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Lean and Green: The Impact of Lean Production Systems on Sustainability in the Manufacturing Sector

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ABSTRACT

This paper analyzes the impact of the Toyota Production System (TPS) on market expansion and brand value by increasing efficiency and addressing environmental issues. Toyota has based TPS production on two fundamental principles: just-in-time (JIT) and automation. In particular, the TPS principles of waste elimination and improvement are recognized as a sustainable business model. This study investigated the impact of Toyota's production efficiency and achievement of environmental targets on the company's brand value through a quantitative approach using a questionnaire survey of 150 general consumers. The study found that the TPS, through its lean and green production methods, has changed the public's view of manufacturing sustainability and provides a valuable model for the sustainable development of the industry as a whole. Toyota's production system efficiency improvement methods and approach to environmental issues have had a very positive impact on market expansion and brand value. The findings will contribute to the promotion of Toyota's continued development in the global automotive market and the ongoing enhancement of its brand value.

Keywords: Brand Value; Consumer Perception; Environmental Sustainability; Lean Manufacturing; Market Expansion; Sustainable Development; Toyota Production System

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INTRODUCTION

Toyota Motor Corporation, founded in 1937 by Kiichiro Toyoda, has evolved into one of the most globally recognized and respected automobile manufacturers. Headquartered in Toyota City, Japan, the company is widely known not only for its high-quality, durable vehicles but also for its strategic leadership in innovation and operational excellence. A defining feature of Toyota's global success is its pioneering development of the Toyota Production System (TPS), a management philosophy that emphasizes efficiency, quality, and continuous improvement (Wada, 2020). TPS has not only transformed Toyota's internal operations but has also had a profound impact on global manufacturing practices, becoming a benchmark for lean production strategies across industries.

The foundation of Toyota's success lies in the alignment of its operational practices with broader corporate values, particularly its strong commitment to sustainability and innovation. Toyota has consistently integrated environmentally responsible strategies throughout its value chain—from product design to manufacturing—ensuring that sustainability is not treated as an add-on but as a core operational principle. TPS is a key driver of this integration, emphasizing the reduction of all forms of waste while maximizing productivity. This operational philosophy has generated measurable environmental benefits, demonstrating that efficiency and ecological responsibility are not mutually exclusive goals. As a result, TPS has inspired numerous organizations worldwide to adopt similar lean-based frameworks for achieving sustainable operations (Toyota Motor Corporation, 2023).

One of the hallmark tools within TPS is the just-in-time (JIT) inventory system, which epitomizes the system's focus on reducing waste and optimizing resource use. JIT ensures that production components are delivered exactly when needed, thereby minimizing the need for extensive inventory storage and the energy required to maintain large warehousing facilities. This approach significantly reduces overproduction, excess inventory, and unnecessary energy consumption, thereby contributing to environmental sustainability alongside operational efficiency (Ohno, 1982).

Toyota's management philosophy is further reinforced by 14 guiding principles that advocate for process standardization, employee empowerment, long-term thinking, and mutual respect for partners and suppliers. These principles form the backbone of TPS and are embedded in the company's culture of continuous improvement, or kaizen, which has allowed Toyota to evolve sustainably while maintaining competitiveness (Liker, 2020). The synergy between lean thinking and environmental stewardship has been pivotal in reinforcing Toyota's dual commitment to economic and ecological outcomes.

Given increasing global concerns regarding climate change, environmental degradation, and resource scarcity, the relevance of sustainable manufacturing has become more urgent than ever. In this context, TPS serves as a compelling model for other manufacturers seeking to balance operational efficiency with environmental accountability. Studies have shown that lean systems like TPS can play a significant role in promoting green manufacturing by minimizing emissions, reducing energy consumption, and optimizing material usage (Reke et al., 2022). Furthermore, TPS aligns closely with sustainability goals without compromising on profitability, making it an attractive model for companies aiming to improve environmental performance while sustaining competitive advantage (Inman & Green, 2018; Rother & Shook, 2003).

The objective of this study is to critically examine the role of the Toyota Production System in promoting sustainable manufacturing practices and enhancing environmental

performance. It seeks to explore how TPS principles and tools—particularly those focused on waste reduction, process efficiency, and continuous improvement—contribute to environmental sustainability in industrial settings. The significance of this study lies in its ability to bridge the gap between lean manufacturing and green practices, offering valuable insights for both practitioners and scholars. The novelty of this research stems from its integrated focus on operational efficiency and ecological responsibility, highlighting how TPS can be strategically leveraged to support global sustainability goals.

This study contributes to the literature by providing a conceptual and practical understanding of how TPS functions as a tool for sustainable development. It offers a reference model for manufacturers seeking to embed environmental considerations into their operational systems, while also contributing to academic discourse at the intersection of lean production and environmental management (Hines & Taylor, 2000). Ultimately, this research underscores that sustainable success in the manufacturing sector is achievable when operational excellence is combined with environmental foresight.

LITERATURE REVIEW

This review examines the pillars of TPS, such as JIT and automation, as well as the impact and application of lean production systems based on these pillars. It then critically reviews the results of existing research and makes reference to future research questions.

Basic principles of TPS

According to the research, TPS was developed as a unique production management method adapted to the economic situation in Japan. Its axes are JIT, which supplies the required goods in the required quantities at the required time, and Autonomation, which features automatic detection of defective goods and problems. These are intended to reduce waste, improve quality, and significantly increase the competitiveness of the manufacturing industry as a whole (Fujimoto, 2012; Ohno, 1982). However, these methods are noted to be challenging to apply, as they require a high degree of management competence and worker training; skilled workers and cultural adaptation are essential for TPS to be successful (Liker & Hoseus, 2011). It has also been noted that prioritizing short-term gains too much in the implementation of JIT may increase the vulnerability of the entire supply chain (Shah & Ward, 2003). We will study the impact of these initiatives on market expansion and brand value, but it is necessary that the basic principles of TPS are recognized and understood by the general public. We therefore present this basic principle as a common understanding.

Sustainability and the TPS

The sustainability of TPS is presented in the reference literature as TPS playing an important role through waste reduction and energy efficiency. First, Palhau et al. (2024) report that companies adopting TPS achieve both reduced environmental impact and economic benefits. In addition, integration with lean production methods strengthens the environmental sustainability of the entire supply chain (Johansson & Sundin, 2014). However, the challenge is that indicators to directly measure the sustainability perspective are lacking in TPS research. Although studies in the reference literature quote waste reduction as a contribution to the environment, quantitative data on specific energy efficiency and carbon emission reductions are lacking.

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Carbon Reduction in TPS

Toyota has set targets and various initiatives to achieve carbon neutrality (Toyota Motor Corporation 2023). The table below shows the CO_2 emissions between 2021 and 2023 (Table 1).

Table 1. Trends in CO_2 Emissions (million t-CO_2)

	2021	2022	2023
Scope 1	2.48	2.37	2.56
Scope 2	3.39	2.87	2.87

The calculation of trends in CO_2 emissions at Toyota is conducted in accordance with the market-based approach outlined by the Greenhouse Gas (GHG) Protocol. This method ensures that emissions data reflect the environmental impact associated with the specific energy sources procured by the company. The organizational boundary for these calculations includes Toyota Motor Corporation as well as all of its consolidated subsidiaries, providing a comprehensive view of emissions across the entire corporate group. The scope of the emissions measured focuses specifically on energy-related CO_2 emissions, which are a major contributor to the company's overall environmental footprint. The period covered for the emissions data corresponds with Toyota's financial reporting cycle, spanning from April 1 to March 31 each year. This alignment allows for consistent tracking and comparison of emissions trends over time within the context of Toyota's annual operational performance.

Scope 1 shows direct emissions, such as fossil fuel use, from Toyota's production facilities. Scope 2 represents indirect emissions from energy purchases, such as electricity, associated with production activities. CO_2 emissions increased in 2023, mainly due to the largest ever production volume, but Toyota is continuing to promote reduction initiatives. Scope 3 represents greenhouse gas emissions generated throughout the company's supply chain (Table 2)

Table 2. Certification and Approval of Targets from SBTi

Emissions		Target Year	Base Year	Reduction Rate	Validation/Approval Class
Scope 1 and 2		2035	2019	68%	1.5°C
Scope 3, category 11 (emission intensity)	Passenger light duty vehicles and light commercial vehicles	2030		33.3%	Well Below 2°C
	Medium and heavy freight trucks			11.6%	

The company aims to reduce CO_2 emissions over the entire lifecycle through hybrid and electric vehicle (EV) technology. In April 2023, Toyota announced that it aims to reduce average GHG emissions from driving new vehicles sold worldwide by 33% in 2030 and by more than 50% in 2035 (compared to 2019). As of March 2022, the company has deployed electric and other vehicles, which contribute to a reduction of approximately 162 million tons of CO_2 emissions.

This means that TPS contributes to optimizing energy efficiency. First, the reduction of inventories through JIT leads to a reduction in the energy required for warehouse management. Then, the increased efficiency of the production line leads to a reduction in machine uptime and energy consumption (Liker & Morgan, 2006) while the increased efficiency of JIT brings short-term results, it also leads to the achievement of carbon

reduction targets in the long term. The above shows that TPS directly contributes to reducing environmental impact.

Global application

The TPS philosophy has been adopted by companies all over the world, and lean manufacturing methods are widely used in the manufacturing industry in North America and Europe. It is particularly being applied to non-manufacturing sectors such as healthcare and the service industry (Psomas, 2022). This has positioned TPS beyond mere manufacturing processes as an optimization tool for overall organizational operations. However, there are cultural and organizational challenges in applying TPS (Holweg, 2007). For example, Western companies have a culture that emphasizes worker autonomy and rights, which may differ from the hierarchical management model of TPS (Cusumano, 1994). In addition, because the global development of TPS requires customization according to regional characteristics, the process is often not systematized.

Discrepancies

Some studies in the reference literature explain that TPS directly contributes to improved sustainability (Villadiego et al., 2022). In particular, waste reduction and efficiency gains are said to lead to a reduction in environmental impact. However, other studies explain that the contribution of TPS to sustainability is mainly indirect. No specific energy efficiency or carbon reduction figures are given. Some studies also state that TPS is successful regardless of cultural background, and in particular, emphasize that the basic principles (JIT and self-employment) are common. However, some studies point to friction with respect to workers' autonomy and rights in different cultures (Muniz et al., 2022). This friction has been identified as a potential barrier to the success of TPS. In other words, the different cultural backgrounds of the countries and companies studied have led to variations in results (Hines et al., 2004). There are also studies that show that TPS reduces the burden on workers and improves efficiency. While some say that standardized processes prevent errors and reduce stress, other studies show that the over-efficiency of TPS increases the burden on workers. It also warns that it may lead to reduced motivation.

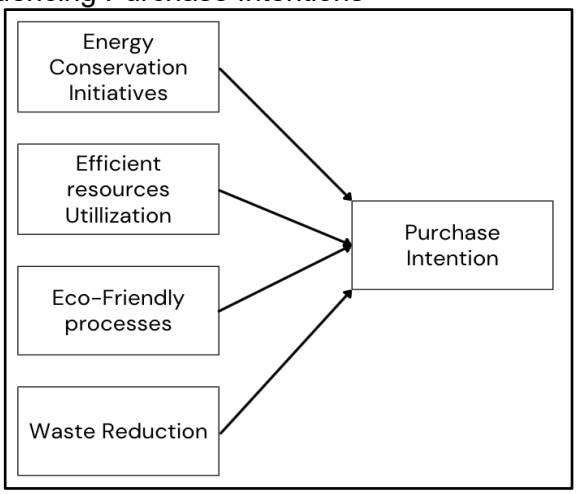
Through the above literature review, it is clear that TPS is a tool that enables both sustainability and efficiency in manufacturing. In other words, the TPS has proved to be a real and applied approach to efficiency and environmental issues. On the other hand, it was also found that challenges exist in adapting this to other industries and different cultures. The following points need to be addressed when conducting future research on TPS: first, to identify uniform indicators, for example, when measuring sustainability and impact on workers (Shah & Ward, 2007); second, to compare case studies of implementation in different cultures and industries. This is necessary to determine similarities and differences, and to find out how consumers perceive Toyota's production efficiencies. The third is to consider not only short-term results but also long-term impacts (Kumar & Mathiyazhagan, 2020). Environmental issues in particular require long-term research. As Toyota is undertaking various initiatives in the short, medium, and long term, this will have an impact on the brand value (Liker, 2020).

RESEARCH METHOD

This study considers methods for analyzing the impact of the TPS's efficiency and environmental initiatives on brand value. Brand value is linked to consumers' willingness to purchase. For this reason, this study considers the following figures (Figure 1) as leading to willingness to purchase. Waste reduction, efficient resource utilization, eco-

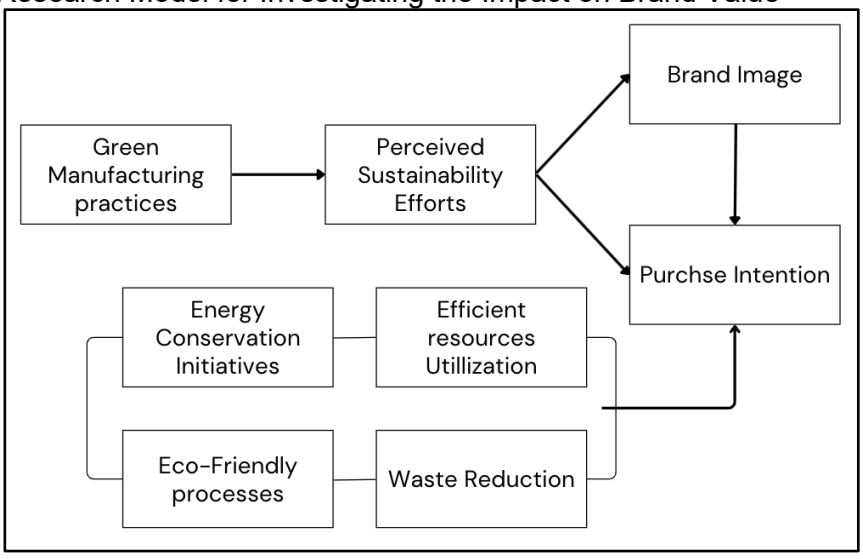
friendly processes, and energy conservation initiatives are considered to be linked to consumers' willingness to buy (Hart, 1995).

Figure 1. Models Influencing Purchase Intentions



A quantitative survey of 150 general consumers is then conducted for the study (Appendix 1). Figure 2 is a research model to investigate the impact of Toyota's production efficiency and achievement of environmental targets on the company's brand value.

Figure 2. Research Model for Investigating the Impact on Brand Value



Green manufacturing practice refers to environmentally friendly manufacturing processes. Green manufacturing practice then leads to perceived sustainability efforts (Nguyen et al., 2017; Rizki & Hartanti, 2021). The arrow from green manufacturing practice to perceived sustainability efforts indicates the extent to which consumers are aware of this company's commitment to environmentally friendly manufacturing processes (Reddy et al., 2023). The arrow from perceived sustainability efforts to brand image indicates how much the company's efforts affect the brand value. The arrows from perceived sustainability efforts to brand image refer to the extent to which a company's efforts influence its brand value. Green manufacturing and environmental friendliness must be perceived as a positive impression by consumers (Chen, 2010). The arrow from perceived sustainability efforts to purchase intention indicates that consumers'

perception of a company's efforts will increase their willingness to purchase the product. Finally, the arrow from brand image to purchase intention indicates that a positive brand image is a factor that increases consumers' purchase intentions. Google Forms was created, and a sample was collected for this survey, using a Likert scale to rate consumer perceptions, perceptions about TPS, etc., on a five-point scale. The collected sample will then be analyzed to deepen the research.

RESULTS

Descriptive Analysis

Analysis of Yes/No Questions

The analysis of yes/no questions provides insight into participants' perceptions of Toyota's production methods and environmental practices. Table 1 summarizes the responses to these questions.

Table 3. Descriptive Statistics for Demographics and Yes/No Questions (N=150)

Question	Yes (%)	No (%)
Efforts to reduce waste impact product quality and costs	68.7	31.3
TPS changed sustainability thinking	62.0	38.0
Efficient production methods improved brand value	75.3	24.7
Waste reduction influences buying willingness	70.7	29.3
Other companies should adopt Toyota's methods	81.3	18.7

According to the data in Table 3, most participants agreed with the positive impacts of Toyota's production system. A total of 68.7% believed that efforts to reduce waste improve product quality and reduce costs, while 62% felt that the TPS has influenced their views on sustainability in manufacturing. In addition, 75.3% of respondents agreed that efficient production methods have enhanced Toyota's brand value, and 70.7% stated that waste reduction efforts affect their purchasing decisions. The highest level of agreement came from 81.3% of participants who believed that other companies should adopt Toyota's methods. These findings reflect the participants' strong recognition of TPS as an effective system that promotes efficiency, supports sustainability, and strengthens brand reputation.

Likert Scale Questions Analysis

The analysis of Likert scale questions captures participants' agreement levels regarding various aspects of Toyota's production practices. Table 4 provides a summary of the mean and standard deviation (SD) for each question.

Table 4. Mean and Standard Deviation for Likert Scale Questions (1-5)

Question	Mean	SD
The TPS is an efficient	4.2	0.7
Toyota's JIT system contributes to improved product quality	4.1	0.8
Eliminating waste in Toyota's production process is key to success	4.3	0.6
The Toyota Production System considers environmental issues	3.9	0.9
Toyota is actively addressing environmental issues	4.0	0.8
Toyota's efforts to meet environmental goals are trustworthy	4.2	0.7
The Toyota Production System contributes to sustainability in manufacturing	4.1	0.7
Efficiency and environmental considerations influence my purchasing decisions	4.1	0.8

Note: Mean scores range from 1 (Strongly Disagree) to 5 (Strongly Agree)

Based on the data in Table 4, participants generally viewed the TPS positively. The statement about TPS being efficient received a high mean score of 4.2, showing that many respondents agree that the system is effective. The highest score, 4.3, was given to the idea that eliminating waste is key to Toyota's success, highlighting how strongly waste reduction is seen as a core strength of their operations. When it comes to environmental aspects, respondents moderately agreed that TPS considers environmental issues (mean 3.9), suggesting some awareness but also indicating that Toyota could enhance its environmental image further. However, stronger agreement was observed for Toyota's active role in addressing environmental issues (mean 4.0) and trust in their efforts to meet environmental goals (mean 4.2), reflecting overall confidence in the company's environmental initiatives. Additionally, sustainability-related perceptions were quite strong, with statements about TPS contributing to sustainable manufacturing and environmental considerations influencing consumer purchasing decisions both receiving a mean score of 4.1. This suggests that Toyota's practices are not only seen as efficient but also aligned with sustainability and consumer values.

Combined Insights from Yes/No and Likert Scale Questions

The combined analysis of Yes/No and Likert scale questions reveals a generally positive perception of Toyota's production practices. The findings consistently show that the TPS is regarded as highly efficient, with respondents agreeing that it contributes positively to product quality, cost control, and overall success. In terms of environmental impact, the results indicate that while participants acknowledge Toyota's efforts in addressing environmental issues, there is slightly less agreement on whether these efforts are fully sufficient. This is reflected in the relatively lower mean score of 3.9 for the statement regarding environmental consideration. Furthermore, the data suggests that Toyota's production practices significantly influence consumer attitudes. High levels of agreement with statements related to brand value and purchasing decisions imply that the company's operational strategies positively affect its reputation and appeal to customers.

In conclusion, the findings demonstrate a strong consensus on the effectiveness and positive influence of Toyota's production system. Respondents appreciate the balance between efficiency and environmental responsibility, reinforcing Toyota's position as a leader in sustainable manufacturing. These insights open opportunities for further research to examine how such perceptions impact actual consumer behavior and how Toyota's model might be adopted in other industrial contexts.

DISCUSSION

The impact of the TPS on global manufacturing is transformative and iconic. Since its inception, it has reshaped traditional production concepts and models. Many leading companies around the world have been following its model. In the automotive industry, it has helped Toyota become a leading global brand, distinguishing itself from fierce competition with its efficiency, high quality, and low cost, thus changing the landscape of the automotive industry and prompting other manufacturers to revisit and optimize their production methods.

Core Elements of the TPS

JIT production

Toyota's JIT production connotes the production of necessary products in necessary quantities at necessary times. Its core purpose is to eliminate waste, especially inventory waste.

For example, in automobile production, JIT can be realized between the engine production shop and the vehicle assembly shop through the Kanban management system. Assuming that the vehicle assembly line needs a certain number of engines to be assembled, and when the Kanban board shows that the engine inventory is close to the reorder point, the assembly shop will send a signal to the engine production shop. When the engine workshop receives the signal, it will immediately produce and supply the engine to the assembly workshop in time, so that the supply of the engine can be accurately aligned with the assembly demand of the whole vehicle. In this process, the Kanban board is like a messenger of information transmission, precisely controlling the time and quantity of production and transportation to ensure that neither the engine shortage leads to the stagnation of the whole vehicle assembly nor the backlog of the engine leads to the waste of inventory.

Automation (Jidoka)

The concept of automation in the TPS emphasizes the integration of man and machine. In the traditional view, automation often means only that machines perform tasks automatically, but Toyota's automation concept requires that people play a key role.

Employees are fully empowered on the production line and have the right to stop the line immediately when they notice quality anomalies, equipment malfunctions, or other non-conformities. For example, in the car seat installation process, if an employee notices a deviation in the position of the seat screw holes in a particular batch, he can immediately press the stop button. This prevents the defective seat from continuing to be installed in the vehicle and avoids the further spread of defective products. Without such a mechanism, vehicles with defective seats may continue to the next process, resulting in more resources being wasted on subsequent ineffective assembly, as well as more quality issues and high rework costs.

Advantages of the TPS

Cost-Effectiveness Advantages of the Toyota Production System

The TPS offers clear cost-saving benefits by reducing inventory and eliminating waste. One of the main advantages is the reduction of inventory backlog, which directly lowers several types of costs. In traditional manufacturing, companies often store large amounts of raw materials and finished goods to avoid stock shortages. This approach requires large warehouse spaces, which increases storage costs, including rent, utilities, and wages for warehouse staff. For example, a traditional machinery manufacturer might need to rent a big warehouse just to keep extra parts. In contrast, TPS uses accurate production planning and close coordination with suppliers, so companies only keep the inventory they truly need. This allows them to use smaller storage areas and save significantly on warehouse-related expenses.

Another important cost-related benefit is the reduction of capital consumption. When a company holds too much inventory, a large portion of its funds is locked up in unused products (Muller, 2019). For instance, if an electronics manufacturer has too many unsold items, the money tied up in those items cannot be used for important activities like developing new products or expanding into new markets. With TPS, inventory levels are kept low, freeing up cash that can be used for upgrading equipment, improving technology, or paying off debts, which helps reduce interest and financing costs.

TPS also helps reduce costs by eliminating waste in the production process. One major form of waste is overproduction—producing more than what is needed. For example, a clothing manufacturer might produce too many clothes based on wrong market predictions, leading to unsold items at the end of the season. TPS avoids this by

producing only what is needed, based on actual market demand. This reduces waste in materials, machinery use, and labor.

Another common source of waste in traditional systems is waiting time. Workers often have to stop working due to equipment issues or poorly coordinated tasks. For example, in some car parts factories, long delays in changing molds can cause workers to wait before they can continue production. Toyota addresses this by optimizing production steps and using quick mold-change technology, which cuts down waiting time and boosts productivity.

Overall, inventory and waste-related costs make up a big portion of expenses in traditional manufacturing. The TPS helps lower these costs, giving companies a stronger cost advantage in competitive markets.

Increased Production Efficiency

By optimizing the production process, the TPS greatly improves the tightness of the process connection and then significantly shortens the production cycle. Toyota's engine production line, for example, before the implementation of TPS, the engine from parts processing to assembly, the entire process needed to go through a number of procedures, there was a lot of waiting time between the processes and an inventory backlog, the production cycle was as long as 10 days. After the implementation of TPS, through the re-layout of the production line, the introduction of Kanban management, and other measures, the seamless connection between the processes has been realized. After the completion of the previous process, parts or semi-finished products are immediately sent to the next process, with almost no stoppages and inventory backlogs in between, dramatically reducing the production cycle time to 5 days.

In terms of output per unit of time, an automotive parts manufacturing enterprise after the adoption of TPS technology, originally 50 parts per hour, due to the reduction of inter-process interference and delays, improved equipment utilization, more efficient operation of the workers, the output per unit of time to 80 parts per hour, production efficiency increased by 60%.

In terms of production flexibility, an electronics manufacturer is able to quickly adjust production plans and process arrangements in the face of rapid changes in market demand due to the adoption of TPS. When the market demand for a particular electronic product suddenly increases, the enterprise can quickly deploy resources to increase the output of the product in a short period of time, from the original production of 1,000 pieces per day to 1,500 pieces, to meet the market demand and enhance the competitiveness of the enterprise in the market.

Quality Control Advantages

The TPS has a great advantage in quality control, the core of which lies in the quality control mechanism that involves all employees. Under this mechanism, everyone, from front-line workers to top managers, is responsible for quality control. Front-line employees rely on their own experience and skills in the production process, and real-time monitoring of each production link, once any factors that may affect the quality of the discovery, such as raw material defects, equipment parameters abnormalities, etc., they will immediately take measures to correct or report, to prevent the generation of defective products from the source.

The integration of automation and quality inspection is a solid guarantee for the stability and reliability of product quality (Chukwunweike et al., 2024). For example, in automotive

production, automated equipment in the completion of key processes will automatically carry out quality testing, such as the precision welding process, the robot will be on the strength of the welded joints, flatness and other parameters of the test, the test data real-time transmission to the quality control system. When quality problems are found, the production line will stop automatically, and the relevant personnel will quickly make adjustments and repairs.

Taking an automobile manufacturer as an example, before the implementation of TPS technology, the defective rate of products was about 5%, and the after-sales repair rate was around 8%. After the implementation of TPS, through the participation of all staff in quality control and the deep integration of automation and quality inspection, the defective rate is greatly reduced to less than 1%, and the after-sales repair rate is also reduced to less than 3%, the product quality index has been significantly optimized, which has strongly improved the brand image and market competitiveness of the enterprise.

Limitations of the TPS

Risk Of Supply Disruption

Since the TPS is highly dependent on suppliers, it is exposed to the risk of supply disruption. For example, when a supplier's region is hit by a natural disaster, such as an earthquake or flood, its production facilities may be damaged, resulting in parts not being supplied on time. If the supplier itself has operational problems, such as a broken financial chain or a production shutdown due to quality control failures, the supply may also be affected. The impact of such supply disruptions on Toyota production is huge. Since Toyota production is based on the JIT concept and inventory levels are low, once the supply of parts is insufficient, the production line may be forced to shut down, which in turn leads to delayed delivery of orders, reduced customer satisfaction, and may even affect the brand image.

Difficulties and Challenges

Toyota faces several significant difficulties and challenges when seeking alternative suppliers, particularly in times of urgent need. One major challenge lies in the company’s stringent quality and technical standards for parts. Identifying new suppliers who can meet these high requirements within a limited timeframe is not straightforward. Even when suitable candidates are found, they require time to adapt their production processes and become fully aligned with Toyota’s established quality benchmarks and supply expectations.

In addition to quality-related hurdles, the development of new supplier relationships often results in increased procurement costs. New suppliers typically lack the economies of scale enjoyed by long-established partners, particularly during the initial stages of collaboration. This lack of scale efficiency can drive up unit costs and weaken Toyota’s negotiating position, especially when time constraints heighten urgency and limit bargaining flexibility.

Furthermore, the integration of new suppliers introduces challenges related to supply chain synergy. A well-functioning supply chain depends on seamless coordination and communication among all partners. When a new supplier enters the network, the interfaces of information systems must be synchronized, and production planning must be recalibrated to maintain operational harmony. Until these processes are finely tuned, the overall efficiency of Toyota’s supply chain can be compromised, potentially disrupting production schedules and performance.

Initiatives and Effectiveness

Toyota has undertaken several initiatives to enhance the resilience and effectiveness of its supply chain, particularly in response to the increasing complexity and volatility of global markets. One key strategy is supply chain diversification. Toyota is actively expanding its supplier network by increasing both the number of suppliers and the geographical spread of supply sources. For instance, the company seeks multiple suppliers for similar parts located in different regions around the world. This approach is designed to minimize the risk of supply disruptions caused by natural disasters, political instability, or other force majeure events in any single region. By reducing its reliance on a single supplier or geographic area, Toyota has significantly improved the robustness and flexibility of its supply chain, making it better equipped to handle unforeseen disruptions.

Another important initiative involves the establishment of long-term strategic partnerships with key suppliers. Through these partnerships, Toyota provides technical guidance and financial assistance, enabling suppliers to strengthen their own risk management capabilities. The collaboration also includes transparent and in-depth information sharing, allowing suppliers to access Toyota's production schedules and anticipated changes in demand. With this advanced insight, suppliers can better manage inventory levels and production planning, ultimately leading to smoother operations. These combined efforts not only strengthen Toyota's ability to respond to supply chain risks but also support sustained production continuity and operational stability.

Implementation Challenges

Requirement for The Degree of Refinement in Corporate Management

Accurate production planning is the key to the TPS. Companies need to take into account market demand forecasts, equipment capacity, staffing arrangements, parts supply, and other factors to develop a detailed production plan down to the daily or even hourly level. For example, an automobile manufacturer in the development of production planning, not only based on the market sector to provide the number of car orders and delivery time, but also to accurately calculate the production beat of each production line, and the supply cycle of parts for different models. In terms of implementation monitoring, the enterprise is required to establish a perfect monitoring system to track the production progress, quality indicators, and equipment operation status in real time. Once deviation occurs, such as production schedule lag or quality anomaly, it can be quickly identified, and timely adjustments can be made. This requires an advanced information management system, as well as an efficient management team to analyze data and make decisions.

Employee Quality Requires Versatility

Employees play an extremely important role in the TPS. In terms of technical ability, employees need to be proficient in the operating skills of their positions (Pinto et al., 2020), whether it is complex mechanical processing or precision electronic assembly. For example, workers on an engine production line should be familiar with the operating specifications of various processing equipment and be able to accurately control the processing parameters to ensure the quality and production efficiency of the parts. Problem-solving ability is also a necessary quality. When the production process equipment fails, has quality problems, or a poor process interface, employees should be able to quickly analyze the root cause of the problem and propose solutions. In terms of teamwork ability, Toyota production emphasizes the participation of all employees, and the employees of each process need to work closely together. For example, in the automotive assembly process, employees in different positions, such as interior

installation, electrical wiring connection, chassis assembly, etc., should work together to ensure the efficiency and quality of the whole vehicle assembly.

Cultural Conflict and Employee Resistance

Implementing TPS in different corporate cultures may face many challenges. Some companies have a cultural tradition of hierarchical and command management, while the TPS emphasizes employee autonomy and full participation, which is prone to cultural conflict. For example, in a traditional family-owned manufacturing company, decision-making is highly centralized in family management, and employees are accustomed to following instructions from their superiors and lack a sense of active participation in management. When TPS was implemented, employees were uneasy about being given more decision-making power and worried about taking responsibility, which led to resistance. Some companies also focus on short-term benefits, while the implementation of TPS requires long-term investment and continuous improvement, which also leads to the lack of understanding and support for TPS by the management and employees, making the implementation process difficult, and even leading to the eventual abandonment of the implementation of some companies or the implementation of the effect is not good.

Application and Promotion of TPS

Application Examples and Expansion in the Automotive Industry

Toyota Itself

Toyota precisely controls the supply of parts and the pace of vehicle assembly through JIT production in the entire vehicle manufacturing process. For example, on the assembly line, according to the production sequence of the vehicle, the required parts are delivered to the workstation at the exact moment they are needed, which reduces the inventory backlog and waiting time. In parts production, Toyota's engine plants use a combination of automated equipment and employee management. Employees carefully check the automated production lines and stop immediately to deal with any anomalies, ensuring high quality and efficiency in engine production. This enables Toyota to occupy a leading position in the global automobile market with rapid product renewal, stable product quality, and high production efficiency.

Other Automobile Enterprises

Taking BMW as an example, it applies the TPS concept to optimize the production process in its automobile production. In the paint shop, the Kanban management system coordinates the supply of different color paints and the spraying process, which reduces the waste of paints and the time for changing colors. In terms of parts supply, it establishes a close information sharing network with suppliers all over the world, realizes on-time supply of parts, improves the flexibility and responsiveness of vehicle production, enhances market competitiveness, and maintains a high market share and brand reputation in the luxury automobile market.

Cross-Industry Applications and Case Studies

Electronics Industry

Apple has borrowed TPS's ideas in the manufacturing of electronic products. In the iPhone assembly plant, unitized production is adopted, with each production unit focusing on the assembly of specific modules, which reduces the handling and waiting time between processes and improves production efficiency. At the same time, through a strict quality control system, from raw material inspection to finished product inspection, incorporating automated testing equipment and employee self-inspection and mutual inspection, to ensure the high quality of the product, so that the iPhone in the global smartphone market is known for high quality and high performance.

Machinery Industry
Caterpillar applies TPS in engineering machinery manufacturing. In parts processing, by optimizing the layout of equipment, it realizes continuous flow production between different processes and reduces work-in-progress inventory. Moreover, employees are trained to master multi-skill operations and can quickly switch the processing tasks of different parts, which improves the flexibility of production, effectively responds to the fluctuation of market demand, and maintains the leading edge of technology and production efficiency in the global construction machinery field.

Aerospace Industry
Boeing introduced the TPS concept in the airplane manufacturing process. At the stage of fuselage assembly, it adopts pull production to coordinate the delivery time of each component supplier and internal production department according to the demand of the general assembly progress, which reduces the funds occupied by inventory. At the same time, the establishment of a rapid feedback mechanism for quality problems, once the quality defects of components are found, the source can be traced back quickly and improvement measures can be taken to ensure the high quality and safety of aircraft manufacturing, which occupies an important position in the global aerospace manufacturing industry.

Lessons and Insights from Cross-Industry Applications
The commonality in the application of TPS across industries lies in the emphasis on reducing waste, improving quality, and increasing production flexibility through process optimization. However, due to the differences in industry characteristics, the application mode is different. The machinery industry has high requirements for equipment accuracy and stability, and focuses on preventive maintenance and in-depth employee skill development. The aerospace industry has extremely high quality and safety standards, emphasizing the rigor and traceability of the quality control system.

Other industries can learn from the experience, first of all, an in-depth understanding of the core idea of TPS, according to their own industry characteristics and the actual situation of the enterprise’s adaptive adjustment, rather than copying. Secondly, focus on employee training and participation to cultivate employees' problem-solving ability and teamwork spirit. Furthermore, establish a culture of continuous improvement and optimize the production process and management system to enhance the overall competitiveness of the enterprise.

Summary
The core value of the TPS lies in the integration of JIT production and automation concepts, elimination of waste, optimization of processes, maximization of output with minimum resources and guarantee of high quality, and the construction of an efficient and flexible production system. Its advantages are extremely significant, in terms of cost control, it can significantly reduce inventory backlogs and various types of waste, to achieve structural optimization; production efficiency can be significantly improved through the optimization of the process, the close connection between the work processes, the output can be increased, and the flexibility is also enhanced simultaneously; quality control through the participation of all employees and automated testing mechanisms, to ensure the stability and reliability of product quality. However, there are limitations, strong dependence on suppliers, the risk of supply disruption, and the implementation of high requirements for enterprise management and staff quality, which may also encounter cultural conflict and resistance.

Looking ahead, the TPS has a bright future. As the manufacturing industry accelerates towards the era of intelligence and digitalization, it can be closely integrated with new cutting-edge technologies such as big data, artificial intelligence, and the Internet of Things (IoT), for example, with the help of which it can accurately predict market demand and further improve the degree of automation and quality control. The core concepts of waste elimination and process optimization can create value while integrating into emerging areas. Through continuous improvement and innovation, the TPS will continue to play a valuable role in many industries, maintain vitality, and continuously enhance its competitiveness.

CONCLUSION

The TPS represents a significant innovation in manufacturing, blending the principles of operational efficiency with sustainability. Rooted in its two core principles—JIT and Autonomation (Jidoka)—TPS strives to eliminate waste, optimize processes, and enhance quality control (Ohno, 2019). This system has not only propelled Toyota to become a global leader in automotive manufacturing but also set industry standards for the practice of lean production. By reducing inventory levels, streamlining production processes, and empowering employees to halt operations in response to quality issues, TPS demonstrates how operational excellence and environmental responsibility can coexist.

Sustainability is an integral component of the TPS framework. Its waste reduction measures directly contribute to lower energy consumption and reduced carbon emissions. For instance, JIT aligns production closely with customer demand, minimizing the energy required for warehousing, while enhanced process efficiency reduces machine runtime and energy usage. However, there remains a lack of comprehensive data on TPS's long-term environmental benefits, highlighting the need for standardized metrics to evaluate its contributions to sustainability. Despite this limitation, TPS remains a proven and effective model for achieving economic gains alongside ecological preservation in manufacturing.

The application of TPS extends beyond the automotive industry and has been widely recognized in sectors such as healthcare, electronics, and aerospace, showcasing its versatility and adaptability. However, challenges arise when implementing TPS in diverse cultural and organizational contexts. In Western companies, where autonomy is highly valued, the rigid hierarchy and standardized operations inherent in TPS may create friction. Furthermore, TPS's reliance on seamless supply chains makes it vulnerable to disruptions caused by supplier issues or external factors. To ensure the successful implementation of TPS across various scenarios, adaptive strategies must be developed.

Looking ahead, TPS has significant potential for enhancement through integration with advanced technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT). Predictive analytics could refine inventory management, while IoT technologies could enhance automation, improving precision and quality control. Future research should also focus on worker well-being and the long-term environmental impacts of TPS, ensuring the system evolves to meet the demands of increasingly complex and interconnected manufacturing environments.

In conclusion, TPS serves as a model for lean and green manufacturing, having a profound impact on the global industry. Its ability to balance efficiency, quality, and sustainability has cemented its status as a transformative framework. As industries

accelerate digital transformation and prioritize environmental protection, TPS is well-positioned to continue driving innovation and sustainable development.

To ensure the enduring impact of TPS, it must remain adaptable to new technologies and methodologies. This adaptability will be crucial in sustaining TPS's leadership in the global manufacturing landscape and ensuring its principles remain applicable in diverse industrial settings. By fostering a culture of continuous improvement and leveraging advanced technologies, TPS can support organizations in achieving both operational excellence and environmental stewardship.

LIMITATION

This research has several limitations that should be acknowledged. First, the study focuses primarily on the TPS as implemented by Toyota, and the findings may not be fully generalizable to other industries or companies adopting similar lean production systems. Second, while the study employed quantitative methods to assess consumer perceptions, it does not include qualitative insights that might provide a deeper understanding of the TPS's broader impacts, such as employee experiences or supplier perspectives.

The study does not extensively examine the potential trade-offs between efficiency and employee well-being, as some criticisms of TPS highlight increased workloads and stress among workers. Fourth, while environmental sustainability is a central theme, specific data on long-term carbon reduction or energy efficiency metrics are limited, making it difficult to assess the full environmental impact of TPS.

The research relies on self-reported data from consumers, which could be subject to biases such as social desirability or a lack of detailed knowledge about TPS. Future studies could address these gaps by incorporating longitudinal data, multi-stakeholder perspectives, and case studies from diverse industries and regions.

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DECLARATION OF CONFLICTING INTERESTS

The authors affirm that there are no conflicts of interest associated with this study. This research was conducted independently and was not influenced by any external financial, institutional, or personal interests. All data were collected and analyzed objectively, ensuring that the findings reflect an unbiased examination of the TPS and its impact on sustainability.

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