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A Two-Phase Stabilization Framework for Manufacturing Ramp-Up in High-Volume Assembly Systems

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Method Article

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Abstract

Manufacturing ramp-up, whether for new product introduction or new line development, is a high-risk phase characterized by process immaturity, workforce learning, and evolving system constraints. Organizations are expected to achieve stable production quickly, often under conditions where reliable baseline data is unavailable. While Lean Manufacturing offers proven performance benefits, its early deployment during ramp-up is frequently constrained by instability and incomplete process understanding.

This paper proposes a conceptual two-phase ramp-up framework that separates rapid startup from post-launch Lean maturation. The first phase prioritizes stabilization and organizational learning, while the second focuses on optimization and standardization once sufficient system stability is achieved. The framework reframes early inefficiency as a managed and temporary condition that enhances problem visibility, accelerates learning, and supports capability development.

Additionally, readiness-based transition criteria are introduced to guide the timing of Lean tool deployment. The framework contributes by clarifying the sequencing logic between ramp-up dynamics and Lean implementation, offering phase-specific managerial guidance and testable propositions for future research.

1. Introduction

Starting up a new production line – getting from the very first product to steady, normal operation – is one of the toughest parts of manufacturing. During this time, companies plan to make more volume, improve quality, and cut costs all at once, even though their processes are still not matured up to a certain level. These immature processes generally have incomplete information, and a workforce that is still learning the system. Prior research consistently describes ramp-up trajectories in terms of learning-curve behavior and emphasizes that early performance instability is not an exception, but a defining feature of ramp-up dynamics (Terwiesch and Bohn, 2001; Schuh et al., 2008). Despite this understanding, many organizations continue to manage ramp-up using steady-state performance expectations. Early efficiency targets, strict takt adherence, and rapid pressure to reach planned OEE levels are frequently imposed, sometimes with the unintended consequence of encouraging reactive firefighting and premature optimization.

Lean Manufacturing, which is deeply rooted in the Toyota Production System, has demonstrated substantial performance benefits. Especially in mature manufacturing environments through systematic waste elimination, standardization, and continuous improvement (Ohno, 1988; Womack and Jones, 2003; Liker, 2004). As a result, both practitioners and scholars often advocate “Lean from day one,” emphasizing early deployment of Lean principles during facility design and ramp-up to prevent waste from becoming embedded in the system. While this logic is intuitively appealing, ramp-up environments differ fundamentally from stabilized operations. Frequent engineering changes, evolving work content, incomplete material-flow definitions, and uneven operator capability can significantly limit the reliability

of baseline measures. Under these conditions, formal optimization initiatives introduced too early may struggle to deliver sustained benefits. In practice, the assumption that “earlier is always better” for Lean deployment can prove operationally fragile.

What remains underdeveloped in the ramp-up and Lean literature is not the availability of improvement tools, but the timing logic that explains when—and under what conditions—those tools should be intensified. Existing studies tend to focus either on ramp-up as a learning and capacity-building problem or on Lean as a methodology for optimizing mature systems. Comparatively little attention has been paid to the managerial sequencing challenges. How organizations can deliberately manage early-stage inefficiencies as a structured learning mechanism and then transition into disciplined Lean maturation. Once sufficient stability and data quality exist to support sustained improvement later a final process can be planned accordingly. As a result, practitioners are often confronted with a false trade-off. They either delay SOP in pursuit of early perfection or launch rapidly and accept instability without a clear pathway to maturity.

To address this gap, this paper develops a conceptual two-phase ramp-up framework that separates the objectives of rapid startup from those of Lean-driven process maturation.

Phase I

This step focuses on getting things stable and letting the team learn. The main idea is to get a safe, repeatable flow using just the necessary processes. It focuses on maximizing problem visibility and shortening feedback loops.

Phase II

It shifts the emphasis toward optimization and standardization, with Lean tools such as Kaizen, 5S, standard work, visual management, and mistake-proofing. This phase deploy more intensively based on validated operational data and frontline experience. This happens based on solid data and real-world experience. The plan includes checkpoints to guide the move between steps, which reduces the chance of trying to fix things too early and helps make sure improvements are real and lasting, not just cosmetic.

The intended contribution of this work is both theoretical and practical. Specifically, the paper

(1) reframes early inefficiency as a managed and temporary condition necessary for learning and stabilization,

(2) proposes a sequencing logic that bridges ramp-up learning dynamics and Lean deployment,

(3) provides phase-specific managerial practices and transition criteria, and

(4) articulates testable propositions to support future empirical evaluation.

The framework is informed by commonly observed patterns in high-volume manufacturing environments, but access to detailed ramp-up data is often limited. Accordingly, the paper takes a theory-building, practice-oriented approach, with validation left to future empirical research.

2. Literature Review

2.1 Ramp-Up and Learning Curves

Manufacturing ramp-up is commonly defined as the transition from start of production (SOP) to the achievement of stable, planned performance in volume, quality, and cost (Terwiesch and Bohn, 2001; Schuh et al., 2008). A consistent finding across ramp-up research is that performance improvement during this phase is fundamentally learning-driven. As organizations gain experience with the product, equipment, and work system, output typically increases and defect rates decline. The rate of this decline of defects and learning-curve trajectories are often described as S-shaped or exponential. Ramp-up, is not a short-lived startup interval. It represents a structured process in which technical readiness and organizational learning must develop together.

During the early stages of ramp-up, core performance indicators such as first-time-right (FTR), overall equipment effectiveness (OEE), throughput, and defect rates tend to fluctuate widely and often in unpredictable ways. Prior studies attribute this variability not to a single dominant cause, but to the interaction of several other resonating factors. These factors are such as, incomplete process definition, ongoing and iterative equipment tuning, team members learning effects, and instability in upstream supply chains (Terwiesch and Bohn, 2001; Schuh et al., 2008; Clark and Fujimoto, 1991). In practice, these factors rarely occur in isolation, which further amplifies performance variation during early production.

Ramp-up is therefore considered a high-risk phase largely because these elements are tightly interconnected at the system level. Even relatively small deviations in material flow, work sequence, or tooling behavior can spread through downstream operations, triggering rework, queueing, missed takt targets, or unplanned stoppages. Therefore, ramp-up effectiveness is increasingly framed in the literature as a socio-technical challenge rather than a purely technical one. Successful outcomes depend not only on equipment readiness and process capability, but also on coordinated problem solving across functions, disciplined learning routines on the shop floor, and managerial decision-making under conditions of uncertainty, rather than on technical commissioning alone (Schuh et al., 2008; Edmondson, 1999).

Studies also show that planned startup timelines often don't happen in real life. Setting goals that are too tough too early, and pushing too hard to meet normal performance levels, can make things even more chaotic. This is because it shifts attention away from learning and fixing root causes towards quick fixes and putting out fires. This repeated observation shows we need startup plans that clearly manage the learning process and stabilize production before attempting full-scale optimization.

2.2 Lean Manufacturing and Early-Stage Implementation

Lean Manufacturing, rooted in the Toyota Production System, is widely recognized as an effective approach for improving quality, flow, and cost performance through waste elimination, standardization, and continuous improvement (Ohno, 1988; Womack and Jones, 2003; Liker, 2004). Lean tools such as Kaizen, 5S, standard work, and visual management have been shown to improve performance across a range of industrial contexts by increasing process transparency, reducing variation, and institutionalizing structured problem-solving routines.

A common piece of advice, both from experts and in practice, is to use Lean as early as possible – often called Lean from day one. This includes during product and factory design, to stop waste from becoming part of the production system. While this logic is compelling, the ramp-up environment differs in important ways from stabilized operations. Early production usually involves changing work, frequent design changes, incomplete information, and workers with different skill levels. In these conditions, basic performance measurements might not be reliable, and standard solutions might become outdated quickly after they're put in place. As a result, formal optimization initiatives launched too early risk locking unstable processes into premature standards.

Therefore, although Lean is well established as a methodology for improving mature production systems, the literature offers comparatively limited guidance on how Lean tools should be sequenced when the operating system itself is still being discovered and stabilized. This raises a practical and theoretical question that extends beyond whether Lean tools are effective. The more critical issue is when, and under what readiness conditions, those tools should be intensified during ramp-up to avoid premature optimization.

2.3 Gaps in Current Research

Existing research streams tend to focus either on ramp-up management as a learning-curve and system-readiness problem or on Lean deployment as a steady-state improvement methodology. Comparatively little attention has been given to the sequencing challenge that sits at the intersection of these domains: how organizations can deliberately manage early inefficiencies as structured learning, and then transition into disciplined Lean maturation once the production system is sufficiently stable and data quality is adequate.

In particular, the literature provides limited practical guidance on whether—and how—accepting reduced early performance as a temporary learning condition can support faster achievement of SOP while improving the effectiveness and sustainability of subsequent Lean interventions. There is also a notable absence of frameworks that explicitly distinguish the objectives of rapid startup (stabilization and learning) from those of Lean-driven process maturation (optimization and standardization), and that define readiness-based criteria for shifting between them.

This paper addresses these gaps by proposing a two-phase ramp-up framework in which early production prioritizes safety, stability, and learning, followed by a deliberate Lean maturation phase grounded in validated operational data and frontline experience. By specifying transition criteria and phase-aligned management practices, the framework seeks to align Lean tool deployment with the realities of ramp-up dynamics rather than with steady-state assumptions.

3. Methodology and Conceptual Framework

This study adopts a conceptual theory-development approach. Drawing on the ramp-up and Lean manufacturing literature, the proposed framework is developed through an integrative synthesis of recurring managerial challenges observed during manufacturing launches. Rather than relying on a single empirical setting, the framework abstracts common patterns across ramp-up contexts in which organizations must balance learning, stability, and performance pressure under conditions of uncertainty. The core constructs—phase objectives, enabling conditions, and transition criteria—are defined to be operationally actionable and to support future empirical examination through the propositions articulated later in the paper.

Consistent with theory-building research in operations management, the framework is intended to provide a structured basis for future empirical examination rather than to serve as a fully validated model. The propositions developed in Section 3.3 are designed to motivate subsequent case-based and quantitative testing across ramp-up contexts

3.1 Two-Phase Ramp-Up Strategy

The paper proposes a structured two-phase ramp-up framework that explicitly separates the objectives of initial production launch from those of systematic process optimization. The framework is grounded in the recognition that early-stage manufacturing systems are inherently learning-driven and frequently operate under unstable conditions with limited baseline data. Under these circumstances, early production requires different managerial priorities than those applied in mature manufacturing environments (Terwiesch and Bohn, 2001; Schuh et al., 2008).

Instead of trying to be fast, efficient, and stable all at once, the suggested approach purposely sets the order of goals across two connected steps: (i) Fast Start, focused on getting stable and letting the team learn, and (ii) Lean Improvements, focused on making things better and more consistent. This order reflects the real-world truth that learning and getting stable must come before lasting improvements if those improvements are to be solid and repeatable.

Phase I: Rapid Startup (Stabilization and Learning Phase).

The primary objective of Phase I is to establish safe, repeatable production flow using minimum viable processes. In contrast to approaches that emphasize early takt adherence or rapid efficiency gains, this

phase prioritizes stability, workforce learning, and early exposure of system weaknesses. Several characteristics define this phase.

First, baseline standard operating procedures (SOPs) are introduced with a narrow focus on safety, correct sequence discipline, and containment of critical quality characteristics. Cycle-time optimization and detailed line balancing are intentionally deferred in favor of clarity and repeatability. Second, material handling and information flows are deliberately simplified to increase transparency and accelerate problem identification, reflecting the need for visibility during early learning. Third, inspection intensity and feedback frequency are temporarily elevated. Short feedback loops between operators, quality, and engineering functions enable early detection of deviations and emerging failure modes. Finally, early performance below steady-state targets is explicitly accepted as a baseline for learning rather than interpreted as a deficiency. This framing reduces pressure for workarounds and supports disciplined root-cause removal.

Taken together, these practices are intended to create a controlled learning environment in which operators, team leaders, and engineers can observe real process behavior, identify main sources of variability, and build the introductory process knowledge required for following optimization.

Phase II: Lean Maturation (Optimization and Standardization Phase).

Once basic production flow has been established and dominant sources of instability are understood, the system transitions into Phase II. During this phase, Lean tools are deployed more systematically to drive performance toward planned targets in a structured and sustainable manner.

Kaizen activities are focused on dominant waste categories revealed during Phase I, such as motion, waiting, rework, over-processing, and material handling. Workplace organization and visual management are introduced or intensified to strengthen abnormality detection, operator ownership, and daily management discipline. Standard work is developed and refined based on validated best practices observed under stabilized conditions, enabling consistent execution, scalable training, and reliable performance measurement. As variability goes down, line balancing and keeping to the schedule are gradually made tighter to make more products and use resources better without making the flow unstable. Mistake-proofing and certain automation are only brought in once how things fail and what the process can handle are well understood. This reduces the risk of building in instability with permanent solutions.

In Phase II, improvement actions are driven by validated operational signals and frontline experience rather than by pre-launch assumptions, increasing the robustness and sustainability of performance gains.

Transition Criteria Between Phases.

The transition from Phase I to Phase II is guided by readiness indicators rather than by passed time alone. This approach comes from startup research that stresses how important stability and learning

progress are, rather than sticking to fixed, calendar-based deadlines. In practice, progression based purely on time often masks unresolved instability and incomplete learning, increasing the risk of premature optimization.

Typical transition criteria include consistently making a minimum amount of product over several shifts, a steady drop in serious safety and quality issues below set levels, finishing initial training for workers on core tasks, and having reliable data on losses for big categories like downtime, defects, and cycle time issues. Together, these indicators provide evidence that the production system has reached a level of stability and observability sufficient to support structured optimization. By relying on such readiness-based criteria, organizations can intensify Lean tool deployment only when the system is capable of benefiting from it, thereby reducing premature interventions and improving the durability and sustainability of improvement outcomes.

3.2 Enablers and Conditions

The effectiveness of the proposed two-phase ramp-up framework ultimately depends on a set of organizational and managerial enablers that shape how learning, stability, and improvement unfold during early production. Past research consistently shows that when these enablers are weak or missing, companies are more likely to push for improvements too soon, deal with long periods of instability, and struggle to achieve lasting performance during a startup. In practice, these conditions rarely fail in isolation. Instead, they work together and decide whether early problems are taken as learning or made worse into constant disruptions.

Rather than functioning as standalone best practices, these enablers influence the system's capacity to make sense of early variability, convert problems into learning, and transition effectively into disciplined Lean maturation.

3.2.1 Cultural and Leadership Alignment

Leadership alignment plays a decisive role in determining how early ramp-up conditions are interpreted and managed. During Phase I, leaders must explicitly frame early inefficiencies as expected and intentional, emphasizing their value for problem discovery and organizational learning rather than treating them as indicators of poor execution. When performance pressure is misaligned during early ramp-up, problem visibility tends to decline. Operators and engineers become more likely to rely on workarounds, and systematic learning is replaced by short-term fixes.

Accordingly, performance management during Phase I should emphasize issue identification, quality of root-cause analysis, and the effectiveness of corrective actions rather than short-term output metrics alone. Such framing supports psychological safety and encourages operators and engineers to surface problems early. Over time, this environment accelerates stabilization and increases the effectiveness of downstream improvement efforts.

3.2.2 Rapid Feedback and Data Infrastructure

Having quick and reliable ways to get feedback is vital for learning during early production. From the very beginning of a startup, data collection doesn't need to be fancy, but it has to be organized. Simple systems that capture key operational information – like types of downtime, kinds of defects, differences in cycle time, and safety observations – build the foundation for structured learning. In early steps, seeing when something is wrong matters more than being super precise with analysis, because catching and responding to problems quickly leads to faster learning.

Visual management systems, daily team meetings, and clear ways to escalate issues help everyone at different levels of the organization understand what's happening. These practices not only prioritize improvement actions but also encourage organized problem-solving behaviors. Over time, they create the data and communication setup needed to move from getting stable to structured Lean improvements..

3.2.3 Workforce Training and Skill Readiness

Workforce capability development is a foundational enabler of the transition from stabilization to optimization. Training for operators and team leaders should begin prior to SOP and continue throughout Phase I, with an emphasis on process discipline, adherence to evolving standard work, and basic problem-solving methods such as PDCA and 5-Why analysis.

Early investment in skill readiness builds operator confidence and engagement, which in turn improves the quality of feedback during Phase I. It also strengthens participation in Kaizen activities during Phase II. By establishing a shared language for improvement early in the startup, companies make Lean deployment more scalable and lasting once things are stable enough.

3.2.4 Cross-Functional Integration

Effective ramp-up requires close and sustained integration across production, engineering, quality, maintenance, and logistics functions. Prior studies show that functional silos during early production phases often contribute to delayed stabilization and repeated problem recurrence, as system-level interactions remain unaddressed.

Daily cross-functional reviews during Phase I support rapid containment and learning by addressing issues at the system level rather than within isolated functional boundaries. In Phase II, structured governance of Kaizen activities helps ensure that optimization efforts remain aligned with overall system objectives and do not result in localized performance gains that destabilize other parts of the production system.

3.2.5 Management of Change and Scope Control

Disciplined change management is crucial for maintaining system stability during Phase I. Engineering changes should be tightly controlled to limit unnecessary chaos in the process, while still allowing important technical fixes to happen. Too many changes, or changes that aren't prioritized well, disrupt learning, make it hard to see what causes what, and delay getting stable.

As the system transitions into Phase II, improvement initiatives should follow a prioritized roadmap aligned with business objectives and the dominant loss categories identified during stabilization. This disciplined approach helps prevent fragmented optimization efforts and ensures that performance gains are built on a stable and well-understood operational baseline.

3.2.6 Ramp-up Project Management and Governance

Effective ramp-up execution requires a project management layer that goes beyond schedule tracking or milestone reporting. Within the proposed two-phase framework, project management functions primarily as a coordination and governance mechanism that aligns cross-functional actions, protects early learning, and regulates the timing of improvement activities.

During Phase I (Stabilization and Learning), the central role of project management is to maintain scope discipline and system stability while learning unfolds. Ramp-up leaders bring different functions together and ensure that early performance variation is openly visible, not buried under temporary fixes. Practically, this requires making deliberate choices about which engineering changes to introduce and when, keeping parallel initiatives under control, and maintaining stable work content long enough for teams to understand how the process actually behaves. Otherwise, this would hide cause–effect relationships. Decision-making during this phase favors repeatability, containment of critical quality issues, and process observability over early takt compliance or efficiency targets.

Governance mechanisms in Phase I therefore emphasize clear decision ownership, rapid escalation paths, and controlled change introduction. By moderating the rate of change and filtering competing priorities, project management helps preserve a stable learning environment in which dominant loss mechanisms can be identified with confidence.

As the system progresses into Phase II (Lean Maturation), the role of project management evolves toward structured execution of improvement initiatives. With baseline performance stabilized and recurring loss patterns visible, project management coordinates Lean activities as a coherent improvement roadmap rather than as isolated events. This involves directing Kaizen efforts toward the most impactful problem areas, coordinating interdependencies across stations and functions, managing resource constraints, and embedding improvements through standard work.

At this stage, milestones are defined less by planned dates and more by observable improvements in system stability and capability, including reduced defect recurrence, stronger compliance with standard work, and reliable takt performance.

Across both phases, project management helps regulate the rate and order of change, enabling organizations to move from learning to stabilization and, ultimately, to sustained optimization. By linking governance decisions to readiness indicators instead of fixed timelines, ramp-up teams reduce the risk of premature standardization and improve the durability of downstream Lean outcomes.

3.3 Propositions for Future Empirical Validation

The conceptual framework developed in this study gives rise to a set of testable propositions that address both the sequencing of ramp-up objectives and the timing of Lean tool deployment. Rather than treating ramp-up as a uniform process, these propositions reflect the view that learning, stabilization, and optimization unfold under different conditions and should be managed accordingly.

P1 (Sequencing). Ramp-ups that explicitly prioritize stabilization and organizational learning before optimization will achieve stable, repeatable production faster than ramp-ups that pursue early efficiency targets in parallel with stabilization.

P2 (Premature Lean intensity). High intensity of Lean tool deployment—such as frequent Kaizen events, strict takt enforcement, or early lock-in of standard work—prior to meeting minimum stability thresholds will be positively associated with operational volatility, including rework, recurring downtime, and increased escalation frequency.

P3 (Baseline data reliability). The effectiveness of Lean interventions during ramp-up is positively moderated by baseline data reliability. Lean deployments initiated after stable loss patterns become observable are expected to yield more sustained performance improvements.

P4 (Transition criteria). Ramp-ups that rely on readiness-based transition criteria, rather than purely time-based milestones, will exhibit more sustainable improvement trajectories and fewer performance regressions during Lean maturation.

P5 (Frontline learning mechanism). Greater frontline participation in Phase I problem identification and feedback processes will be positively associated with the rate of improvement in Phase II, mediated by increased problem visibility and shared process understanding.

P6 (Change governance). Stronger discipline in engineering change governance during Phase I will be associated with faster stabilization, particularly in production systems characterized by higher technical and organizational complexity.

P7 (Delayed automation and lock-in). Deferring automation, poka-yoke proliferation, and rigid line balancing until dominant failure modes are well understood will result in higher long-term process capability and lower embedded waste than early lock-in approaches.

P8 (Leadership framing). Leadership framing of early inefficiency as intentional learning, rather than failure, will be positively associated with psychological safety and problem reporting, which in turn will predict faster stabilization and more effective Lean maturation.

4. Illustrative Application Example

This section presents an anonymized, practice-informed vignette to illustrate how the proposed two-phase framework may be applied during a high-volume manufacturing ramp-up. The vignette is not intended as an empirical case study. Instead, it serves to contextualize the framework and make its

underlying mechanisms more concrete, particularly in settings where proprietary constraints limit the disclosure of detailed operational data. This approach is consistent with prior conceptual research in operations and manufacturing management.

4.1 Manufacturing Context

Consider a newly launched body-shop assembly line for a commercial vehicle platform operating under aggressive time-to-market constraints. The line combines manual and automated operations, including joining, welding, and material handling. The workforce is newly assembled and has limited prior exposure to the specific product architecture, tooling concepts, and cross-station interactions required by the new platform.

As is typical in such launches, early production is characterized by evolving work content, iterative technical adjustments, and pronounced learning effects. Under these conditions, operational instability is expected. Early performance variability reflects the interaction of human learning, process immaturity, and system-level interdependencies rather than isolated technical deficiencies.

4.2 Phase I: Rapid Startup (Stabilization and Learning)

To achieve SOP, the ramp-up team prioritizes safe, repeatable production flow and accelerated organizational learning over early efficiency optimization. Initial standard operating procedures emphasize safety-critical sequence discipline and containment of key quality characteristics, while allowing a degree of flexibility to accommodate operator learning and process discovery.

Inspection frequency is temporarily increased to accelerate identification of defect patterns and process sensitivities. Material flow and control mechanisms are intentionally simplified in selected areas to maximize constraint visibility and shorten feedback loops. Daily cross-functional tier reviews—bringing together production, quality, engineering, maintenance, and logistics—are used to triage abnormal conditions, capture dominant loss categories, and assign rapid containment actions.

Typical observable signals during this phase include high variation in station cycle times, recurring defect modes linked to ambiguous work content, downtime concentrated in a small number of dominant loss categories, and frequent escalation driven by cross-functional handoffs. Importantly, these signals are treated as learning inputs rather than performance failures. They guide prioritization of stabilization efforts and inform subsequent improvement focus.

4.3 Phase II: Lean Maturation (Optimization and Standardization)

Once minimum stability criteria are met—such as repeatable throughput across consecutive shifts, reduction of critical safety and quality incidents, completion of initial workforce certification, and availability of reliable baseline loss data—the system transitions into structured Lean maturation.

Lean activities are prioritized against the dominant loss categories identified during Phase I. Kaizen events target recurring sources of waste, while 5S and visual management are introduced or intensified to improve abnormality detection and operator ownership. Standard work is formalized based on validated best practices observed under stabilized conditions, and line balancing is progressively tightened as variability decreases. Mistake-proofing and selective automation are introduced only after failure modes and process capability are sufficiently understood, reducing the risk of embedding instability into fixed solutions.

Observable signals during this phase include reduced recurrence of dominant defects, increased stability of downtime patterns, improved adherence to standard work, lower escalation frequency, and gradual tightening of takt compliance without destabilizing production flow.

4.4 Insights from the Vignette

The vignette illustrates the central logic of the proposed framework. Early inefficiency, when deliberately managed, functions as a learning condition that increases problem visibility and capability development. Lean tools are then intensified once readiness conditions support sustained optimization. By explicitly separating stabilization from optimization, the framework provides a structured pathway that aligns Lean deployment with the realities of ramp-up dynamics, reduces premature optimization, and improves the robustness of downstream performance gains.

5. Discussion

5.1 Theoretical Contributions

This paper contributes to the literature on manufacturing ramp-up and Lean production by clarifying the temporal logic that links learning dynamics, system stability, and improvement deployment.

First, the study advances ramp-up theory by reframing early inefficiency as a managed and temporary operating condition rather than as a deviation from desired performance. While prior research acknowledges learning-curve effects during ramp-up, it largely treats early performance variability as an outcome to be minimized. In contrast, this framework conceptualizes early inefficiency as an instrumental mechanism for learning and stabilization, shifting analytical attention from early optimization to early system understanding.

Second, the paper extends Lean manufacturing theory by introducing a sequencing perspective on Lean tool deployment. Existing Lean literature emphasizes waste elimination and standardization but offers limited guidance on timing under conditions of system immaturity and data scarcity. By distinguishing between a stabilization-focused startup phase and a subsequent Lean maturation phase, the framework clarifies when Lean tools are most likely to be effective during ramp-up, addressing a long-standing gap between Lean design principles and launch realities.

Third, the study bridges ramp-up and Lean research streams by proposing readiness-based transition criteria as a linking construct. Rather than relying on calendar-driven milestones or universal best practices, the framework introduces stability, data reliability, and workforce readiness as contingent conditions governing the shift from learning to optimization. This contribution responds directly to calls for more context-sensitive and contingency-aware production theories.

Finally, by articulating a coherent set of testable propositions, the paper provides a foundation for future empirical research on ramp-up sequencing and Lean deployment. These propositions translate practice-informed insights into theoretically grounded hypotheses, supporting cumulative knowledge development across manufacturing contexts where direct data access is often constrained

5.2 Benefits of Accepting Initial Inefficiencies

The proposed two-phase ramp-up framework reframes early inefficiencies not as failures to be eliminated immediately, but as a deliberate and temporary investment in organizational learning and system stabilization. This perspective is consistent with ramp-up and learning-curve research, which characterizes early performance variability as an inherent feature of new manufacturing systems rather than a deviation from normal operation (Terwiesch and Bohn, 2001; Schuh et al., 2008). By explicitly legitimizing this variability during Phase I, the framework shifts managerial attention and decision-making in ways that generate several interrelated benefits.

First, prioritizing safe and repeatable production flow over early optimization supports faster achievement of SOP milestones. When organizations defer detailed line balancing and efficiency tuning until basic stability has been established, they reduce launch delays caused by excessive pre-launch refinement or repeated rework of prematurely optimized processes. In this sense, accepting early inefficiency functions less as a performance concession and more as a practical accelerator of time-to-market.

Second, the framework promotes more realistic performance expectations during early ramp-up. Explicit recognition of reduced early performance as part of the learning process helps align leadership expectations with the natural dynamics of system maturation. This alignment reduces pressure on frontline teams to meet steady-state metrics prematurely and limits reactive firefighting and short-term workarounds that often obscure root causes. The resulting shift in performance framing encourages systematic problem identification and disciplined learning behaviors.

Third, early acceptance of inefficiency enhances problem visibility and organizational learning. Simplified processes, temporary manual controls, and elevated inspection frequency during Phase I expose dominant loss drivers more clearly than highly optimized but opaque systems. This improves the quality of baseline data and reduces reliance on pre-launch assumptions or virtual validation models that may not reflect actual operating conditions. As a result, Lean interventions introduced in Phase II tend to be more precisely targeted and more effective.

Fourth, this approach strengthens worker involvement and ownership of the process. Getting workers involved early in finding problems and giving feedback deepens their understanding of the process and builds a sense of ownership over how the system performs. Studies about people and machines suggest that such early participation helps with long-term continuous improvement and accepting standard work, especially when learning is seen as legitimate rather than punishable.

Finally, Lean improvements developed based on solid operational data are more likely to be strong and lasting. By putting getting stable before making things better, companies reduce the risk of building waste or instability into standard work, automation, or mistake-proofing solutions. As production changes less and volume goes up, these data-backed improvements are better positioned to last and grow over time.

5.3 Risks and Boundary Conditions

While the deliberate acceptance of early inefficiencies offers clear advantages, it also introduces risks that must be actively managed. Without appropriate governance, early inefficiency can be misinterpreted or misused, undermining the intent of the framework.

One risk is misinterpretation by leadership as a signal of low ambition or weak execution. This risk can be mitigated through explicit pre-launch communication, clearly articulated Phase I objectives, and visual dashboards that track stabilization and learning progress rather than output alone. Such mechanisms help distinguish intentional learning from unmanaged underperformance.

A second risk is the normalization of waste or substandard practices. To avoid this outcome, Phase I must be bounded by explicit exit criteria, and the transition to Phase II must include clear expectations for Kaizen activity and performance improvement tied to business objectives. Without such boundaries, temporary inefficiencies may become institutionalized.

A third risk relates to data quality during early production. While early data are often noisy, disciplined but simple data capture from the outset—such as downtime logs, defect Pareto analyses, and operator feedback boards—ensures that learning is cumulative rather than anecdotal.

Additional risks include delayed or deprioritized Lean deployment and workforce fatigue resulting from rapid change. These risks can be mitigated by integrating Lean activities into the master launch plan, pacing improvement initiatives, stabilizing processes before tightening takt, and recognizing early contributions to reinforce engagement. When these mitigation strategies are applied, early inefficiencies function as a controlled learning mechanism rather than evolving into a permanent operating condition.

5.4 Managerial Implications for Ramp-Up Leadership

The two-phase framework developed in this study provides several actionable implications for managers responsible for new line launches, new product introductions, or plant ramp-ups in high-volume manufacturing. A central practical message is that effective ramp-up leadership requires deliberate

sequencing of priorities, rather than attempting to maximize speed, stability, and efficiency simultaneously from day one.

Phase I: Stabilization as a Managed Learning Period

In the earliest weeks after SOP, managers should explicitly treat ramp-up as a stabilization and learning phase rather than a performance optimization phase. The primary objective is not immediate takt compliance or world-class OEE, but the establishment of safe, repeatable production flow and rapid discovery of dominant loss mechanisms.

Practically, this requires leaders to implement “minimum viable standardization,” focusing early SOPs on safety-critical steps, correct work sequence, and containment of key quality characteristics. Overly detailed standard work or aggressive balancing introduced too early may lock unstable practices into the system and reduce problem visibility.

Ramp-up managers should also intensify feedback mechanisms during this period. Daily cross-functional tier reviews, structured abnormality escalation, and simple downtime/defect logging are essential for converting early variability into organizational learning. In Phase I, the managerial KPI focus should shift from efficiency outcomes to learning indicators, such as:

- rate of problem identification and closure,
- recurrence of critical defects,
- stabilization of dominant downtime categories, and
- workforce certification progress on core operations.

Importantly, leadership framing is decisive. Managers must communicate that early inefficiency is expected and temporary, functioning as a controlled learning investment rather than evidence of failure. This reduces firefighting behavior, discourages hidden workarounds, and increases frontline willingness to surface problems early.

Phase II: Lean Maturation Driven by Validated Operational Signals

Once minimum stability thresholds are met, managers should transition deliberately into Phase II, where Lean tools are intensified to drive systematic optimization and standardization. The framework emphasizes that Lean deployment is most effective when anchored in observable loss patterns and validated shop-floor experience rather than pre-launch assumptions.

During this phase, Kaizen activities should be prioritized against the dominant waste categories revealed during stabilization, ensuring improvement resources are directed toward the highest-impact constraints. Similarly, 5S and visual management should be expanded to strengthen abnormality detection, operator ownership, and daily management routines.

Standard work development becomes critical in Phase II, but it should be built from proven practices under stabilized conditions rather than imposed prematurely. This enables consistent execution, scalable training, and reliable performance measurement. Only after failure modes are understood should managers introduce tighter line balancing, mistake-proofing, or automation, reducing the risk of embedding instability into permanent solutions.

Readiness-Based Transition Governance

A key managerial contribution of the framework is the use of readiness-based transition criteria rather than calendar-driven milestones. Managers should avoid shifting into optimization simply because "six weeks have passed." Instead, transition should occur when operational signals demonstrate sufficient system observability and repeatability, such as:

- consistent throughput across consecutive shifts,
- sustained reduction in critical safety/quality incidents,
- completion of baseline workforce training, and
- availability of reliable Pareto loss data (downtime, defects, rework).

This governance approach prevents premature optimization and improves the durability of Lean outcomes.

Practical Takeaway for Manufacturing Leaders

Taken together, the framework provides a structured roadmap for ramp-up leaders: stabilize first, learn fast, then optimize systematically. By legitimizing early inefficiency as a controlled learning mechanism, organizations improve problem visibility, accelerate workforce capability development, and create the conditions under which Lean tools can generate sustained performance gains.

For practitioners, the key implication is clear: Lean is not less important during ramp-up—but its timing and intensity must be aligned with system readiness. Organizations that manage this sequencing effectively are more likely to achieve faster stabilization, stronger continuous improvement culture, and more robust long-term operational excellence.

6. Conclusion and Future Work

6.1 Conclusion

This paper develops a pragmatic two-phase framework for manufacturing ramp-up that explicitly separates the objectives of rapid production launch from those of Lean-driven process optimization. Rather than pursuing early perfection, the framework conceptualizes initial inefficiencies as a deliberate and temporary condition that supports organizational learning, operational stabilization, and workforce capability development during early production stages.

By susing Lean tools like Kaizen, 5S, standard work, and visual management within a post-launch improvement step, the plan matches improvement efforts with solid operational data and real-world worker experience, rather than with assumptions made before launch. In doing so, the study re-frames early problems not as a failure to be fixed right away, but as a managed way of operating that leads to more effective learning and more lasting improvements down the line.

The primary contribution of this work lies in clarifying the temporal logic that links ramp-up learning dynamics and Lean deployment. Through readiness-based transition criteria and phase-specific management priorities, the framework offers a structured alternative to both premature optimization and unmanaged startup variability. For manufacturing leaders, it provides a practical roadmap for balancing speed, stability, and long-term operational excellence during one of the most critical phases of industrial operations.

6.2 Future Work

Future research should focus on extending and empirically validating the proposed framework across a range of manufacturing contexts. Promising directions include the development of quantitative ramp-up models that explicitly link learning-curve behavior, stability indicators, and the timing of Lean interventions to operational outcomes; multi-site empirical studies across automotive and other high-volume manufacturing environments to assess generalizability and contextual contingencies; and longitudinal analyses examining the long-term effects of ramp-up sequencing on productivity, quality, cost, safety, and workforce engagement.

Another area for future work involves connecting the plan with digital manufacturing systems, like manufacturing execution systems, advanced analytics, and Industry 4.0 technologies. Such connections might boost early learning while still keeping things simple and visible during stabilization. Together, these research directions can help improve the plan, clarify its limits, and strengthen its contribution to making data-driven decisions in complex manufacturing startups.

Declarations

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This work is based on generalized industry observations and does not disclose any proprietary or confidential information from any specific organization.

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Data Availability

No datasets were generated or analyzed during the current study.

Ethics Approval

Not applicable.

Consent to Participate

Not applicable.

Consent for Publication

The author consents to the publication of this manuscript.

Author Contribution

N.S. conceived the study, developed the framework, conducted the literature review, analyzed and interpreted the data, prepared all figures and tables, and wrote the manuscript. N.S. reviewed and approved the final version of the manuscript and is accountable for all aspects of the work.

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