshire revealed that firms practicing lean principles produced superior inventory control and delivery performance while reducing raw material shortages (NHMEP 2024a). Firms applying lean technique for reorder point estimation, as well as visual management, realized improved performance of a 50% reduction in supply chain delays (Majumdar 2024).

Research Questions and Hypotheses

Research Questions:

- RQ1: How has lean supply chain practice been seen (in terms of JIT, Kanban, VSM), to positively affect both SMEs cost and lead-time reduction facing supply chain disruptions?
- RQ2: How does AI technology actually fortify the supply chain industry (lean) SMEs against disruptions?
- RQ3: What is the different trend between SME and large enterprise adoption of lean with regard to efficiency, agility, and technological integration?

Hypothesis Development:

The present study, based on literature surveys, gives the following hypotheses:

- **H1**: The introduction of Lean tools (just-in-time, Kanban, and VSM) results in a reduction of operational costs, as well as reductions in lead times, up to at least 30%, in SMEs, being able to sustain the resiliency in the supply chain.
    - **Justification**: Just-in-time (JIT) and value stream map (VSM) enhances the process efficiency and waste minimization that led to quite considerable savings (Demir and Paksoy 2023).
- **H2**: The adoption of AI technology in a lean supply chain will result in increased resilience and recovery speed for SMEs regarding disruption compared with those that did not adopt technology.
    - **Justification**: The adoption of AI for demand forecasting combined with inventory tracking through IoT-enabled will provide real-time insight to SMEs, thus allowing them to mitigate disruptions more effectively (Guo and Mantravadi 2025).
- **H3**: The presence of lean within the small and medium enterprises makes the operations nimbler as compared to larger enterprises, which respond much slower to disruptions in supply chain activities.
    - **Justification**: SMEs, because of flat hierarchies and flexibility in decision-making, can implement lean processes more easily than those behemoths with their typically bureaucratic structures (Gruchmann et al. 2024).

Lean supply chain management still proved to be a highly effective instrument to make the resilience of SMEs much more enhanced. However, with supply chains becoming extremely dynamic, future opportunities should lie in integrating AI for lean optimization. Besides the high costs, tailored AI solutions could help enhance forecasting, automating inventory management, and increasing agility for SMEs.

State of the Art Benchmarking and Research Gap

Research from the Lean Construction Journal has provided a wealth of evidence for the role of Production Control, Reliability of Workflow and Flow-Based Planning with three key outcomes being the establishment and promotion of the Last Planner System (LPS), the utilization of Visual Management and the proliferation of Takt Based Planning and Location-based Management Systems. How Committed Planning, Removing Constraints, and Visible Production Control Improve Project Level Reliability and Learning and therefore establish Lean as Socio-Technical, not simply a set of Efficiency Tools (Howell 1999, Ballard 2000, Umstot et al. 2014).

From within this body of research, visual management has continually been identified as a Fundamental Mechanism of Lean to facilitate coordination of workflow, create collective situational awareness and support learning and corrective action (Pasquire 2012, Umstot et al. 2014). Takt Based Planning and LBMS have been shown to Support Stabilization of Flow and

Reduction of Variability Particularly in Complex Production Environments. However, most of this literature focused primarily upon project delivery systems and large organizational settings, specifically in the Construction Industry and Infrastructure Industries.

Relative to prior research in digital industries, some recent studies have identified how advances in digital technology allow for greater visibility and control of production processes. Many studies published in automation in construction describe the use of real-time tracking, sensing technologies, and data-driven monitoring systems for the purpose of improving production control and production responsiveness. Many studies published in construction management, economics, and engineering, construction and architectural management describe how visual information sharing and dissemination of coordinating information can help site managers make more informed decisions and improve their operational alignment. Recent research in the ASCE Journal of Construction Engineering and Management and journals oriented towards sustainability have focused on how Lean principles can be integrated with BIM, digital twins and Cyber Physical Systems to improve flow and ultimate System Performance) (Sacks et al. 2009, Kamble et al. 2022, Gruchmann et al. 2024).

However, a clear gap continues to exist in literature. The literature currently viewed through a Lean Construction and digital production lens focuses primarily on larger projects or longer-term operational relationships between equally capable organizations and does not have much empirical focus on the conditions of small and medium sized enterprises (SME's) that have persistently fluctuating resource constraints. In addition, the digitalization aspect of Lean construction and digital production have generally been positioned as the primary improvement mechanism, while in comparison few of the studies focusing on the development of resilient Lean systems from a culture-first perspective (emphasizing ownership, learning and low-cost production control) have been included in the same research as studies pertaining to resilience-oriented production systems.

This paper addresses these gaps by benchmarking SME supply chain-related activities against Lean Construction best practice in production control and flow, while also providing the context for the paper's digital claims in relation to other research in cross-venue research and the use of real-time tracking and visual systems. Specifically, this paper proposes a culture-first Lean perspective for SMEs, utilizing the selective and incremental adoption of AI to improve the resilience of their supply chains. Using evidence from a set of 200 SME surveys and 50 direct meetings, this paper illustrates how Lean systems based on people, learning, and reliable workflows continue to maintain their relevance as fundamental and how the application of targeted digital technologies can augment, rather than replace, these systems during instances of disruption.

Methodology

Of the 50 firms visited as part of the study, those firms were identified using purposive sampling and two criteria: (1) companies in current supply chain disruption crisis; and (2) companies showing an interest in utilizing lean principles to mitigate these issues. Although the author, as a project manager with industry engagement background, was able to reach out to many companies, site visits were limited to those firms that were willing to have open

discussions and share operational challenges encountered by their business. The author also used this method to allow for detailed observation and conversation of actual supply chain disruptions. This method resulted in a reliable source of qualitative data as well.

The second sample of 200 companies surveyed was collected as part of a larger study. These companies have previously participated in training and/or technical assistance programs and were surveyed to gain insight into emerging supply chain disruptions and determine support needed for these small businesses. The survey therefore serves not only as a means of collecting information on the status of the current conditions but also as a way of continuing to monitor the shifting nature of the supply chain disruptions in SMEs. By combining the site visits and survey results, a mixed-methods approach is created. Companies involved in case studies furnish in-depth information while the larger trained sample of SMEs consists of similarity patterns / validation of results. The quantitative survey responses were analyzed using descriptive statistics to identify patterns and to establish priority areas based on frequency of occurrence. Qualitative survey responses were thematically coded to capture recurring operational challenges and improvement initiatives. The mixed-method analytical approach allowed for triangulation to be conducted between quantitative trends and qualitative practitioner narratives without over-inflating causal connections in data. Figure 1 shows the framework for methodology analysis.

Ethical considerations: Clear and explicit consent was sought from all the trainers before collecting any data. Further, to ensure complete adherence to research ethical standards, we were properly informed of the intent of the study, and their confidential information was handled discreetly.

Mitigating supply chain issues with reorder points

Table 1 highlights several ordering strategies that may be used to control inventory, with the focus on order points management. The order point refers to the stock level where a new order is placed to prevent stock outs while ensuring there is no excess inventory. A good order point strategy can eliminate supply chain inefficiencies such as shortage of raw materials or surplus inventory (Womack and Jones 1997).

For one such company in New Hampshire, by paying attention to the order point, the results were striking, reducing the number of occasions they were short of raw materials from 43% to 5% in 4 months: As a project manager in the New Hampshire government, we manage projects with subject-matter experts and produce measurable results. Companies report improvements for 6 months post-project completion and success stories after one year. The average four-month timeline for determining improvements to the reorder point process may vary depending on the complexity of the process. Our approach focuses on measurable impact and continuous improvement.

- **Regular Timing and Fixed Quantity**: Used for stable-demand items, allowing them to undergo regular replenishment cycles. It was this predictability that enabled consistent keep of stock at necessary levels to prevent the occasions of understocking or overstocking. So, this is required by many SMEs.

- **Regular Timing and Unfixed Quantity**: The company, for heavy variable demand items, uses this approach to change the quantities of items based on present demand trends. This enabled them to use resources effectively and adequately address vastly changing stock levels.
- **Irregular Timing and Fixed Quantity**: For certain materials, where demand was irregular yet predictable in quantity, the company used this approach to maintain sufficient stock without surplus.
- **Irregular Timing and Unfixed Quantity**: The company used this ordering policy for highly variable items. Resources would be made available only when necessary and extra inventory, and wastage would be avoided (Minh t al. 2019).

Through their careful consideration for the calculation and maintenance of their order points, the company was able to fine-tune inventory control to minimize any disturbance of the cycle of production due to missing materials (Demir and Paksoy 2023). Moreover, the costs of inventory were dramatically reduced because of the avoidance of excess stock. Successes in such projects highlight the importance of customizing order point strategies to individual inventory characteristics and demand patterns.

Management visualization

This case study illustrates how a small business utilizes management visualization to address production delays and optimize its operations through lean tools. Management visualization is a technique designed to enhance process transparency, allowing businesses to identify inefficiencies, monitor task progress, and ensure that daily production targets are met.

The company, seeking to improve revenue to cover operational expenses, faced challenges with a slow-performing job shop that was falling short of production targets. Initially unfamiliar with lean methodologies, the company embarked on a lean transformation journey in 2017, engaging external lean specialists to implement the approach across its production processes, which were managed by a small team of job shop operators.

Through the application of lean principles, the company significantly revamped its job shop processes. Over six years of continuous lean application until the end of 2023, substantial improvements were realized, particularly around late deliveries, which had previously been a major issue. Before implementing lean, late deliveries accounted for 35% of all shipments. The production control manager relied on outdated computer systems that were ill-suited for effective scheduling, further compounding the delays.

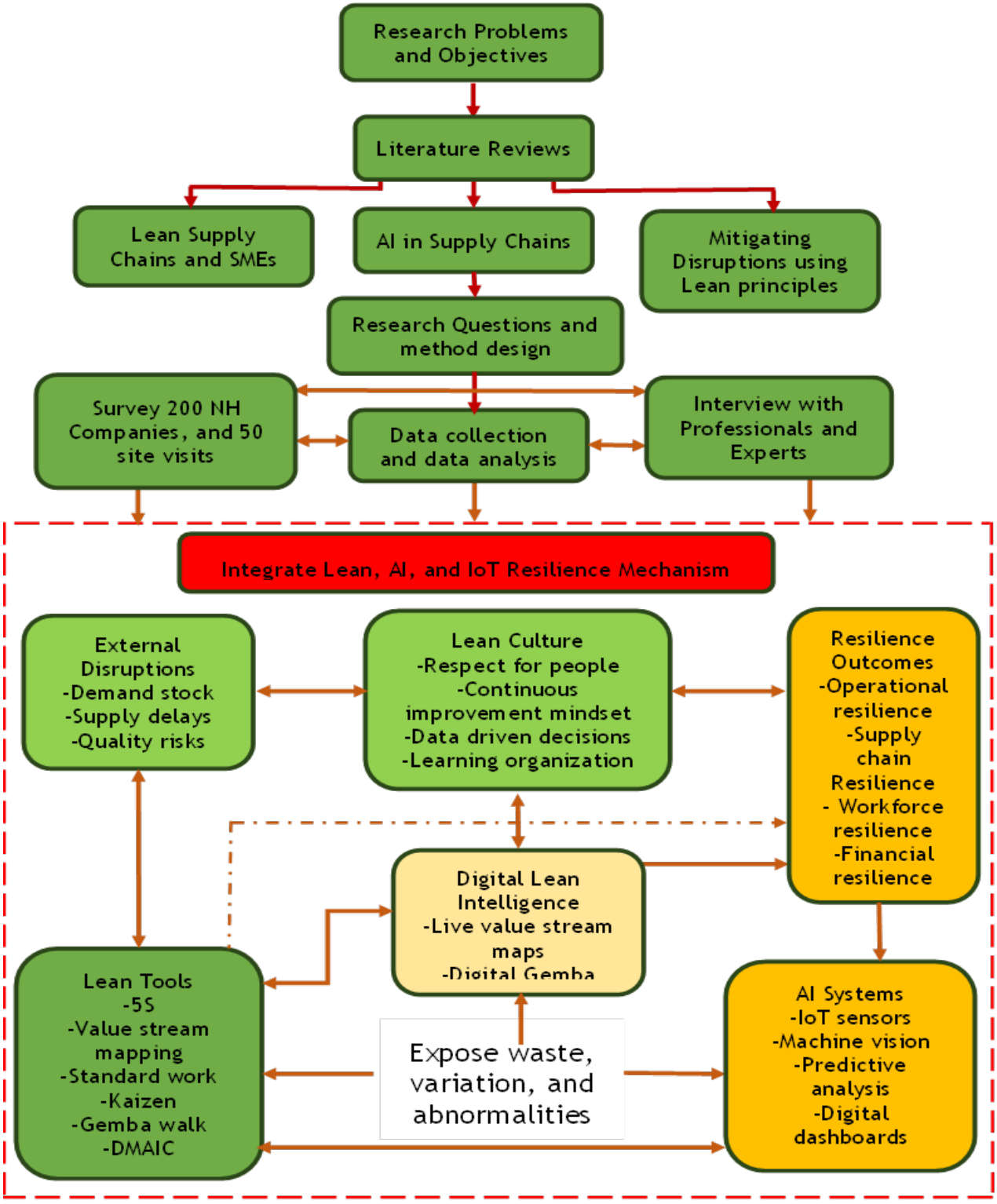

Figure 1. Research development and method proposed

Table 1. Reorder point strategies

Order Timing	Order Quantity Type	Advantages	Challenges
Regular	▪ Fixed ▪ Regular Timing and Fixed Quantity	▪ Predictable replenishment cycles. Suitable for stable-quality and low-cost products.	▪ Requires regular checks to ensure proper quantity.
Regular	▪ Unfixed ▪ Regular Timing and Unfixed Quantity	▪ Facilitates easy scheduling. ▪ More flexible inventory control.	▪ Demands precise tracking of inventory and calculations.
Irregular	▪ Fixed ▪ Irregular Timing and Fixed Quantity	▪ Simple procurement for steady demand items.	▪ May lead to inefficiencies if demand fluctuates.
Irregular	▪ Unfixed ▪ Irregular Timing and Unfixed Quantity	▪ Maximum flexibility for fluctuating demand.	▪ Ineffective for long-term optimization. ▪ High risk of overstocking or stockouts.

To address these inefficiencies, the company introduced a visual management system, initially starting with simple tools such as paper-based tracking in Excel and construction paper, evolving into a whiteboard with magnets, and eventually adopting a more advanced steel board with chart tape. Each magnet on the board represents a specific job in the production process, allowing for clear tracking of progress across various stages. We showed in Figure 2 the real visualization process. The color-coded magnets offer detailed status updates in Table 2

This visual system not only made the scheduling process more accurate but also facilitated better communication between production, purchasing, and shipping departments. The production control manager schedules jobs and shares timelines with the shipping scheduler, ensuring that deliveries align with production timelines. The shipping board provides real-time updates, such as whether jobs are in the shipping department, ready for picking, or awaiting materials, as presented in Figure 2 from real case study of small business.

As a result of implementing this visual management system, the company was able to reduce late shipments to an average of just 3%, a significant improvement from the initial 35% in the timeline for 4 months. The system also allows for dynamic updates based on changes, such as employee availability or adjustments in the production flow, ensuring that the process remains flexible and responsive to shifting demands.

This example demonstrates the power of lean tools, particularly visual management in transforming small operations. It highlights how, through clear visibility and enhanced coordination businesses can significantly reduce inefficiencies and improve overall performance.

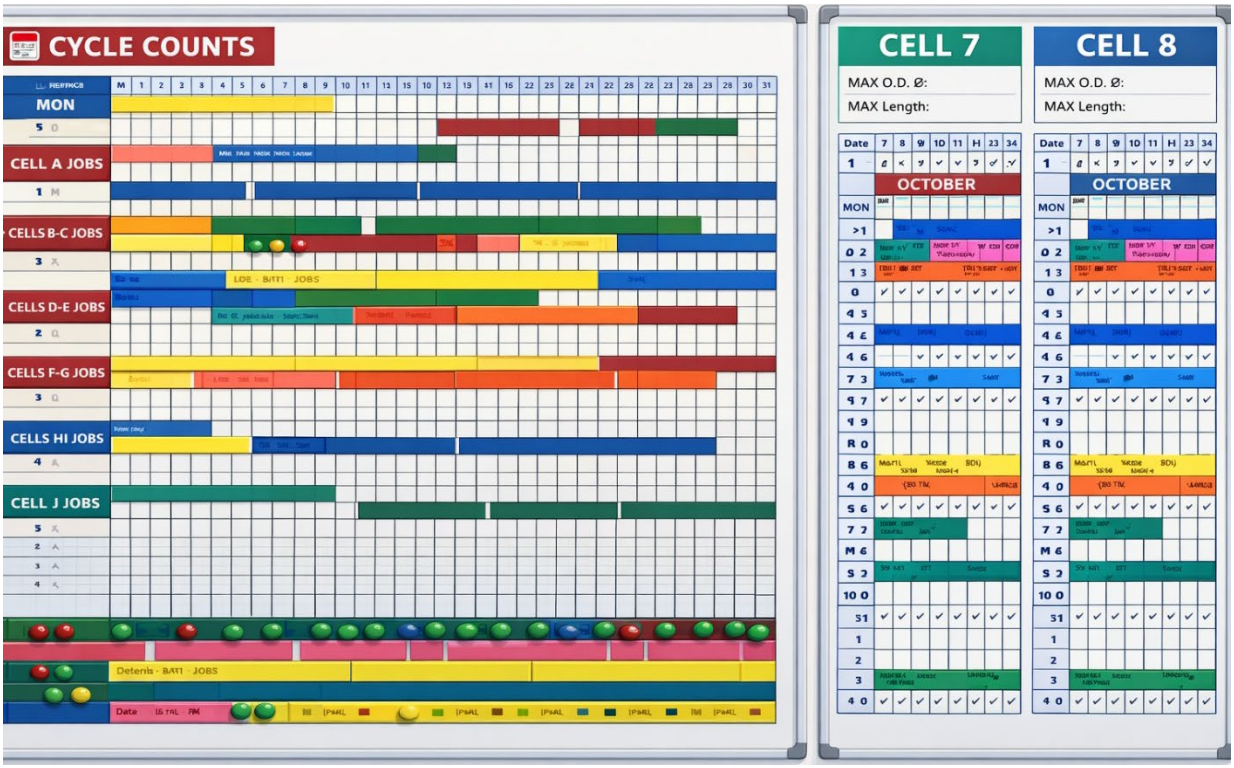

Figure 2. Visualization process in small business

Table 2. Color visualization

Color job	Description
Yellow	▪ Job is in process.
Pink	▪ Job is currently out in the shop
White	▪ Job is being worked on at a specific cell
Green	▪ Materials have been ordered, and the job is ready to proceed
Pink	▪ (on the shipping board): Material is awaiting selection
Red	▪ No material is available for the job
Blue	▪ The job is on hold due to customer credit issues

The company utilizes the Kanban system to manage its inventory, ensuring transparency and visibility across all departments. This system is critical for maintaining the necessary levels of raw materials to meet customer demand and ensure continuous production. The company has established specific minimum stock levels for each material to avoid disruptions in the manufacturing process.

When an operator consumes raw material, they measure the remaining quantity and, if it falls below the established reorder point, they move a designated magnet to indicate the need for replenishment. This triggers the next step: an employee retrieves the corresponding tag from a "need hook," signaling that the material needs to be restocked. The replenishment is then scheduled, and the necessary materials are procured the following day (Arif and Ahsan 2014).

This Kanban-driven approach ensures that the company maintains a constant supply of raw materials, eliminating delays in the job shop and preventing production stoppages due to material shortages. Figure 3 from real case study illustrates the reorder process in action, showing how this system supports timely availability of materials and helps the company avoid operational disruptions.

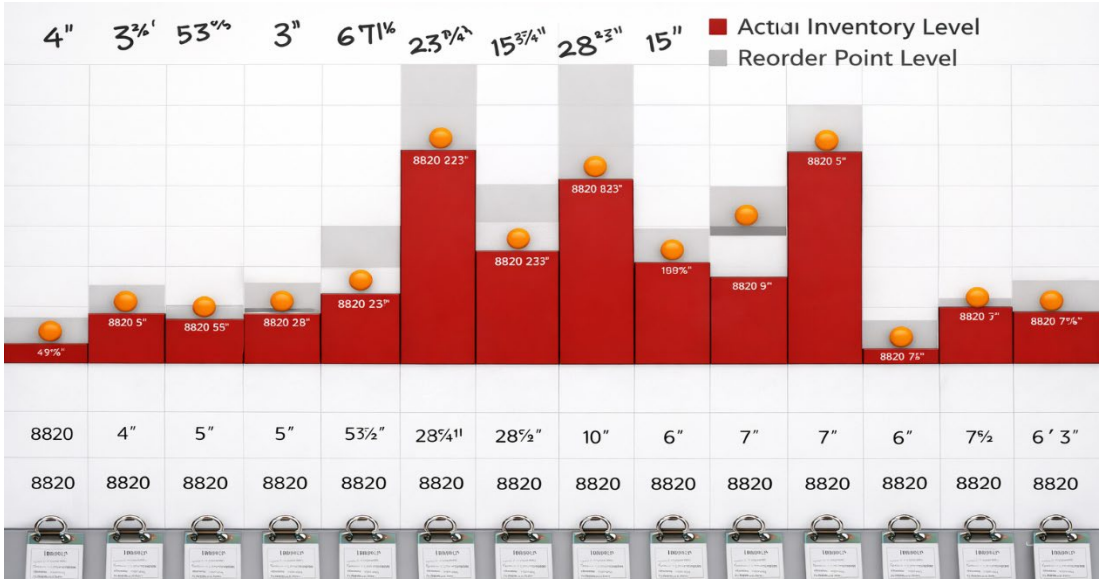

Figure 3. Reorder point in SMEs

The daily target in Table 3 is set as an integrated daily and weekly plan by the production management team to maintain the high efficiency of the workers. This process has increased the employees' willingness to cover the daily demand and increase the company's revenues (Ohno 2019).

Before Lean was applied by the company, there were no measured or estimated production targets, and many demands were delayed. But after Lean utilization, production efficiency increased, and the response to customer demands improved from 52% to 92% in 6 months.

Table 3. The daily planned work for small company (Data got from small company)

	Monday	Tuesday	Wednesday	Thursday	Friday	TARGET
Order	▪ 70	▪ 41	▪ 44	▪ 17	▪ 28	▪ 55
Cells Late	▪ 1	▪ 0	▪ 2	▪ 2, 4,1	▪ 5, 2, 2	▪ <4
Near Misses	▪ 0	▪ 0	▪ 0	▪ 0	▪ 0	▪ 1
Accidents	▪ 0	▪ 0	▪ 0	▪ 0	▪ 0	▪ 0
Machine Down	▪ 1	▪ 0	▪ 0	▪ 1	▪ 0	▪ 0
Rejects	▪ 0	▪ 1	▪ 0	▪ 0	▪ 1	▪ 0
Late Shipment	▪ 0	▪ 3	▪ 2	▪ 0	▪ 2	▪ 0
Customer Complaints	▪ 1	▪ 0	▪ 1	▪ 0	▪ 0	▪ 0
Requests for Quote	▪ 27	▪ 20	▪ 15	▪ 21	▪ 17	▪ 25
Customer Survey Score	▪ 10	▪ 10	▪ 9	▪ 10	▪ 9	▪ 10
Minor Injury	▪ 0	▪ 0	▪ 0	▪ 1	▪ 0	▪ 0
Non-Conforming	▪ 5	▪ 8	▪ 7	▪ 4	▪ 11	▪ 0

Table 3 summarizes real case of task performance on a weekly basis from small-sized manufacturers in NH. Orders were met on target only on Monday. Delays (late cells) on Thursday and Friday probably caused the underperformance on both days. Machine downtime on Monday and Thursday was found to have caused disruptions in production. High rejections and non-conforming output were recorded on Tuesday and Friday affecting shipments and overall efficiency in production. Customer satisfaction remained high, however, with high scores in the survey while complaints being voiced on both Monday and Wednesday.

To counter the problems raised, an early scheduling production activity was conducted by the manufacturer to restore order and fulfill targets. Quality control team was tightened up to reduce non-conformances and rejects on Fridays. Predictive maintenance was also effectively adopted to reduce machine down time. Steps planned to be applied to counter late shipments, adjust resources against request-for-quotation patterns, and succeed in delivering better customer experience. Besides, safety procedures were reviewed, and customer complaints were dealt with proactively in order to uphold service satisfaction and functioning reliability.

Lean principles application more effective in small companies

Lean techniques are often better suited for small businesses because of their scalability, direct communication, and close-knit teams. These companies are able to rapidly adjust and

use Lean methods such as Kaizen and 5S in an uncomplicated way without the usual bottlenecks introduced by top-down decision making. In smaller organizations, employees in general tend to have a deeper knowledge of operations, so they may be able to detect inefficiencies and propose useful solutions. Furthermore, due to their resource-limited nature, small businesses are challenged to reduce waste and maximize value by default, and attribute perfectly in line with the Lean philosophy (NHMEP 2024d).

On the other hand, large enterprises face challenges such as bureaucracy, resistance to change, and the complexity of scaling Lean initiatives across multiple departments. Despite possessing more resources to put on Lean, these practices are often expensive, require greatly extensive training, and deliver deep cultural changes. But small businesses are in a better position to concentrate on customer needs and adapt Lean principles to their unique operating structure. Consequently, they routinely make more positive results more quickly. The philosophy of continuous improvement and waste reduction are found to be more readily used in small business (Demir and Paksoy 2023).

Based on my experience, in some large companies a significant number of Lean facilitators are employed, whose contributions are, however, blurred as they are occupied with routine tasks such as data collection and reporting. This constrains them to be able to really think about process improvements. By contrast, small businesses that typically do not have the resources to hire dedicated facilitators often use their employees to lead Lean efforts. Although they may have a small number of financial resources, their workforce's motivation and dedication do compensate in many cases. On, for instance, in a project with a small manufacturing plant, I witnessed full ownership by the workforce of Lean initiatives, leading to real improvements in workflow and efficiency. This degree of commitment very often results in deeper and more lasting and effective changes than in less participated and more structured Lean implementation in companies of high volume. Here are the important thoughts from Lean application for small and large businesses outlined in Table 4.

Table 4. Comparison between small and big businesses

Criteria	Small Businesses	Big Businesses
Resources for Lean Expertise	▪ Small budgets for hiring full-time lean specialists; have to rely on external consultants for specific objectives.	▪ Significant budget to hire full-time lean specialists or build internal lean teams.
Decision-Making Agility	▪ High level of agility and faster decision-making thanks to flat hierarchies and fewer stakeholders.	▪ Slower decision-making because of bureaucratic structures and several layers of management.

Criteria	Small Businesses	Big Businesses
Process Complexity	▪ Less complicated proc esses: thus, it is easier to point out and ▪ eliminate wastes.	▪ Very complex processes across various ▪ departments and locations, requiring ▪ an enormous amount of analysis.
Employee Engagement	▪ Potentially high direct involvement of all employees in lean implementation.	▪ Engagement of a big workforce is difficult; ▪ structured training and communication are required.
Customization of Lean Tools	▪ Smaller operations may find it easier to tailor lean tools to their particular nee ds.	▪ Standardized processes might reduce ▪ flexibility in implementing customized lean solutions.
Cost of Implementation	▪ Lower cost as a result of smaller ▪ scales but can be significant ▪ regarding the budget constraints.	▪ Higher absolute costs, although economies of scale may balance out per-unit costs.
Focus on Supply Chain Efficiency	▪ Immediate focus on improving local and short supply chains.	▪ More holistic focus, global supply chains, and multifaceted vendor relationships.
Adoption of Technology	▪ Limited access to advanced technology but can quickly adopt cost-effective tools that are available.	▪ Have greater access to new, pioneering ▪ technologies; however, can only be deployed at a slow rate because of scale and older ▪ legacy systems.
Cultural Resistance	▪ Less resistant, since e mployees are bound to see direct benefits ▪ accruing from the lean initiative.	▪ Resist more due to broader and diversity ▪ teams and long-lived practices.
Scalability of Lean Practices	▪ Easier to implement on a small scale; tough to sustain with ▪ sudden spurts of growth	▪ Proven practices can scale departments and locations.

Criteria	Small Businesses	Big Businesses
Supply Chain Visibility	▪ Limited but easier to have ▪ visibility into all aspects ▪ related to the supply chain	▪ Can provide broad visibility, but generally challenged integrating data across multiple constituent systems.
Innovation and Experimentation	▪ Greater willingness to experiment; the risks associated with this are much lower in relation to small-scale operations.	▪ Generally, risk-averse because often ▪ experimentation is too dangerous if ▪ operational continuity has to be maintained.
Customer Focus	▪ Strong focus on specific customer needs as a result of direct relationships, faster ROI due to quicker implementation and results.	▪ Larger market; difficult to balance lean practices with requirements of a mass market.
Lean ROI (Return on Investment)	▪ Faster ROI due to quicker implementation and results.	▪ Slower ROI since benefits are diluted across large-scale operations.

Results

Supply chain challenges shared by 200 companies in New Hampshire

Figure 4 summarizes the supply chain challenges reported by 200 companies in New Hampshire (Heffernan and Stecker 2004), bringing into light critical issues to business operations. The highest concerns are increased costs (101 mentions) and raw material shortage (95 mentions); these are vital in disrupting production and profitability. Shipping delays mentioned 81 times, and labor shortages mentioned 60 times, further exacerbate these problems, while demand peaks-52 mentions-and issues with logistics providers-41mentions-underline the unpredictability and inefficiencies within the supply chain. Besides, driver shortages and accuracy of raw materials, both at 40 mentions, point to gaps in transportation and quality control.

With these issues in mind, business strategies must take a more multifaceted approach. Synergies in relation with suppliers, the development of substitutes or alternative sources of supply will alleviate shortages of materials; workforce development programs and automation may mitigate labor constraints. Technology investment in forecasting and logistics processes

can reduce delays in shipping and better management of peaks in demand. Such arrangements are more pertinent in building a resilient supply chain framework for the companies across New Hampshire.

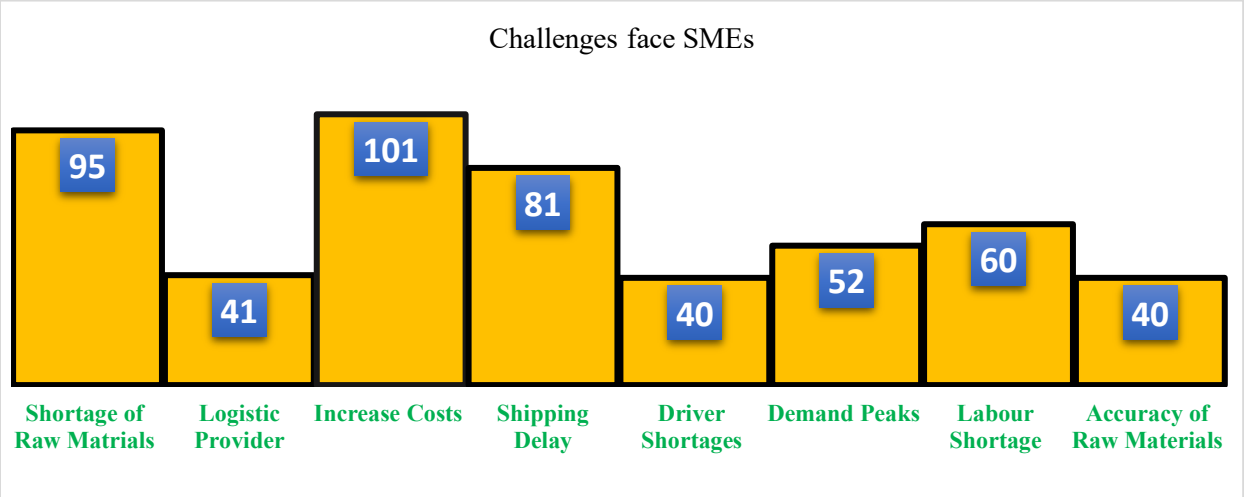

Figure 4. Issue of supply chains encountered by manufacturers in New Hampshire

Figure 5 clearly shows the different priorities for training required to improve supply chains, as brought forth by 200 companies based in New Hampshire. They showed a huge need for training in the areas of Kanban (65 mentions) and Value Stream Mapping (63 mentions), suggesting that such tools improve workflow efficiency and help in the identification of waste present in one or more processes. Lean Practices (50 mentions) are followed closely with their request, which indicates the demand for the methodology that allows productivity enhancement with less usage of resources. Further, finding multiple suppliers (44 mentions) has also been specified by companies to reduce reliance on limited vendors to mitigate the issues with supply chain vulnerability.

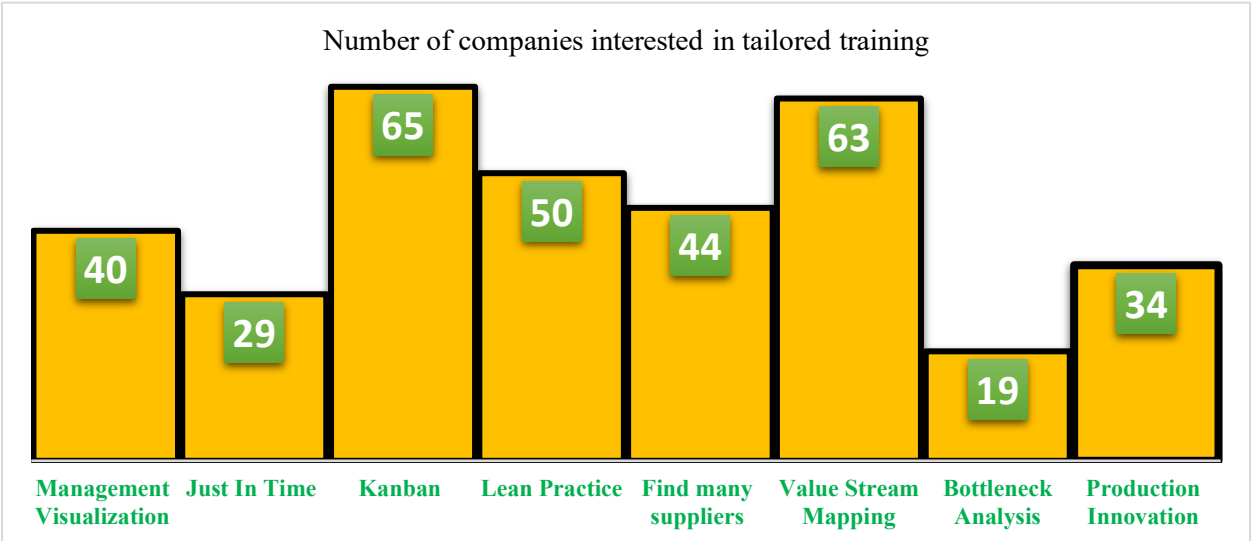

Figure 5. Number of companies that have requested tailor-made training

Other training needs in Management Visualization (40 mentions) which implies the tools to provide proper decision-making and operational clarity, and Production Innovation (34 mentions) which proved the importance of developing advanced production methods. While Bottleneck Analysis (19 mentions) and Just-In-Time (29 mentions) exhibit a lesser degree of emphasis on them, this should in no way undermine their power for addressing explicit inefficiencies and enhancement of inventory management systems. Together, these training areas show a clear need for companies to prepare more flexible and streamlined supply chains.

Supply chain disruption analysis in New Hampshire SMEs during global crisis

The site visits and discussions with a variety of New Hampshire-based companies aimed at getting an understanding of their challenges and the situation (Heffernan and Stecker 2004). The cause for such challenges included several factors at this time: COVID-19, and the Russian-Ukrainian conflict (Srai 2023). While these conditions were considerably ramming hard enough on the enterprises and the businesses, there were other failures, such as leadership failure, inefficiencies in operations, breakdowns in communication, and other internal inefficiencies compounding challenges for small and medium-sized enterprises (Ohno 2019).

Diagnosis of the main external problems identifies rising energy-related costs, shortages in raw materials, and supply chain delays stemming from Russia, Europe, and Asia. Inflationary pressures on the production process in America have made things even worse.

In contrast to large corporations that can easily shift toward scattered working methods, small and medium enterprises lack that convenience. A case of COVID-19 infection in a single employee could mean the closing down of a company, while enhanced chill in the supply chain indeed has propounded variability issues (Srai 2023).

New Hampshire's energy costs are the highest in the nation, which adds to the pressure. A local business manager revealed that the energy bill hit an embarrassing $80,000 a month, well above the $40,000 range of its sister facility in North Carolina. Ongoing import restrictions left businesses dependent on Russian supply in disarray, forcing them to halt production or involve themselves in high-cost sourcing alternatives (Heffernan and Stecker 2004).

According to the survey data from the region, for the supply chain disruption, 44% blame the COVID-19 pandemic and 46% Russian-Ukrainian conflict. The remaining responses, 10% in total, did not identify specific causes as presented in Figure 6.

Early order to mitigate supply chain issues

Companies can improve their early ordering by offering structured training on Lean and supply chain management tools (Anand and Kodali 2008). This includes Reorder Point Estimation, Just-In-Time (JIT), Value Stream Mapping (VSM), Kanban, Lean Thinking, Sales Forecasting, and Management Visualization. These tools give manufacturers an obvious way to manage their inventory and make their operations more efficient. Take Reorder Point

Estimation for example, it helps manufacturers figure out exactly what inventory levels to order at. So, they do not run out of material. When used with Sales Forecasting, companies can forecast demand. So, they can synchronize their ordering with real market demand and reduce extra inventory costs.

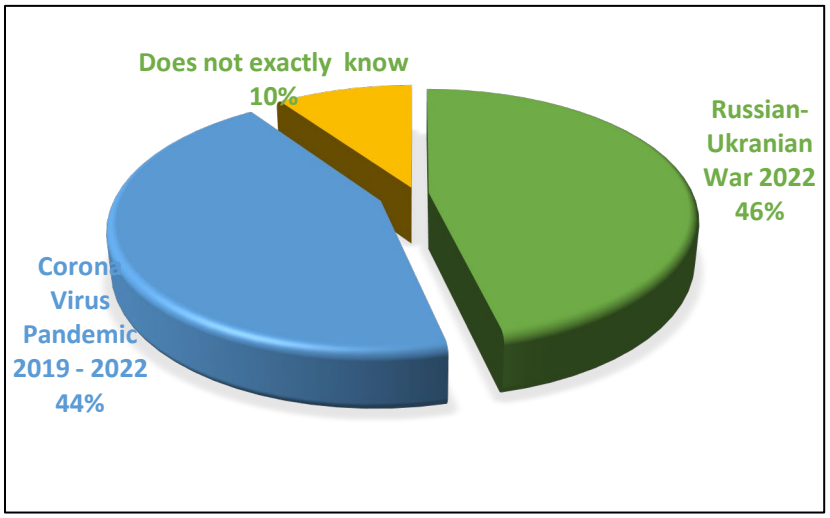

Figure 6. Main external challenges of supply chain for SMEs

Learning to use tools like Kanban and JIT puts the spotlight on managing inventory through visuals and flow (Demir and Paksoy 2023). This helps manufacturers set up systems that can change and respond. Take Kanban cards, for instance, they can tell you when stocks are running low, and it is time to order more. This makes sure you always have what you need. JIT, on the other hand, cuts down waiting times by lining up what you buy with what you make. What is more. VSM and Management Visualization make supply chain steps clear and easy to see. This lets manufacturers spot problems and make their work better. Companies in New Hampshire have put these ideas to work. Small and medium-sized businesses there used these tools to manage problems, keep making stuff, and make smarter choices. By giving local manufacturers these tools, they can start ordering. This helps them get ready for changes in what customers want, stand strong when things go wrong, and stay ahead of the competition. Figure 7 presents early ordering that helps mitigate supply chain issues.

In Table 5, we summarize the tools and strategies provided to small and medium-sized enterprises (SMEs) in New Hampshire to improve processes and effectively manage supply chain disruptions, including Kanban, which helps improve workflow and manage inventory level. Value stream mapping is used to identify and eliminate waste in the supply chain. and just-in-time (JIT) practices to reduce inventory costs by aligning production schedules with demand. We also introduce Reorder Point techniques to maintain optimum stock levels and reduce delays. At the same time, it promotes the development of multi-source supply chains to increase flexibility from supplier disruptions. Management visualization tool was applied to improve decision making through clear and real-time data visualization. Lean manufacturing principles are also used to optimize overall operations. At the same time, it provides forecasting techniques to better inform demand-based planning resources. Together, these

strategies aimed to reduce challenges for SMEs and promote long-term supply chain stability. Table 5 shows the impact and percentage contribution from New Hampshire manufacturers based on customer reviews (NHMEP 2024a, NHMEP 2024c).

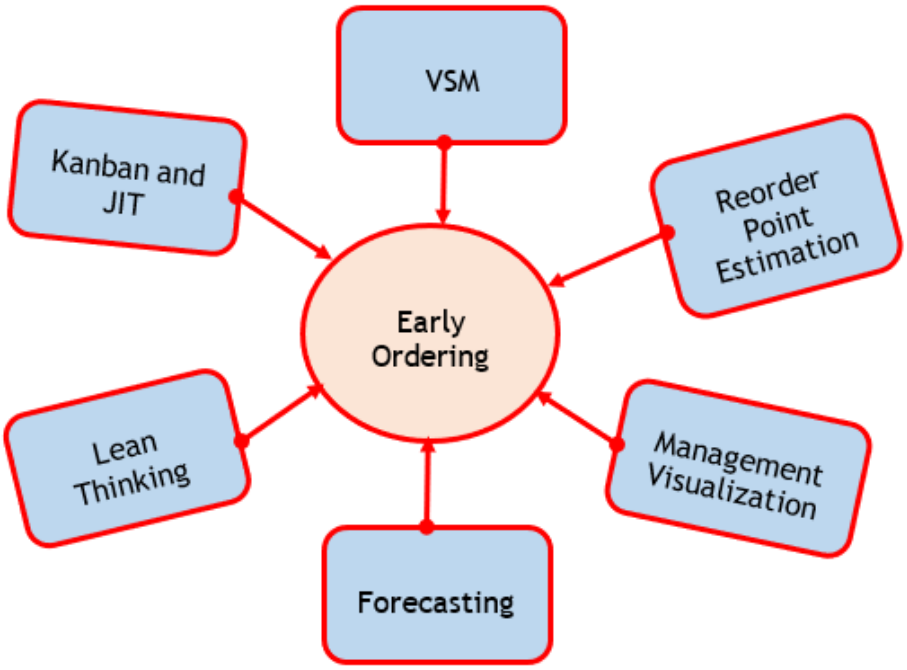

Figure 7. Early order to mitigate supply chain

The training approach involves not just conducting surveys but also sharing success stories from manufacturers in New Hampshire. The impact of delivered projects can be effectively gauged by examining these success stories (NHMEP 2024b), with tangible outcomes and improvements being highlighted. Additionally, lessons learned from these cases are analyzed and applied to planning and execution of future projects, guaranteeing constant improvement and higher success rates. The manufacturers keep some of the data from these stories hidden and treat it with great respect but share other information to highlight achievements and best practices. Despite this, many details remain. Companies and their notable achievements in executing these projects are depicted below in Table 6 (NHMEP 2024d)

Table 5. Strategies and tools delivered to improve SMEs (With many projects delivered)

Strategy or Tool	Benefit	Supply Chain with Lean	Impact/Percentage Contribution
Kanban	▪ Better visibility: replenishes only the materials needed at the moment.	▪ Optimizes tool usage and inventory levels, improving operational efficiency by reducing excess stock.	▪ **92%**: Improved inventory management and workflow efficiency. Customer average evaluations (**9.2/10**)

Strategy or Tool	Benefit	Supply Chain with Lean	Impact/Percentage Contribution
Value Stream Mapping	▪ Optimizes processes in delivering value to customers.	▪ Provides data-driven, graphical representations to identify inefficiencies and opportunities for improvement.	▪ **100%**: Better process optimization and waste reduction. Customer average evaluations (**10/10**)
Just in Time (JIT)	▪ Optimizes production by reducing waiting times and transport costs.	▪ Reduces lead times and minimizes inventory holding costs, aligning production with actual demand.	▪ 81%: Reduced lead time and operational cost. Customer average evaluations (8.1/10)
Reorder Point	▪ Builds effective inventory by ensuring sufficient stock.	▪ Prevents stockouts and delays by ensuring timely replenishment based on demand and usage patterns.	▪ **70%**: Maintains consistent production without delays. Customer average evaluations (**7/10**)
Multi-Source Supply Chain	▪ Increases risk mitigation and flexibility in crisis situations.	▪ Reducing reliance on a single supplier, provides a safety net in case one supplier faces disruptions.	▪ **71%**: Ensures supply more flexibility and continuity. Customer average evaluations (**7.1/10**)
Management Visualization	▪ Identifies problems, hidden patterns, and new opportunities efficiently.	▪ Allows quick response to supply-demand fluctuations and better decision-making based on real-time data.	▪ **93%**: Accelerates response times and data-driven decisions. Customer average evaluations (**9.3/10**)
Lean Manufacturing	▪ Reduces waste, improves productivity, and increases efficiency.	▪ Eliminates non-value work and inefficiencies throughout the production process, reducing costs and increasing output.	▪ **100%**: Waste reduction, streamlined operations, and higher productivity. Customer average evaluations (**10/10**)
Sales Forecasting	▪ Provides enough knowledge to estimate future demand.	▪ Ensures timely inventory replenishment, minimizing stockouts and optimizing sales forecasts.	▪ **80%**: Better demand forecasting and inventory management. Customer average evaluations (**8/10**)

Table 6. Achievement stories from SMEs (NHMEP 2024d)

Company	Tools Applied	Main Achievements	Date	Impact on Supply Chain	New Investment	Jobs Created	Increase in Sales
Filtrine Manufacturing Co	Lean Principles and Process Improvement	Reduced lead times and improved customer satisfaction	May-23	Strengthened delivery timelines and customer trust within the supply chain	$150,000	5	15%
Rumford Stone Co	Lean Training and Implementation	Improved operational efficiency and overall business performance	Jul-24	Optimized resource utilization and reduced process waste	$120,000	10	Not specified
Harvey Building Products	Lean Training and Implementation	Increased operational efficiency and production outcomes	Mar-24	Enhanced production flow, reducing lead times and waste	Not specified	15	$2M
ABTech Co	Marketing Strategies Collaborative Program	Clearer marketing strategy and increased customer engagement	Dec-24	Strengthened customer base through refined marketing approaches	$500,000	12	$3M
Micro-Precision Technologies	CMMC Compliance	Defense business continuity ensured through compliance	Jun-23	Secured defense contracts by meeting cybersecurity requirements	$250,000	8	Not specified
Pleasant View Gardens	Lean Training and Process Optimization	Boosted operational margins and efficiency by streamlining greenhouse operations	Feb-23	Improved process flow, reducing waste and increasing productivity	Not specified	6	Not specified
Costa Precision	Lean Training	Improved production processes and customer satisfaction	Sep-21	Retained and attracted new customers through	$200,000	4	$1.5M

Company	Tools Applied	Main Achievements	Date	Impact on Supply Chain	New Investment	Jobs Created	Increase in Sales
				operational excellence			
MuShield Company	Geometric Dimensioning and Tolerancing (GDandT) Training	Enhanced product accuracy for aerospace and defense sector clients	Apr-22	Expanded market reach in aerospace and defense through technical capability improvements	$300,000	7	$2.5M
XMA Corporation	AS9100D On-Site Registration Upgrade Training	Strengthened company culture and expanded into aerospace markets	Dec-21	Enhanced market sustainability and expanded supply chain opportunities	$180,000	5	$2M
Textiles Coated International	ISO Certification Upgrade	Gained new clients and retained key customers through quality enhancements	Jan-21	Strengthened supplier relationships and ensured market competitiveness	Not specified	3	Not specified

Adapting AI in NH's SMEs to mitigate supply chain

We called several companies in New Hampshire and found many of them interested in lean principles as an old tool for mitigating supply chain disruptions. However, In NH, small-medium enterprises (SMEs) are gradually adopting AI, albeit at a lower rate than the national average, with only 3.5% of SMEs in NH utilizing AI, whereas 5.4% of SMEs do so nationwide (NH Businesses Ink Link 2025). Limited adoption of IoT among SMEs may be ascribed to its costly implementation, the dearth of expertise, and integration challenges, all putting such technologies within the reach of large corporations with greater resources. To overcome the barriers, various programs including "Small Business, Big Solutions" and AI training at the University of New Hampshire aim to empower the SMEs with AI and IoT tools for digital transformation. In addition, the federal government has awarded $400,000 to assist the SMEs in fortifying their supply chains, so they remain competitive notwithstanding financial and technological constraints (NHMEP 2024e, NHMEP 2024d).

Validation and construct check

Cross-checking improvements observed with quantitative production control indicators collected at the respective facility site visits were used to ascertain both reliability and construct validity.

- Late Shipments: A median (best case) improvement of between 15% and 22%, based on 8 weeks of shipment boards.
- Lead Times: An average (as noted in the observations) of a 20% to 25% reduction in Lead Times after Visual Reorder Points were implemented.
- Stockouts: Kanban Replenishment Logs reflect a 30% to 40% decrease in shortages.
- Percent Plan Complete: Based on the use of Daily Production Control Boards, 85% to 90% of the scheduled production days have fewer than 5% of planned production days to recover.

Link to production control

The trends found in the Percent Plan Complete, and the variance reason logs reflect levels of discipline for both constraint management and planning. Most of the variance between the actual and planned percent plans is the result of supplier delays or machine downtimes (which have now dropped from 5 days closure to 2 days closure) and indicates a decrease in the lead times to resolve the constraints.

Triangulation of Evidence:

- Aggregate Data: Cycle Time Logs, Reorder Point tracking and PPC boards.
- Anecdotal Validation: Narrative responses to inquire from operators and supervisors collected during 50 Site visitation. Table 7 outlines the main achievements in the Post-Lean

Table 7. Validation summary of production control

Metric	Baseline (Pre-Lean)	Post-Lean	N / Period
Late Shipments	▪ 35%	▪ 3-5%	▪ 8 weeks
Lead Time	▪ 10-12 days	▪ 7-8 days	▪ 12 cases
Stockouts	▪ 43%	▪ 5%	▪ 6 SMEs
PPC (Plan Complete)	▪ 70%	▪ 88%	▪ 10 cells
Constraint Closure Time	▪ 5 days	▪ 2 days	▪ 10 events

Results from validating the test process reveal measurable and consistent across all indicators for controlling production. Lead-time, late shipments, and stockouts exhibited a downward trend, while both PPC as well as constraint closure ability demonstrated improved scheduling discipline and reliability.

Figure 8 presents a unified Lean - Digital - SME Production Control Framework connecting the three practitioner components. The SME Checklist and Training Ladder provide essential inputs for the progressive lean capability; both define production control and daily cadence. The visual management system (VMS) enables the monitoring of backlog, flow, and bottlenecks through the use of color-coded Kanban signals as well as supports inventory accuracy through the reorder point formula. Digital support provided through IoT and AI

dashboard helps identify late shipments and lead time variance in real-time alerts. All of these components come together into a single framework that demonstrates the connection between Lean Control, Digital Visibility and SME Training, allowing for measurable improvement of Supply Chain Resilience.

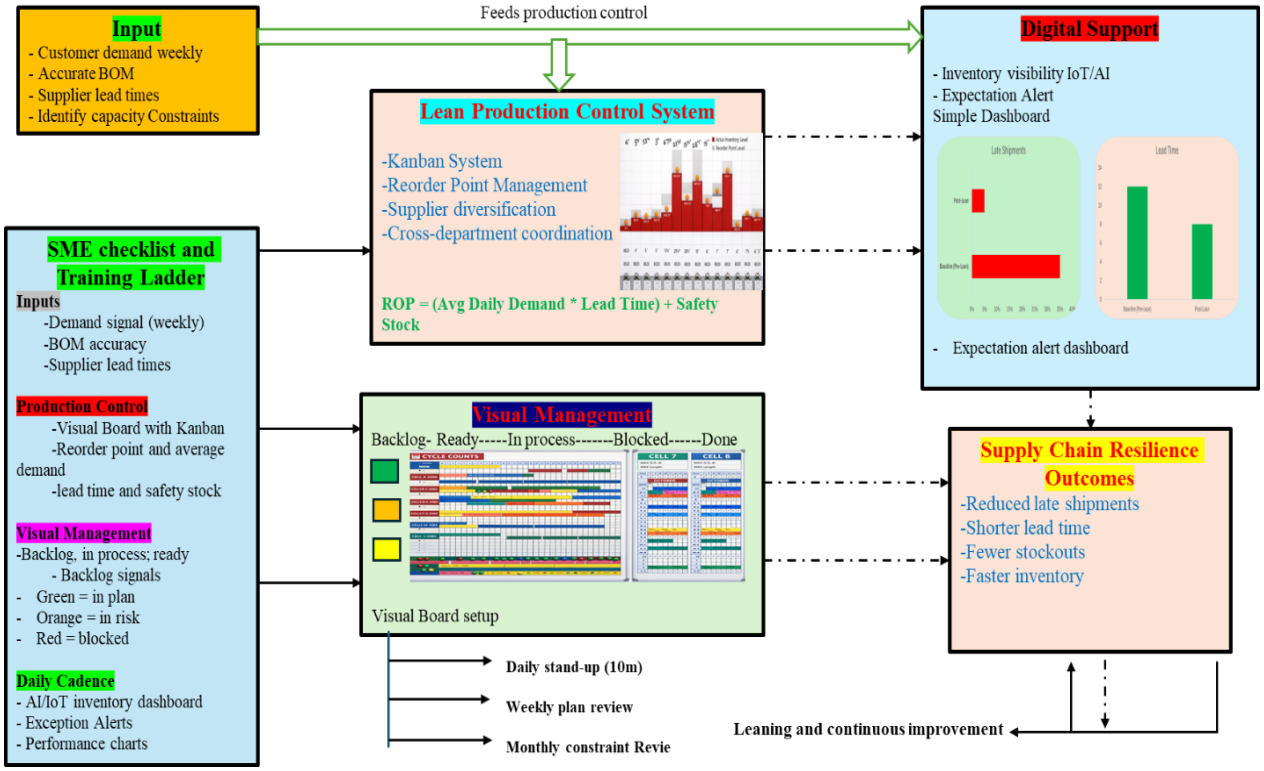

Figure 8. Lean - Digital - SME Production Control Framework

Discussion

Lean supply chain management (LSCM) is a way for small and medium-sized enterprises (SMEs) to become more resilient to supply chain disruptions. Unfortunately, due to financial and technical barriers, advanced digital technologies have not been well integrated into the lean framework (Garcia-Buendia et al. 2021). Another major type of supply chain disruption affecting SMEs in New Hampshire is limited supplier availability, which has increased material costs and worsened logistics (NHMEP 2024a). Lean tools such as Just-in-Time (JIT), Value Stream Mapping (VSM), and Kanban have demonstrated effectiveness in lowering costs and enhancing supply chain agility (Demir and Paksoy 2023).

The integration of advanced digital technologies to enhance lean supply chain practices was a significant research question, and recent findings have shed light on the challenges faced by SMEs. The literature indicates that AI-powered predictive analytics bolster demand forecasting, augment supplier selection, and allow smart sensors to automate inventory tracking (Guo and Mantravadi 2025). Evidence suggests that supply chain resilience, responsiveness, and transparency improve with the integration of Artificial Intelligence and

the Internet of Things into lean frameworks (Majumdar 2024). However, they did not meet most of the SMEs' expectations due to the costs involved and the lack of specific knowledge about the subject (Gruchmann et al. 2024).

The U.S. government, by providing $400,000 in federal funding, has enabled small and medium-sized enterprises (SMEs) in New Hampshire to acquire advanced digital technology-based facilities (NHMEP 2024e). The initiative is designed to reduce imports, improve supply chain performance, and enhance operational agility for SMEs. AI-powered analytics will enable the SMEs to predict supply chain disruptions, while IoT-enabled smart sensors establish real-time monitoring and automated inventory management (Singh et al. 2023). The funds will be used to create appropriate technological infrastructure, develop training programs, and establish partnership models between local manufacturers and technology providers.

The study's hypotheses aligned with these developments. Lean tool adoption (H1) will lead to a 30% reduction in operational costs and increased supply chain agility (Demir and Paksoy 2023). The integration of advanced digital technologies (H2) will certainly further enhance small- and medium-sized enterprises' resilience through predictive maintenance and dynamic resource allocation (Guo and Mantravadi 2025).

H3 is supported by additional evidence; however, the SMEs have higher levels of organizational agility than other businesses and therefore can benefit from establishing a digital transformation strategy. (Gruchmann et al. 2024).

Effectively, SMEs need to integrate advanced emerging technologies with lean thinking to future-proof supply chains. This opportunity creates pathways for small and medium-sized enterprises (SMEs) to develop stronger supply chains, operate more efficiently, and enhance their longer-term competitive advantage. This is an ideal time for SMEs to move towards improved supply chain resiliency, enhanced operational performance, and greater competitiveness in the long term. However, its success will depend heavily on how far SMEs are willing to adopt innovative technologies and on how well-designed the government-backed training is.

Scope, Assumptions, and Future Research Directions

The objective of this paper is to explore how SMEs within the manufacturing sector of New Hampshire have been impacted through repeated supply chain disruptions. for purposes of this discussion, we consider the fact that many of these SMEs experience price and skills constraints which limit their ability to adopt wholesale digital transformation initiatives, therefore utilizing AI, IoT, etc., as a more selective, low-cost enablement mechanism for improving lean manufacturing and human coordination as a supporting mechanism to support the development of lean manufacturing practices.

Data specific to the operational context of SMEs will not be generalizable for either larger firms or/or more capital-intensive organizations.

While the mixed methods approach supported the development of "Practice" Insights, longitudinal studies related to the changes in Resilience for companies over time would expand understanding of the evolution of this phenomenon. In addition, a systematic manner

in which to collect PPC (Production Planning & Control) Data and Constraint/Variance Log Information will provide additional clarity around SLIMS deciding factors related to production control and resilience outcomes. Collecting open-ended PPC data over a more extended period of time will also provide insight related to sustainability and decline effects associated with lean adoption.

Future research can explore additional low-cost AI and IoT tools such as inventory visibility, alerting, and demand sensing dashboarding as additive value within lean manufacturing system. Additionally, comparative research between construction suppliers and subcontractors could provide insights regarding flow variability and coordination difficulties. Finally, research that expands this framework to include large enterprises will further clarify how lean manufacturing does/does not interact with large/diverse culture and highly complex structures and advanced digital maturity.

Conclusion

This research analyzed the impact of Lean supply chain methodologies on the resilience and performance of Small and Medium-sized Enterprises (SMEs) that were supported by both the digital enablement of key functions and a strong corporate culture to support those methods. We conducted 200 surveys and 50 site visits to develop our findings regarding the use of Lean Tools such as Just-in-Time, Kanban, Value Stream Mapping, and Visual Management, which helped in significantly reducing the time lost through lead-time, reducing inventory-related inefficiencies, ultimately reducing late deliveries, and increased the employee's professionalism.

Based on the data collected, we found that by leveraging their flatter structural organization, closer to the end-users, and having the ownership of improving processes within their business, those SMEs would adopt Lean supply chain methods faster and more robustly than the comparative size of large enterprises.

This research adds to the academic literature on supply chain resilience, as it provides, through empirical data, an understanding of how resilience is established by SMEs. The mixed-methods design of this study has strengthened understanding of how Lean practices operate within the context of operational constraints and disruptions.

Practically, the research takes Lean principles and produces practical applications that may be replicated. Daily operational disciplines create resilience in SMEs, and the research provides examples of how to successfully execute Lean supply chain principles, such as using reorder points and visual management systems to coordinate Production, Purchasing, and Shipping departments.

Politically and as, it pertains to workforce development, the research highlights the need for accessing appropriate Lean training, using supplier diversification strategies, and having managers that can visualize the production process to build stronger SME supply chains. While technology remains a priority in building supply chain resilience, the successful development of supply chain resilience is dependent upon the alignment of SME operational realities with the necessary skills, culture, and resource-based tools.

While this research is based upon evidence from small- and medium-sized enterprises (SMEs) located within the state of New Hampshire, the learnings gleaned from it apply to many other regions and resource-limited manufacturing industries. The results demonstrate that the establishment of a resilient supply chain does not require large scale investments or total digitalization; instead, it is dependent on the measured implementation of Lean principles with strong organizational ownership, along with targeted external assistance. Future research can build upon this study by examining longitudinal or inter-regional equivalent cohorts, especially as SMEs begin to adopt digital tools incrementally. This research has demonstrated a significant opportunity to embed Lean-based resilience methodology into training for SMEs, policies related to industry advancement, and systems that support the entire manufacturing supply chain at the ecosystem level.

Conflicts of interest statement

The author declares that there is no conflict of interest

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Appendix

The participant feedback and needs assessment for the manufacturing program

Assessment provides valuable insight into how we can effectively deliver future training opportunities that will meet the specific requirements of industries involved in business services and manufacturing.

Participant Information

Your Name: _____

Current Job Title: _____

Company Name: _____

Work Email:_____

May we email you regarding future training or support opportunities?

☐ Yes ☐ No

Training Engagement

Main reason for joining this training (check all that apply):

☐ Skill development ☐ Solving a current business problem
☐ Professional growth ☐ Communication and Leadership
☐ Other:

_____

How did you hear about the training? (check all that apply)

☐ Colleague / referral ☐ University or partner organization
☐ Email / newsletter ☐ social media ☐ Our website ☐ Other:

_____

Training Evaluation

How would you rate the coach's delivery and expertise?

☐ Very Excellent ☐ Excellent ☐ Very Good
☐ Good

Did the training design and topic meet your business interests?

☐ Strongly agree ☐ Agree ☐ Neutral ☐ Not agree

Future Learning Interests

Which topics would you like more information on training? (Check all that apply)

☐ Innovative manufacturing technologies ☐ Lean Six Sigma
☐ Root Cause Analysis ☐ Supply chain risk mitigation and resilience
☐ Business development ☐ Next steps of Lean implementation
☐ Other (please specify):
_____

Supply Chain Challenges

What supply chain challenges does your organization currently face?

☐ Supplier delays ☐ Material shortages
☐ Long lead times ☐ High costs
☐ Single-source dependency ☐ Use AI/IoT technologies
☐ Other: _____

Did the COVID-19 pandemic negatively impact on your business?

☐ Yes ☐ No ☐ Still experiencing impacts

If yes, Please explain:_____
_____
_____

Additional info

Any additional information, needs, or suggestions:_____
_____
_____

Your feedback is appreciated!