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Research on the Application of Lean Production in Multi-Variety Small-Batch Production Mode

Yinghui Zhang, Hui Li*, Zhaoyang Tang
School of Management, Shandong University of Technology, Zibo, Shandong, China
**Corresponding Author*

Abstract: Since the beginning of the 21st century, the production of a diverse range of products in limited quantities has emerged to meet the increasingly stringent yet reasonable demands of consumers. At present, manufacturing enterprises are developing or transitioning towards this multi-variety, small-batch production models. This paper optimizes three key areas, production management, material management, and quality management under multi-variety small-batch production model through the application of lean production. Drawing on lean production and management theories, it explores how to optimize production processes, reduce material waste, ensure quality, and achieve continuous improvement. By doing so, enterprises can better adapt to the ever-changing market demands, achieve optimal integration and utilization of resources, and ultimately secure higher benefits.

Keywords: Multi-Variety and Small-Batch Production; Lean Production; 5S Management; Material Management

1. Introduction

Against the backdrop of continuous technological innovation and the deep integration of the "Internet+", consumers are increasingly focusing on how well products align with their personal needs. The rise of personalized customization has significantly enriched product diversity, posing serious challenges to the flexibility of enterprise production systems [1-2]. To effectively meet customers' personalized demands and sustain corporate development, the multi-variety, small-batch production model has emerged. Since the 1980s, the market landscape has undergone significant changes. The once homogeneous, stable market environment no longer exists, and mass production methods, epitomized by Ford Motor Company, have gradually become inadequate in satisfying the diverse needs of consumers, losing their dominance in the market. Meanwhile, the customer-centric philosophy has begun to gain traction, with consumers increasingly inclined to purchase products that align with their specific requirements, leading to a market characterized by diversity and dynamic changes. The stabilization of the global situation has spurred economic growth and innovation, and products that fail to adapt promptly to market changes will see their market life cycles significantly shortened [3]. The rapid development of communication and transportation technologies has accelerated the flow of information, intensified global competition, and further increased market uncertainty. The rise and fall of Ford's Model T prompted the industry to deeply reflect on the applicability of mass production methods. The multi-variety, small-batch production model, with its ability to reduce production waste and closely align with market demands, has attracted many enterprises to transition to this model.

The significant increase in product diversity has brought a series of pressing issues for enterprises to address. Traditional mass production methods struggle to adapt to rapid market changes, while single-item, small-batch production suffers from inherent inefficiencies [4]. In today's fiercely competitive market environment, enterprises can no longer rely solely on advanced equipment and new technologies to secure a dominant position.

Lean production originated in the mid-20th century at Toyota Motor Corporation in Japan. Its core principle is just-in-time production, emphasizing the elimination of various forms of waste in the production process, cost reduction, and continuous improvement to maximize production efficiency and profitability [5-6]. Compared to mass production, lean production differs significantly in logistics triggering mechanisms, inventory control strategies, and management philosophies. As a distinct production organization and management technology, lean production's success lies in its people-oriented, customer-centric, and demand-driven core principles, which minimize waste and work-in-progress inventory, effectively reducing production costs. However, in a multi-variety, small-batch production environment, the complexity of production scheduling and planning leads to prolonged pre-production preparation times, extended delivery cycles, and difficulties in ensuring product quality, with many quality issues remaining unresolved. Against this backdrop, this paper focuses on exploring how to optimize the lean production model to better adapt to multi-variety, small-batch production environments, thereby helping enterprises enhance economic efficiency and market competitiveness.

2. Literature Review

2.1 The Origin and Development of Lean Production

The concept of lean production originated from the Toyota Production System (TPS) developed by Toyota Motor Corporation in Japan. In this context, after in-depth investigation and research, Toyota pioneered a new production method that was fundamentally different from the traditional mass production of the West. Based on the philosophy of lean production, Toyota established the basic principles of Just-In-Time production. JIT defines the relationship between suppliers and demanders in production activities, providing a forward-looking benchmark for various production management models in coordinating the production activities of both parties, while also serving as a constraint mechanism. As an idealized state of production, JIT leaves ample room for the continuous improvement of the production system. The birth of lean production completely overturned traditional manufacturing concepts, prompting the industry to examine the production process from a new perspective and with new methods. Its impact is broad and profound, not only changing the way people live and work in social production but also reshaping the paradigm of thinking about problems. In the automotive and related industries, lean production, following Ford's assembly line, triggered another milestone transformation, hailed as the "Second Revolution in Production Methods." Many scholars, through in-depth research on Toyota's development history, have detailed the evolution of lean production from its inception to gradual maturity, revealing its key characteristics and innovative practices at different stages.

2.2 Multi-Variety Small-Batch Production Mode

With the continuous development of the global economy, the world market has shown an overall trend of oversupply. The deepening degree of market segmentation and the increasingly significant trend of consumer diversification have compelled manufacturing enterprises to actively adapt to these changes. Since the market demand remains relatively stable over a certain period, consumer demand increasingly exhibits personalized and diversified characteristics, this directly leads to a corresponding decrease in the market demand for single products. Based on this, the production methods of enterprises are gradually shifting towards a multi-variety small-batch production mode.

2.2.1 Characteristics of Production Dimension

In the multi-variety small-batch production mode, the product types are diverse and the production batches are small, with products being highly targeted in their applications. Enterprises need to have the ability to respond quickly to orders and adopt a pull production strategy, which means conducting production activities based on market demand signals and replenishing inventory only when necessary to ensure that the produced goods can be sold in a timely manner. This mode demonstrates strong market adaptability but also faces issues of instability. Due to the complexity of product types, low frequency of repetitive production, and small batch sizes, establishing standardized production lines is challenging, placing high demands on the precision, flexibility, and coordination of production management. From a production process perspective, multi-variety small-batch production is a typical discrete processing and assembly type of production. The production process involves the processing and assembly of numerous components, with complex and variable procedures, making the organization and coordination of the production flow quite difficult.

2.2.2 Characteristics of Quality Dimension

Multi-variety small-batch production adheres to the concept of build-to-order, customizing products based on the personalized needs of customers. Due to the diversity of orders, products have lower universality and stronger specificity. As the market evolves, consumer demand has gradually shifted from mere quantity requirements to a focus on product quality. This requires enterprises to provide a wide range of high-quality product options for different levels of customers, posing significant challenges to the quality control systems of enterprises. In the current competitive market environment, enterprises must rapidly introduce high-quality, low-cost products to achieve sustainable development. Therefore, ensuring the stability and reliability of product quality during the production process has become a core element for gaining a competitive advantage in the multi-variety small-batch production mode.

2.3 Methods of Lean Production

Lean production is a comprehensive concept that focuses on the core objective of improving the production status, eliminating waste, and achieving continuous improvement by applying a series of scientific methods to the overall production and related activities of an enterprise [7-8]. Common methods include the 5W1H analysis, ECRS principles, KANBAN management, Six Sigma, and 5S management.

2.3.1 5W1H Analysis Method

The 5W1H analysis method plays a crucial role in the analysis and decision-making support during the production planning process. This method focuses on six key elements: what to do, why to do it, when to do it, where to do it, who will do it, and how to do it. By thoroughly examining these elements, it provides a comprehensive understanding of the current situation of production issues, thereby offering a scientific basis for formulating production execution plans and determining the necessary measures to be taken.

2.3.2 ECRS Four Principles

After completing the decision-making process based on the 5W1H analysis, the production improvement process should adhere to the four principles of ECRS: Eliminate, Combine, Rearrange, and Simplify. The Eliminate principle aims to achieve optimal results by removing unnecessary investments and project tasks, striving to reduce waste at its source. When tasks cannot be directly eliminated, the Combine principle becomes the focus of optimization, which involves integrating identical or similar tasks to effectively avoid the waste caused by dispersed work. For tasks that cannot be eliminated or combined, the Rearrange principle involves scientifically analyzing and reasonably adjusting the sequence of operations to achieve the optimal order under existing conditions [9]. The Simplify principle seeks to find the most straightforward and efficient way to execute tasks after elimination, combination, and rearrangement, thereby enhancing work efficiency. In a multi-variety small-batch production environment, the flexible application of the ECRS principles helps optimize complex production processes and improve the precision of production management.

2.3.3 KANBAN Management Method

The KANBAN Management Method is a management approach that utilizes KANBAN cards to facilitate on-site management and production scheduling. As a medium for information transmission, KANBAN cards accurately and succinctly convey work instructions. Within the lean production management system, the principle "no production without KANBAN, no transportation without KANBAN " is crucial. All production and transportation activities are conducted based on KANBAN instructions, effectively preventing overproduction and inefficient transportation. The KANBAN Management Method is a core component of Just-In-Time production. Through visual information transmission and production control, it achieves precise coordination and efficient operation of the production process. In a multi-variety, small-batch production model, the KANBAN Management Method can provide real-time updates on production progress and material requirements, enhancing transparency and controllability in the production process. Its effectiveness has been thoroughly validated through practical applications in numerous enterprises.

2.3.4 Six Sigma Methodology

The Six Sigma Methodology is oriented towards continuous improvement, aiming to streamline workflows and minimize error rates to the greatest extent possible. From the procurement of raw materials to the completion of product manufacturing, this method systematically identifies and eliminates the impact of adverse factors, effectively improving process capability, significantly reducing or even eliminating defective products, and markedly enhancing product quality levels. As quality improves, enterprise production costs are reduced, and customer satisfaction increases accordingly. In the context of a multi-variety, small-batch production model, the stability and consistency of product quality are of paramount importance. The Six Sigma Methodology provides enterprises with a powerful tool for achieving high-quality production.

2.3.5 5S Management

Seiri (Sort): By clearly distinguishing between necessary and unnecessary items, unnecessary items are removed from the production environment, optimizing the layout of the production space and reducing interference factors during the production process. This creates favorable conditions for efficient production.

Seiton (Set in Order): Emphasizes the rapid location of required items in the shortest possible time. By rationally planning the placement of items and the identification system, the time cost of searching for items is minimized, enhancing production efficiency.

Seiso (Shine): Requires employees to ensure that their workstations are kept clean, free of waste and dust accumulation. This creates a tidy production environment, which helps to boost employee motivation and reduces potential quality issues caused by environmental problems.

Seiketsu (Standardize): On the basis of Seiri, Seiton, and Seiso, a comprehensive standardization system is established to ensure the continuous optimization of the production environment and workflow. This promotes transparency in management and enhances the overall management level of the enterprise.

Shitsuke (Sustain): Focuses on cultivating the spiritual culture and professional qualities of employees, encouraging them to consciously abide by the company's rules and regulations. The 5S management philosophy is internalized into the daily behavior habits of employees, forming a good corporate production culture atmosphere. In multi-variety, small-batch production enterprises, 5S management can effectively improve the management level of the production site, enhance the cohesion and execution of the enterprise, and its positive role has been fully demonstrated in the practices of numerous enterprises.

3. Issues in Multi-Variety Small-Batch Production Methods

3.1 Production Challenges

3.1.1 High Complexity in Production Organization Activities

In multi-variety, small-batch production, the number of product types increases significantly, and the work pieces required for different products vary greatly. Due to the small production batches, the connection between processes is not tight, leading to prolonged waiting times and disrupted production continuity. A significant amount of time is spent on non-value-added activities such as equipment setup and material handling, resulting in low production efficiency and a substantial extension of production lead times.

The processing routes and technical parameters for different types of parts are highly diverse, requiring a wide range of production equipment types and functionalities. To meet the diverse needs of product processing, the production environment must possess a high degree of flexibility and adaptability, which undoubtedly greatly increases the complexity of production organization. From the perspective of production resource allocation, resources such as equipment, labor, and materials need to be frequently switched between different production tasks, significantly increasing the difficulty of resource scheduling.

3.1.2 Urgent Need for Improvement in On-site Management

In the process of multi-variety and small-batch production, the production and processing stages involve a wide range of materials, and the flow of goods on-site lacks effective planning, resulting in a chaotic and disordered state. The phenomenon of work-in-progress (WIP) accumulation is quite common, and the scheduling of process times lacks scientific rigor, which can easily lead to imbalances in

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the production process. This not only reduces production efficiency but may also pose threats to equipment safety and personal safety due to material pile-ups and abnormal equipment operations, thereby increasing the risk of accidents.

On the production floor, the use and placement of tools lack standardization, and employees have insufficient awareness of the importance of on-site management, leading to delays in the transmission of production task information. This not only extends the production cycle but also negatively impacts product quality and value. The disordered workshop environment makes the transfer of WIP between processes extremely difficult, further hindering the smooth progression of the production process and increasing potential safety hazards, such as item tipping and personnel collisions, which occur frequently. Numerous enterprise practices have shown that good on-site management can effectively enhance production efficiency, ensure product quality, and safeguard personnel safety. However, the weak links in on-site management under the multi-variety and small-batch production model severely restrict the improvement of enterprise production efficiency.

3.2 In terms of quality

3.2.1 Weakness in Quality Control System of Production Process

In the multi-variety and small-batch production model, frequent loading and unloading operations and repeated tool changes are prominent characteristics, which can easily introduce quality risks. Currently, some enterprises primarily rely on random sampling for quality control, lacking sufficient emphasis on full-process quality management. The absence or inadequacy of quality control measures makes it difficult to detect potential quality issues in a timely manner, leading to a significant increase in after-sales maintenance workload. This not only results in unnecessary financial losses for enterprises but also negatively impacts their brand image. Taking the electronics industry as an example, work-in-progress (WIP) during production often consists of small components. Minor deviations in employee operations or unreasonable tool designs can damage materials, ultimately affecting the final product quality.

Some enterprises, in an effort to reduce costs and cut management expenses, fail to fully recognize the importance of product quality as the foundation for their market presence. Reducing investment in quality control essentially undermines the core value of the enterprise and its products, which is highly detrimental to long-term development. Conducting quality inspections only at the final stage of production has two major drawbacks: first, it is easy to overlook quality issues accumulated during earlier stages of production, leading to inspection errors; second, once quality issues are identified, they often result in significant waste of raw materials.

3.2.2 Challenges in Material Quality Control

During the production preparation phase, enterprises often rely on qualitative analysis for supplier selection decisions, lacking systematic quantitative evaluation. This leads to inconsistent quality of purchased raw materials. In multi-variety and small-batch production, frequent material changes increase the likelihood of issues such as incorrect material usage or inherent material defects. Given the high investment costs of production equipment, enterprises typically do not adjust product types easily in the short term. Therefore, it is crucial to establish clear and scientific selection criteria for suppliers of different product varieties. Inappropriate suppliers can not only delay production schedules but also severely impact product quality.

Under the multi-variety and small-batch production model, the wide variety of materials makes it challenging to ensure material quality during procurement. Currently, some enterprises overly focus on price factors in the procurement process, even using price as the sole criterion for supplier selection, while neglecting material quality and other critical factors. This unreasonable procurement strategy seriously threatens product quality. Enterprises should comprehensively consider factors such as material quality, supplier reputation, and supply stability in procurement decisions to ensure that purchased materials meet production requirements. Only by guaranteeing the quality of procured materials can Total Quality Management in the production process truly function effectively.

3.3 Material Aspects

3.3.1 Instability in Material Procurement and

Its Causes

Under the multi-variety and small-batch production model, the diversity of products and limited production quantities lead to frequent changes in material procurement. Insufficient procurement can directly hinder production progress, while excessive procurement results in inventory buildup, wasting storage space and increasing capital costs. Enterprises often lack scientific and rational planning in material procurement, failing to accurately differentiate the importance of materials, which significantly increases the complexity and difficulty of management.

The root cause lies in the inadequate coordination mechanisms and insufficient communication between internal departments. Enterprises operating in multi-variety and small-batch production often face a market environment with high order randomness. In such a context, the ability of departments to respond promptly and collaborate effectively becomes critical. Any deviation in material procurement planning, production demand communication, or supplier interaction can lead to missed delivery deadlines and lost orders.

3.3.2 Waste Issues Caused by Unreasonable Material Inventory

Given the continuous and dynamic changes in market demand and the shortening product life cycles, excessive inventory can lead to material depreciation or even obsolescence due to technological advancements or shifts in consumer preferences. This often results in write-offs, causing financial losses for enterprises. Whether through discounted sales or outright disposal, excessive inventory leads to significant economic losses, severely compressing profit margins and weakening the enterprise's competitive position in the market.

For example, in the electronics industry, where technological iterations are rapid and product updates frequent, the losses caused by excessive inventory are particularly severe. For enterprises focused on specific products, if materials are procured and stored in advance without confirmed orders, and no orders are received over an extended period, additional costs for material maintenance and storage will be incurred, increasing overall production costs.

4. Application of Lean Production in Multi-Variety and Small-Batch Production Models

4.1 Lean Optimization of On-site Management

4.1.1 Strengthening the Dissemination and Knowledge Update of Lean Production Concepts

Actively promote and educate employees on lean production concepts across all workshops, establishing lean production as the core guiding principle. Workshop managers should continuously learn about lean production systems and propose innovative management approaches tailored to the workshop's actual conditions, providing intellectual support for on-site management optimization.

4.1.2 Customizing Implementation Plans and Guidelines Aligned with Workshop Realities

Develop detailed and actionable lean production implementation plans and guidelines based on the workshop's actual production conditions and strategic goals. Define overall objectives and phased tasks, allocate resources rationally, and ensure the steady advancement of lean production practices. This process should consider factors such as equipment status, employee skill levels, and production process characteristics to ensure the scientific and effective implementation of the plan.

4.1.3 Optimizing Workshop Layout Planning

Design a scientific and rational workshop layout, precisely dividing production areas and optimizing equipment placement based on product processes and production needs. A well-planned layout reduces material handling distances, enhances production flow continuity, and minimizes non-value-added activities.

4.1.4 Deepening the Implementation of the 5S Management System

Gradually expand the successful practices from these pilot zones to the entire workshop. Systematically organize tool placement based on "5S" principles, continuously improve the work environment and processes, and assign clear responsibilities to ensure refined and efficient management.

4.1.5 Continuous Improvement and Waste Elimination

Use the 5W1H analysis method to identify and eliminate over-service and waste in production processes. Apply the ECRS (Eliminate, Combine, Rearrange, Simplify) principle to review production activities, eliminating unvalued and added tasks. Introduce a KANBAN management system to clarify production tasks and reduce waiting time caused by task ambiguity. Establish standardized work methods and process standards to eliminate inefficiencies and resource waste caused by improper practices.

4.2 Lean Transformation of Quality Management

4.2.1 Establishing Customer-Centric Quality Philosophy

Recognize that product quality is a core value and prioritize customer quality requirements. Conduct in-depth market research to understand customer expectations and use this as the basis for setting quality standards and production strategies, ensuring products meet customer needs and enhance satisfaction and loyalty.

4.2.2 Building Full Quality Monitoring System

Move beyond traditional end-product inspection and implement quality control throughout the entire production process. Strictly monitor each stage, from raw material procurement and production processing to product assembly and final inspection, to identify and resolve potential quality issues early, preventing the accumulation and escalation of defects.

4.2.3 Promoting Full Employee Participation in Quality Control

Encourage all employees to participate in quality inspection and control, strengthening their sense of responsibility. Through training and incentives, help employees understand the impact of their work on product quality, fostering a culture of quality awareness and control, which is essential for achieving Total Quality Management.

4.3 Lean Upgrade of Material Management

4.3.1 Building an Information-Based Material Management Platform

Classify and statistically analyze materials, scientifically planning storage locations based on material characteristics and usage frequency to ensure efficient retrieval. Newly procured materials should be promptly and accurately entered into the system by the procurement department, with designated personnel responsible for maintenance. Update system data immediately when material specifications change to ensure accuracy. Improve the precision of the Bill of Materials and reduce the frequency of BOM changes. Enable integrated material information queries to quickly access relevant data. Establish dynamic links with warehouse management software for real-time inventory updates.

4.3.2 Implementing Categorized Material Procurement Strategies

Classify materials into bottleneck, strategic, general, and leverage categories based on demand and importance, and develop corresponding procurement strategies:

Bottleneck Material Strategy: For large enterprises, strengthen partnerships with high-quality suppliers through equity participation or joint procurement with peers to enhance supply stability and negotiation power.

Strategic Material Strategy: Focus on building long-term, stable relationships with strategic material suppliers, emphasizing on-time delivery, cost improvement, and innovation capabilities.

General Material Strategy: For less critical materials, use trading companies as agents to save costs and simplify management, prioritizing service levels, quality stability, and on-time delivery over price.

Leverage Material Strategy: For materials with ample supply and low differentiation, prioritize cost control and maintain a flexible supplier selection process, establishing backup suppliers for stability and mutual benefit.

Enterprises should adopt a balanced production model to improve material turnover rates, eliminate equipment idle time and material waste caused by production imbalances, and avoid quality instability during equipment changeovers. Balanced production is the foundation for KANBAN management, enabling JIT and pull-based material management. By breaking down monthly production plans into daily plans and controlling production rhythms, inventory levels and waste can be reduced. Daily plan fluctuations should be kept within 20% to ensure production stability and continuity.

5. Conclusions

This paper explores the application of lean production principles to the multi-variety and small-batch production model, guided by the core concepts of continuous improvement and waste elimination, with the ultimate goals of zero waste, zero inventory, and high quality. From the perspectives of production management, quality management, and material management, the paper systematically optimizes and improves production processes, quality control systems, and material management strategies using lean production tools and methods.

In production management, lean optimization measures, starting from production line layout improvements and integrating process specialization, object specialization, and group production units, combined with 5S on-site management, effectively eliminate waste in both manufacturing and management processes, significantly enhancing production efficiency and resource utilization.

In quality management, a lean-based Total Quality Management system shifts the traditional focus from inspection to process control. By establishing and continuously improving quality system mechanisms, product defect rates are reduced, and quality stability and reliability are enhanced.

In material management, lean material management strategies, supported by an information-based platform and differentiated procurement approaches, optimize material flow through KANBAN management and pull-based production. This reduces inventory and material handling waste, lowering operational costs.

In summary, the coordinated application of lean production principles across production, quality, and material management helps multi-variety and small-batch production enterprises improve overall operational efficiency and market competitiveness. The findings of this paper provide valuable insights and practical guidance for enterprises transitioning to this production model, supporting sustainable development in a complex and dynamic market environment.

References

[1] V. G. Cannas., P. Rossella., S. Nicol., et al. Unveiling the interaction among circular economy, industry 4.0, and lean production: A multiple case study analysis and an empirically based framework [J]. International Journal of Production Economics, 2025, 282.

[2] E. Afum., Y. Li., P. Han., Z. Sun. Interplay between lean management and circular production system: implications for zero-waste performance, green value competitiveness, and social reputation[J]. Journal of Manufacturing Technology Management, 2022, 33 (7): 1213-1231.

[3] U. Awan., R. Sroufe., M. Shahbaz. Industry 4.0 and the circular economy: a literature review and recommendations for future research. Business Strategy and the Environment, 2021, 30 (4): 2038–2060.

[4] X. Xue., N. Hu., F. Qiu., et al. Chief operating officers' long-term orientation and corporate lean production[J]. Journal of Business Research, 2025, 191.

[5] A. Arash., P.C. Patel., Z. Abouzar ., L. Kevin. The effect of environmental complexity and environmental dynamism on lean practices [J]. Journal of Operations Management, 2013, 31 (4):193-212.

[6] M. Bevilacqua., F.E. Ciarapica., I. Sanctis. Lean practices implementation and their relationships with operational responsiveness and company performance: an Italian study [J]. International Journal of Production Research, 2016, 55(3): 769-794.

[7] C. Castiglione E. Pastore., A. Alfieri. Technical, economic, and environmental performance assessment of manufacturing systems: the multi-layer enterprise input-output formalization method [J]. Production Planning and Control, 2022, 35 (2): 133-150.

[8] C. Vasanthakumar, S. Vinodh., K. Ramesh. Application of interpretive structural modeling for analysis of factors influencing lean remanufacturing practices [J]. International Journal of Production Research, 2016, 54 (24): 7439-7452.

[9] G. L.Tortorella., D. Fettermann., F. S. Fogliatto., et al. (2020). Analysing the influence of organisational culture and leadership styles on the implementation of lean manufacturing [J]. Production Planning & Control, 2020, 32(15): 1282-1294.