Seasonality Mitigation Through Exiting Manufacturing Tools Leading to Productivity Improvement and Wastage Reduction

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Abstract

Seasonal demand variability in the automotive industry, particularly in bus body manufacturing, imposes highly complex operational and environmental challenges. Low production volumes combined with mass customization intensify resource consumption, increase planning instability, and elevate waste generation throughout the production cycle. In this context, the present study proposes a sustainability-oriented production framework designed to mitigate the impacts of seasonality while strengthening environmental management through the strategic integration of innovation and data management. The model is grounded in the application of established production management tools enhanced by structured data capture and multifunctional analytics. This architecture expands process transparency, traceability, and decision-making accuracy. The integration of different manufacturing modes, such as Make to Order, Make to Stock, and hybrid configurations, enables alignment of planning and execution under a data-driven logic, promoting synchronization of production flows and optimizing workforce allocation in response to demand fluctuations. Environmental gains are reflected in reduced inventory, minimized material obsolescence, lower energy intensity per unit produced across the Whole production cycle, and improved rational use of inputs. The framework is built on financial constraints on the acquisition of new tools or on consulting fees, requiring investment discipline and prioritization of high-impact initiatives. As a result, data governance combined with a waste-reduction culture enhances operational responsiveness, improves economic returns, and consolidates sustainable systems within environmental management. This integrated approach demonstrates how data-enabled governance structures can support resilient, resource-efficient production systems in highly variable manufacturing environments.

Keywords: *Seasonality, Mass customization, Production optimization, Lean manufacturing tools, Bus manufacturing. Simulation.*

1. Introduction

This article discusses solutions that can ease the seasonal effects on the ongoing trend of increasing product variety demanded by the market, and ways to manage the uncertain demand across different vehicle models and categories, which also require greater manufacturing flexibility (Müller; Lehmann; Kuhn, 2021). The challenge is more demanding in the bus manufacturing industry, as transportation is considered a pillar of economic growth; further, mass transportation is more economically sustainable and helps mitigate global warming (Rylková; Čemerková; Pokorná, 2021).

In industrial practice, synchronization in a manufacturing system is closely related to the nature of the product and the way it is built to achieve its full functionality, in line with the customer's expectations (De Medeiros et al., 2025). Handbooks on the strategy for selecting the best manufacturing process model and product delivery requirements, such as those written by Slack, can serve as a basis for finding a solution (Slack; Brandon-Jones; Johnston, 2015). In contemporary manufacturing environments, companies adopt distinct manufacturing modes to balance efficiency and market responsiveness, ranging from mass production to highly customized outputs. These modes, Make to Stock (MTS), Make to Order (MTO), Assemble to Order (ATO), and Engineering to Order (ETO), are differentiated according to three primary customer priorities: speed, cost, and delivery flexibility. Bus Business is a mix of MTO and MTS, hence opposite planning modes; when executed on the same manufacturing line, this leads to tight financial gains as they try to balance both modes. Seasonality further increases this pressure on delivery and financial gains. Quality is excluded as a distinguishing factor because it is a fundamental, non-negotiable requirement across all manufacturing modes (Kingsman et al., 1993; Peeters; Van Ooijen, 2020; Subash Babu, 1999).

The implementation of strategies to meet this requirement aims for a holistic approach, requiring all the direct and indirect areas to work together, supporting each other by focusing on industry best practices respectively and seamlessly integrating them without exacerbating the defects embedded in the solutions; in other words, without increasing fluctuations in the production line or inventory (Naciri et al., 2022). Production line fluctuations in product flow and sequence cause losses, resulting in reduced productivity, mainly related to equipment failures, unprepared operators, poor inventory tracking, and other elements that support the production system and are not perfectly synchronized, resulting in a lack of competitiveness (Ikeziri et al., 2023). Seasonality exerts additional stress on planning, further disrupting the harmony of a dedicated production line.

In the bus manufacturing industry, production involves both Original Equipment Manufacturers (OEMs) and Body Builders (BBs) who operate under OEM accreditation and guidelines but remain outside the OEMs' direct managerial control and standardized manufacturing models. This structural arrangement creates a production "grey zone" characterized by fragmented responsibilities and coordination challenges. End customers typically interact directly with BBs, who are responsible for configuring the final vehicle specifications. Consequently, BBs rely on mixed-model assembly lines (MMALs), which integrate Make to Order (MTO) and Make to Stock (MTS) strategies, to effectively respond to increasing product customization and the dynamic manufacturing and market conditions of the automotive sector (Boysen; Scholl; Wopperer, 2012).

This article addresses the following research questions: first, whether it is possible to develop a seamless framework to manage seasonality in production; and second, whether the framework can be reliable within an existing manufacturing line without requiring significant capital investment.

2. Theoretical Background

2.1. Manufacturing strategy and resource utilization in bus manufacturing

Since the early 2010s, increasing resource constraints and competitive pressures have intensified the need for more efficient utilization of manufacturing resources. Within the domains of operations strategy and manufacturing systems modes, this shift has historically driven operational areas to plan installations with higher production capacity to meet future demand, justifying the internal requirement to mitigate seasonality or unforeseen opportunity demands.

The adoption of process strategies supported by analytical models and algorithms has become central to this evolution (Kusiak, 2018). These strategies are grounded in theories of manufacturing flexibility, modularity, and economies of scale, highlighting the importance of customer proximity, product and process modularization, and supply chain integration (Axsäter, 2015). Lean manufacturing theory provides the foundational principles for these approaches, with methodologies such as 5S serving as a baseline for waste reduction and process standardization. More recent frameworks extend lean principles to address higher levels of customization and operational complexity (Kumar et al., 2014).

Importantly, these frameworks increasingly integrate functional domains traditionally treated in isolation—such as human resource management and financial planning—into a cohesive production system. This integrated, process-oriented approach aligns with empirical findings indicating that significant productivity improvements, in some cases exceeding 50%, can be achieved through organizational and operational redesign rather than capital-intensive investments (Ribeiro et al., 2019).

2.2. Characteristics of the bus manufacturing industry

From a production systems and labor economics perspective, bus manufacturing is characterized by a high degree of labor intensity and product variety (Mourato et al., 2021). These structural characteristics increase sensitivity to demand fluctuations and emphasize the maximization of returns on both labor and capital investments. Maintaining cost competitiveness under such conditions requires manufacturing systems capable of absorbing variability without excessive idle capacity.

To address product diversity, some manufacturers adopt decentralized production strategies, including multiple specialized facilities or outsourcing selected activities. However, systems dynamics theory suggests that increased fragmentation can amplify coordination complexity, introduce feedback delays, and ultimately result in cost overruns and reduced operational efficiency (Sterman, 2000). From a theoretical standpoint, centralized production systems capable of delivering both variety and volume offer a competitive advantage by reducing coordination losses and improving overall capacity utilization.

These structural characteristics provide the context for managing seasonality and highlight the need for integrated, system-level approaches rather than isolated or asset-driven solutions.

2.3. Takt time, capacity planning, and dynamic alignment

Within capacity planning and lean production theory, takt time is a central mechanism for synchronizing production output with customer demand. Takt time directly reflects market feedback and demand variability, including seasonal fluctuations. As market conditions evolve, production systems designed around static takt times risk misalignment, leading to declining operational relevance and economic inefficiency.

Theoretical models of manufacturing system evolution emphasize that persistent misalignment between demand and capacity necessitates adaptive responses at the process level. Firms may redesign workflows, adjust sequencing and staffing, or reconfigure planning and control mechanisms to restore alignment with updated delivery expectations. Such adaptations reinforce the role of dynamic capacity planning in managing seasonality without resorting to physical capacity expansion.

This perspective positions takt time not merely as an operational metric, but as a strategic lever for managing predictable demand variability within existing production infrastructures.

2.4. Seasonality in bus manufacturing

Seasonality is a predictable, recurring fluctuation in demand over a given period (Sanguri et al., 2024) and the corresponding internal production adjustments required to respond to these fluctuations (Bhat; Krishnamurthy, 2016). In bus manufacturing, seasonality is critical as it involves high levels of customization, extended lead times, and demand patterns often linked to public procurement cycles and regulatory schedules.

From a theoretical standpoint, seasonality introduces challenges related to resource allocation, inventory management, and production scheduling. Manufacturers employ strategies such as flexible production rates, inventory buffering, and planning algorithms to mitigate these effects, each involving trade-offs between cost, responsiveness, and stability. Research in production smoothing theory suggests that maintaining stable production levels, rather than strictly matching output to sales, can reduce operational risk and inefficiencies (Petersen; Handfield; Ragatz, 2005). Nevertheless, even advanced manufacturing sectors continue to experience financial and operational strain due to seasonal demand variability (Mollick, 2004).

In the bus manufacturing business, coordination between original equipment manufacturers (OEMs) and body builders (BBs) is important, as OEMs typically operate standardized, high-throughput chassis production systems. In contrast, body builders rely on slower, labor-intensive customization processes. This structural asymmetry amplifies seasonality, underscoring the importance of synchronized planning, takt alignment, and inventory coordination to minimize financial losses and enhance system reliability.

2.5. Bus manufacturing and product constraints

Bus manufacturers generally adopt one of two primary production approaches: monocoque construction or body building on a modified ladder or truck chassis. From a manufacturing process theory perspective, monocoque designs are driven by OEMs, as they offer high structural integration but require stable regulatory and market environments to support the high investment required, limiting their suitability in highly customized or volatile-demand contexts. Consequently, in developing markets, chassis-based production systems are favored due to their superior flexibility and adaptability (Piran et al., 2016).

Chassis-based production enables manufacturers to respond to diverse local requirements at lower cost (T Shekar et al., 2014), though it transfers certain maintenance and reliability risks to operators. These process characteristics define the operational constraints within which seasonality management strategies must function, reinforcing the need for adaptable, process-oriented solutions.

2.6. Core theoretical concepts supporting the framework

Building on the preceding theoretical foundations, this study integrates established manufacturing and operations concepts to support the development of a framework for managing seasonality in bus manufacturing:

- Mass Customization: Enables manufacturers to balance high product variety with production volume through hybrid production models (Hayes; Wheelwright, 1979)Womackallowing responsiveness to diverse customer requirements while maintaining cost control (Peeters; Van Ooijen, 2020).
- Value Stream Mapping (VSM): A core lean manufacturing tool for identifying and eliminating non-value-adding activities (Womack; Jones, 1997), thereby improving flow and operational stability. The integration of VSM with simulation techniques further enhances its applicability by enabling proposed changes to be evaluated before implementation (Thulasi et al., 2022).
- Value Analysis and Value Engineering (VAVE): Focuses on optimizing component design by systematically evaluating functionality relative to cost and customer expectations, supporting cost-effective adaptation under variable demand conditions (He; Han; He, 2024).

- Frugal Engineering (Frugal Innovation): Emphasizes the development of affordable, resource-efficient solutions under constrained conditions, promoting adaptability, resilience, and sustainable value creation without reliance on significant capital investment (Hossain, 2020).

Importantly, the theoretical foundations of lean manufacturing, frugal engineering, mass customization, and production smoothing emphasize process reconfiguration, coordination, and operational control rather than asset expansion. Taken together, these perspectives support the feasibility of a seamless, integrated framework that can manage seasonality within existing manufacturing lines. They further suggest that reliable seasonality management can be achieved without requiring significant capital investment, relying instead on systematic process design, alignment of planning, and cross-functional integration.

Taken together, the reviewed theories demonstrate that seasonality in bus manufacturing is a predictable and manageable phenomenon. By integrating principles from capacity planning, lean manufacturing, systems dynamics, and frugal engineering, it is theoretically feasible to develop a seamless framework that aligns takt time, production processes, and organizational coordination. Such a framework can operate reliably within existing manufacturing infrastructures, addressing seasonal demand fluctuations through operational and managerial interventions rather than capital-intensive expansion.

3. Methodology

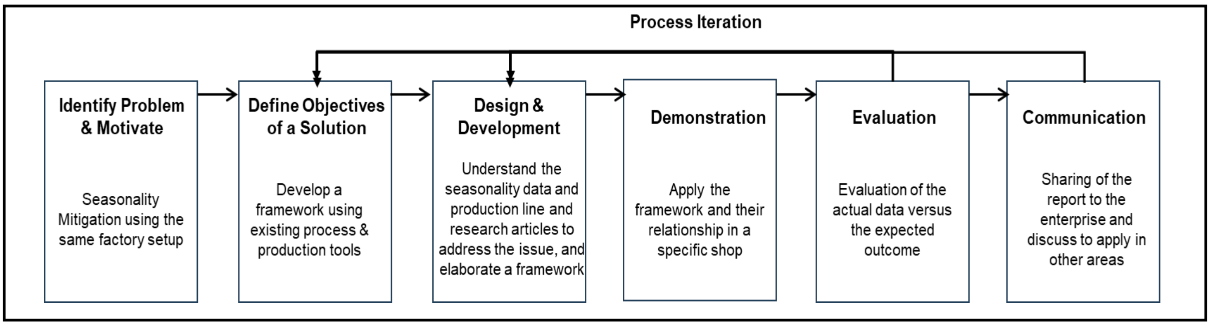
The Design Science Research (DSR) framework is well-suited to this study, as it addresses real-world problems by creating and evaluating artifacts, methods, and frameworks. By linking practical challenges with academic knowledge (Lukka, 2023), DSR operates through iterative cycles of building and assessing solutions, thereby ensuring both industrial relevance and academic rigor (Jesus et al., 2023).

The DSR process structures around a sequence of key stages: problem identification and justification, definition of solution objectives, design and development of the artifact, demonstration of its applicability in practice, evaluation of its effectiveness, and communication of results to relevant stakeholders (Vom Brocke; Hevner; Maedche, 2020). This systematic structure ensures that proposed solutions achieve both methodological rigor and practical value.

Moreover, DSR is inherently interactive and iterative, enabling the continuous refinement of the framework. This characteristic allows the integration of existing tools outlined in the previous chapter, particularly given their low implementation cost and proven reliability, while also permitting adjustments to the scope of the objectives based on outcomes observed during application (Dresch; Lacerda; Antunes Jr, 2015). Figure 1 illustrates the adaptation of the DSR process sequence to the case study examined in this paper.

Following the DSR process, the team set a six-month timeline to monitor changing elements during the seasonal period. The second stage of the plan is to perform in three months, with a 2-month lag after the first step. The following sequence is to have the framework design, demonstration, evaluation, and communication over the four months to allow for the implementation of the findings, followed by two months to evaluate and properly communicate the findings for the pilot area.

Figure 1 – DSR Process Sequence



Source: Dresch adapted from Hnever (2015)

The research context for applying the DSR framework is the bus manufacturing industry in the Indian subcontinent, recognized as the second-largest bus market globally as published in the newsletter of Truck and Bus Builder ,magazine on 6th December 2024. Despite its scale, demand in this sector exhibits pronounced cyclicity, particularly during the second half of the calendar year, when procurement driven by school transportation requirements can nearly double order volumes. Furthermore, evolving regulatory standards and the high degree of product customization characteristic of this market create additional operational complexity, requiring manufacturers to adopt highly flexible production systems.

Such conditions typically necessitate substantial capital investment to achieve the required levels of manufacturing flexibility and output responsiveness. However, given the financial constraints faced by the focal company in this study, the research challenge centers on developing a cost-efficient solution. Accordingly, the proposed framework leverages established, low-investment tools such as Value Stream Mapping, Value Engineering, and

Frugal Engineering to address production variability and customization demands. The framework development culminates in changes to the assembly process to better align operational capabilities with market requirements.

The scope of the framework application is a bus manufacturing plant producing a full range of vehicle variants, including mini, micro, midi, large buses, and a coach model. The production design concept is to have three main assembly lines running straight through the facility, as the products are large and bulky. The scale and operational sensitivity of the production environment described above made a full-plant intervention infeasible.

Accordingly, the study focused on a production area characterized by diverse work modes, including direct material supply, sub-assembly integration, and in-house component manufacturing. Based on these criteria, the paneling line was selected as the pilot application area, as it concentrates these operational attributes within a manageable scope for framework deployment.

During the monitoring stage, which lasted almost 6 months, operational data were systematically monitored, including line-wise takt time, which was, on average, 30% above the requirement; material wastage levels, which were 10% below the requirement; and instances of line shortages, which were 10% above the requirement. Observations both at the workstation level and within the bus staging and dispatch areas to capture end-to-end production flow impacts. Shop floor teams maintained operational records, while production and process managers reviewed them daily and consolidated the data for weekly managerial assessment.

The research team adopted a non-interventionist observational role, supporting data collection and conducting structured interviews to develop the case study. This investigation formed part of a broader research project submitted to the UNICAMP Research Ethics Committee (CAAE: 84486324.5.0000.5404), approved on 16 Dec., 2024. All participants provided Free and Informed Consent before inclusion in the study.

The evaluation phase begins with applying Value Stream Mapping (VSM) to analyze material and information flows across the selected production lines, enabling the identification of bottlenecks, workflow congestion, and supply interruptions. Building on these insights, Value Analysis and Value Engineering (VAVE) techniques are employed to develop solutions to reduce line disruptions and material shortages. Mass customization principles are subsequently applied to support line-balancing across varying product configurations. At the same time, frugal engineering focuses on low-cost customization of tools, fixtures, and material-handling trolleys to meet operational requirements.

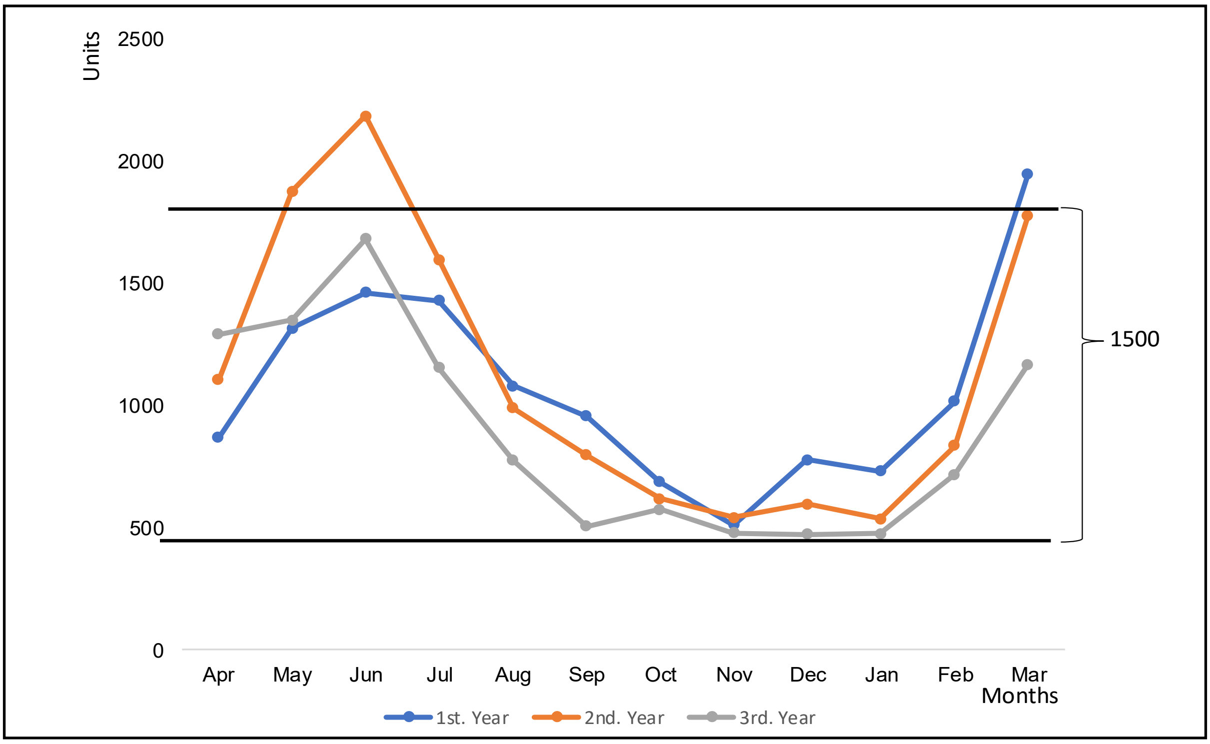
Framework validation through a practical deployment of these integrated tools within the assembly and line-feeding systems. Operational performance assessment by monitoring achieved takt times against seasonal demand requirements, as well as the system's ability to maintain production continuity with minimized inventory buildup. This validation approach enables the assessment of both production responsiveness and stock optimization under cyclical market conditions.

4. Results and Discussion

The challenge faced by the studied manufacturing facility extends beyond equipping the factory to produce a wide variety of bus models; it also involves accommodating significant seasonal fluctuations in production volumes to consistently meet customer demand. Figure 2 below shows substantial demand fluctuations during seasonality. An analysis of production output over the past three years highlights the severity of seasonal variation, with volumes ranging from approximately 500 units during low-demand periods to more than 2,000 units at peak demand. The shifts in the production mix between Make-to-Stock (MTS) units, mainly with school transportation cycles, and Make-to-Order (MTO) units linked to government tender contracts are responsible for these fluctuations.

The magnitude of the observed capacity gap underscores structural constraints in production planning, workforce allocation, and supply chain responsiveness, underscoring the need for an integrated mitigation framework. Given the labor-intensive nature of bus manufacturing, organizations often respond to demand surges by rapidly increasing headcount. However, this reactive approach frequently leads to cost escalation, delivery delays, and quality deviations, particularly when firms rely on unskilled labor as a short-term countermeasure, resulting in approximately a 35% reduction in productivity. Production data further illustrate the severity of seasonality: output rises to an average of approximately 1,500 units per month during a six-month peak period and declines to nearly 500 units during the corresponding six-month valley. This pronounced fluctuation creates a significant imbalance in the production line and operational instability.

Figure 2 – Seasonality Effect in Production



Source: Adapted from Production Data from the Analyzed Company

4.1. Framework development and structural basis

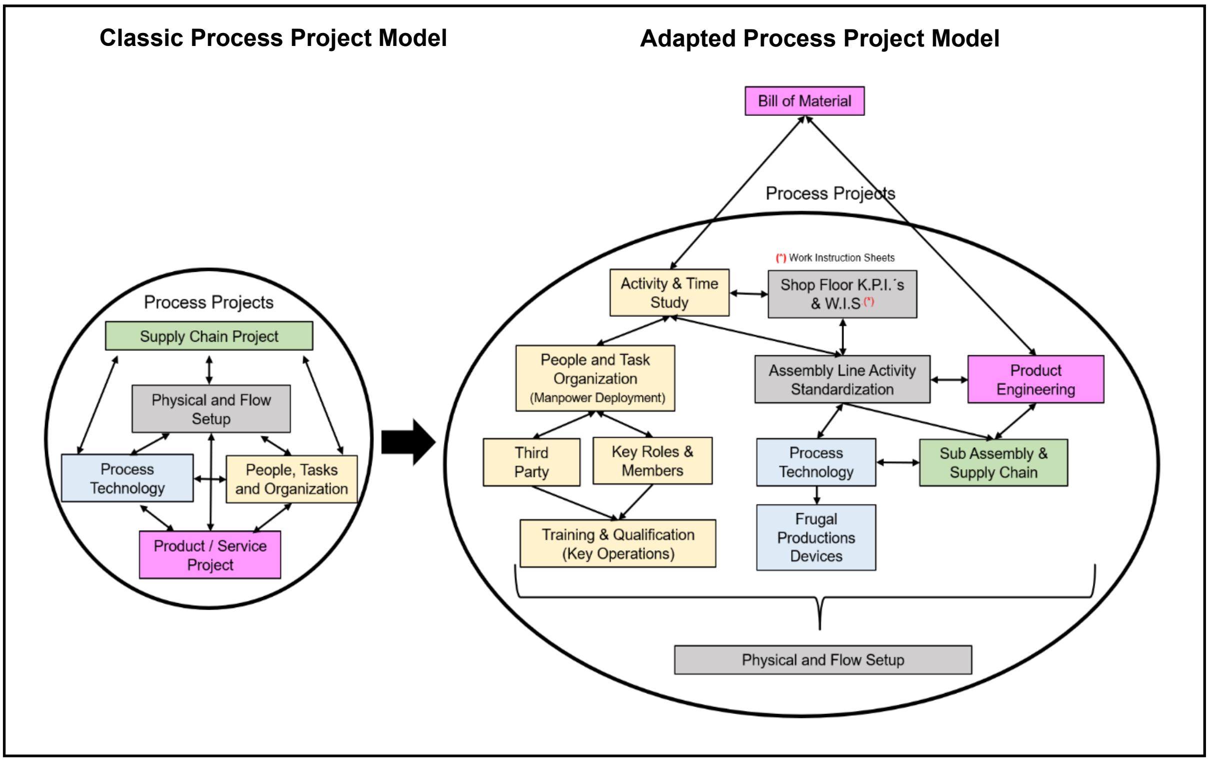
To address these challenges, this study developed a structured framework to mitigate seasonality impacts by systematically integrating proven production system tools into current manufacturing processes. The analysis identified core production principles that form the foundation for achieving the study's objectives. The best way to build a new approach is to use the most well-known base structure as a baseline, referred to as the Classic Process Project (Slack; Brandon-Jones; Johnston, 2015). In the team assessment, researchers reconfigured the model to reflect the operational realities of the observed organization, enabling them to map functional interactions and process dependencies.

Following the Design Science Research (DSR) framework, the development integrated two perspectives:

- Academic rigor derived from established theory, and
- Practical applicability grounded in real-world operational constraints.

The organizational diagnosis examined how functional units interact to support production objectives. For example, the Supply Chain function collaborates directly with Product Engineering through supplier benchmarking initiatives to identify alternative sourcing and design rationalization opportunities. Insights derived from this assessment enabled the restructuring of the classical model into a more comprehensive and responsive framework, presented in Figure 3.

Figure 3 – Process Project Restructuring



Source: Adapted from Slack; Brandon-Jones; Johnston (2015)

4.2. Production system configuration and line design

The restructured framework addresses the core operational problem by leveraging interactions among Process Project elements. To enable consistent performance assessment, the study established a common analytical basis to evaluate current throughput and takt time. This approach led to the development of a normalization factor expressed in equivalent units, derived from the Standard Man-Hour (SMH) required for each bus. The SMH was calculated theoretically by aggregating all activities involved in bus production. This normalization enabled an objective evaluation of throughput and supported assembly-line flow optimization while incorporating demand-variability parameters.

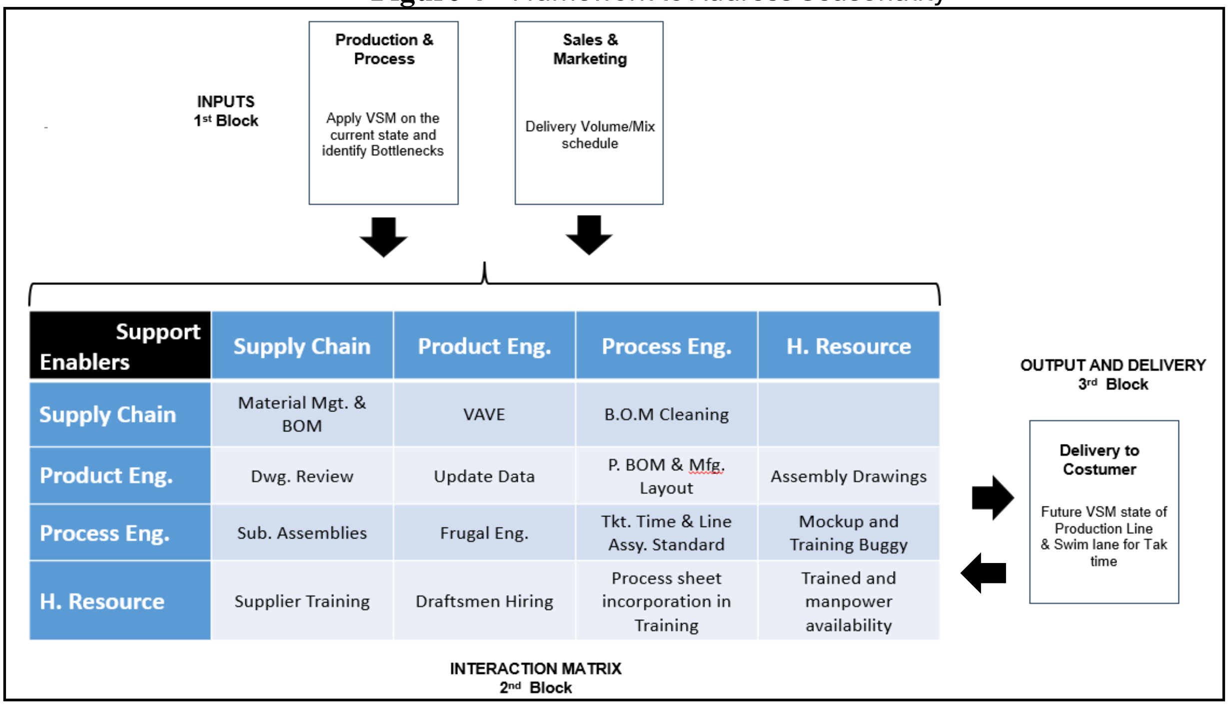
The approach subsequently recalibrated the manufacturing system using SMH as the reference metric to support segregation and production planning for 15 distinct bus models. It configured the assembly line around a minimum takt time of 22 minutes, which served as the baseline operational constraint. To meet the mass-customization requirements driven by customer demand, the team redefined activity sequencing, restructured workstation interdependencies, and reallocated task times across the production system.

The first action standardized a common set of activity stages across all production lines, enabling managers to reallocate the workforce more quickly when delays occurred, since the distance was shorter and the skills were the same. Because space constraints limited the ability to increase the workforce to balance activities with model processing times, the team implemented line balancing to meet demand. This effort led them to segregate production lines and products according to manageable takt-time ranges. For example, Line 1 operated at a takt time of 20–25 minutes, while Line 2 operated at a takt time of 25–45 minutes.

4.3. Framework architecture integration with existing manufacturing tools

Figure 4 emerged from structured iterations during the seasonality period and from Figure 3. It defines three functional analytical blocks based on the order-to-delivery flow. The first block focuses on production inputs. The second block addresses shopfloor execution, emphasizing order deployment and interdepartmental coordination. The final block is the feedback mechanism to ensure proper action and documentation.

Figure 4 - Framework to Address Seasonality



Support Enablers	Supply Chain	Product Eng.	Process Eng.	H. Resource
Supply Chain	Material Mgt. & BOM	VAVE	B.O.M Cleaning	
Product Eng.	Dwg. Review	Update Data	P. BOM & Mfg. Layout	Assembly Drawings
Process Eng.	Sub. Assemblies	Frugal Eng.	Tkt. Time & Line Assy. Standard	Mockup and Training Buggy
H. Resource	Supplier Training	Draftsmen Hiring	Process sheet incorporation in Training	Trained and manpower availability

Source: Prepared by Author

After designing the Value Stream Mapping (VSM) and correlating it with the required product model mix, the output enabled the identification of the operational changes and required modifications. Given the labor-intensive nature of bus manufacturing, the organization primarily responded to increased demand by expanding its workforce and adding hand tools. However, it did not implement corresponding improvements in process design, manufacturability, engineering modifications, or workflow reorientation to enhance production efficiency and reduce water usage.

Block 1 — Inputs: demand and production alignment

In the first block, considering the current VSM, the marketing and production team defined, in terms of SMH, the volume mix and models to be planned, with at least 45 days before plan execution. Improving in the following:

- Quality of orders through discussions with the marketing, production, and engineering teams, understanding profitability, timelines, and manufacturability.
- The team addressed seasonality at its source by aligning demand planning with shopfloor capacity readiness.

Block 2 — Cross-functional interaction matrix

The second block centers on the manufacturing process and focuses on production execution. Multiple departmental interactions shape this stage, requiring a matrix structure to manage coordination effectively. Positioned at the core of the operational flow, this block translates customer requirements (1^{st} Block) into shopfloor deployment. The matrix format enables the identification of interaction types and the application of appropriate tools identified and proven during the literature background review, furthermore strengthening communication and improving delivery performance. Within this structure, functional areas operate either as Enablers (support providers) or Support Targets (beneficiaries of improvement actions), ensuring the systematic application of proven tools identified in the literature and validated through the Design Science Research (DSR) process.

As the team elaborated the full factory Value Stream Mapping (VSM), the analysis identified panelling as the critical area. This finding coincided with its prior selection as the study's focus, given that it operates in a mixed production mode.

The implementation of these improvements achieved the forecasted inventory-reduction targets. The team established a just-in-time supply of subassemblies and ensured synchronized line feeding on a bus-by-bus basis. In addition, the manufacturing and supply chain teams formalized a service-level agreement (SLA) to anticipate and address part shortages or supply inaccuracies in a timely manner. These measures enabled the organization to maintain required takt times for delivery, optimize workforce requirements, and ensure proper workforce deployment.

Table 1 summarizes the interactions and key findings, along with the inputs required for process modifications within the production flow, which the team incorporated into the future-state Value Stream Mapping (VSM). Furthermore, it improves the understanding of the framework and tool allocation.

Table 1 – Cross-Functional Improvement Action

Enabler Function	**Target Function**	**Improvement Action**	**Operational Impact**
Supply Chain	Production Flow	Early material staging, checklist validation, trolley delivery systems	Reduced line stoppages and improved material flow
Supply Chain	Product Engineering	VAVE collaboration for part rationalization	Cost optimization and component simplification
Supply Chain	Process Engineering	BOM cleaning and documentation refinement	Reduced assembly errors and improved clarity
Supply Chain	Human Resources	Supplier capability training	Improved compliance and reduced rework
Product Engineering	Supply Chain	BOM accuracy and specification updates	Improved sourcing efficiency
Product Engineering	Production System	Continuous design updates	Alignment with manufacturability requirements
Product Engineering	Process Engineering	Manufacturing BOM and layout development	Ergonomic workstations and sub-assembly standardization
Product Engineering	Human Resources	Assembly drawings and technical documentation	Enhanced workforce training effectiveness
Process Engineering	Supply Chain	Assembly kitting and supplier alignment	Improved material readiness
Process Engineering	Product Engineering	Frugal engineering solutions	Ergonomic and cost-efficient improvements
Process Engineering	Production Line	Takt time definition and line configuration	Optimized cycle time and line balance
Process Engineering	Human Resources	Process sheets and standard work training	Improved onboarding and method adherence
Human Resources	Supply Chain	Supplier training programs	Quality at source
Human Resources	Product Engineering	Draftsmen hiring	Faster documentation turnaround
Human Resources	Process Engineering	Integrated technical training	Reduced ramp-up time
Human Resources	Production System	Seasonal hiring, incentives, medical and welfare support	Workforce stability during peak deman

Source: Prepared by the Author

Block 3 — Output and delivery

This block focuses on the feedback process, where the team evaluates operational outputs against the original production plan. When major deviations arise, the team conducts structured reviews and incorporates the findings into the future-state Value Stream Mapping (VSM). Based on this reassessment, they revise process sheets, customize tools, relocate part and sub-assembly operations, adjust material flow and control mechanisms, and redeploy labor to achieve the desired operational outcomes.

5. Conclusion

Working in a labor-intensive industry demands a strong focus on developing soft skills and providing continuous guided training. Supervisors balance theory with practical examples relevant to daily workforce routines, ensuring shop floor employees actively engage in seamless quality delivery. This approach also enables efficient implementation of cultural developments and organizational changes.

The designed framework effectively reduced seasonality, increasing productivity from 30% with the internal methodology to nearly 45%. This improvement directly enhanced financial performance.

Enhancing this application with simulation can help analyze multiple VSM implementation scenarios and identify bottlenecks. In today's AI-driven world, neural networks can optimize output and improve efficiency.

Manufacturers can explore automation and robotic implementation as technology advances. However, determining suitable applications and assessing customer willingness to absorb investment costs remain crucial. Additionally, supervisory systems and digital twins can provide real-time debottlenecking solutions, further improving operational efficiency.

The state of the art in the current manufacturing bus manufacturing industry is using artificial intelligence to develop the next level of improvements by the proposed model using Back Propagation Neural Network, further optimizing production through improved scheduling, equipment performance, and communication, standardizing company methods, and contributing to industrial development (Sivakumar et al., 2023).

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