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The Evolution and Implementation of the Toyota Production System

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ABSTRACT

The Toyota Production System (TPS) and Just-in-Time (JIT) manufacturing have revolutionized global manufacturing practices since their introduction to Western countries in the 1970s. Initially disseminated through key conferences and publications, TPS principles were rapidly adopted by American industries, eventually spreading to various sectors including food, healthcare, aerospace, and defense. This paper delves into the critical components required for the successful implementation of TPS, particularly focusing on efficient supply chain management and manufacturing flexibility. Lean manufacturing techniques, integral to TPS, emphasize minimizing inventory and waste while ensuring timely delivery of parts at optimal cost and quality. The adoption of JIT methodology has been pivotal in managing supplier relationships and production processes. Value stream mapping is highlighted as a vital tool for analyzing and optimizing the entire production journey. Additionally, the paper discusses the necessity of complementary practices such as close partnerships with transportation carriers, stringent supplier delivery schedules, and strategic shipping distance limitations. Flexibility within supply chains, defined as the capacity to adapt to demand fluctuations and external disruptions, is explored through various lenses, including agility and adaptability. The paper underscores the importance of maintaining flexibility to enhance market responsiveness and competitiveness. Special attention is given to the challenges and benefits of hybrid vehicle assembly, which necessitates unique processes due to additional components. Finally, the evolution of manufacturing systems inspired by TPS, including those of Mercedes-Benz, BMW, and Audi, is examined. These systems, while tailored to specific organizational needs, retain the core principles of lean manufacturing. The paper concludes with a discussion on the advantages and disadvantages of implementing TPS, highlighting its effectiveness in waste reduction and continuous improvement despite initial complexities and investment requirements.

Key words: Toyota Production System (TPS), Just-in-Time (JIT), Lean Manufacturing, Supply Chain Management, Manufacturing Flexibility, Value Stream Mapping, Supply Chain Efficiency, Automotive Manufacturing, Mixed Model Assembly Line (MMAL), Continuous Improvement.

INTRODUCTION

In the 1970s, news about the Just-in-Time and Toyota Production System (TPS) reached Western countries through two English-language articles from Japan. In 1980, a conference held at Ford World Headquarters in Detroit, co-sponsored by the Repetitive Manufacturing Group (RMG), featured Fujio Cho explaining the Toyota system, which had a significant impact on the audience. Following this conference, numerous case studies documented the implementation of TPS, leading many American industries to adopt and benefit from the system. In the 1990s, the publication of more books on Just-in-Time implementations further sparked interest among various industries, prompting many to implement TPS in their companies. The Toyota Production System (TPS) is no longer limited to the automotive industry. It is now extensively used in various sectors, including the food industry, hospital management, aerospace, and defense.

To successfully implement the Toyota Production System (TPS), an efficient supply chain and manufacturing flexibility are crucial. The following sections will explore these aspects in detail.

SUPPLY CHAIN IN LEAN MANUFACTURING

Lean techniques play a crucial role in eliminating unwanted inventory and preventing waste. These objectives are achieved through effective supply chain management, where transportation and delivery are prioritized. Specifically, small and frequent shipments are favored, provided they can be managed at a lower cost. The Just-In-Time (JIT) methodology was developed to address the complexities inherent in the relationships between various suppliers and companies.

The philosophy of lean manufacturing emphasizes the timely delivery of parts at the lowest cost and highest quality. To this end, value stream mapping is employed to analyze both the current and future states of the production process. This mapping encompasses the entire journey of a product from the beginning of production (post-supplier) to its final delivery to the customer. Key metrics considered include lead time for each process, inventory levels between stations, cycle time, and changeover time.

An illustrative example of value stream mapping within the context of supply chain management is provided in the accompanying image (Fig. 1).

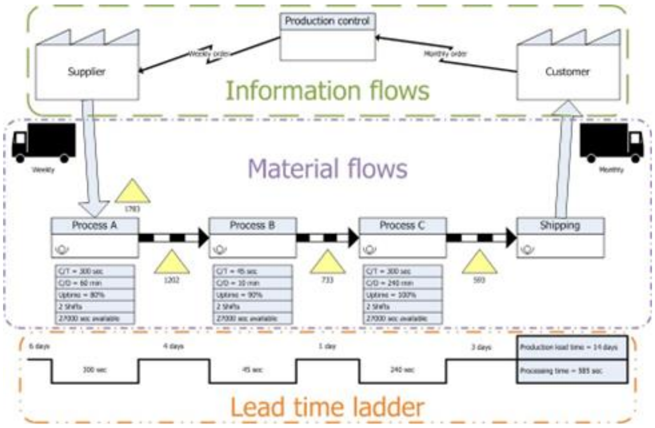

Figure 1: Value Stream Mapping | Source: [10]

Implementing pull system alone is not sufficient to maintain smooth processes with suppliers and customers. Several other critical factors need to be considered. Toyota has been continuously enhancing its supply chain to increase efficiency. The key practices to follow includes:

- Developing close relationships with transportation carriers by using only one carrier. This will create priority exchange with the carrier and ensure on-time delivery.
- Setting strict delivery requirements for suppliers to efficiently handle high-frequency, low-load supply. Providing a specific schedule and enforcing adherence to it helps reduce chaos in the loading and unloading areas.
- Limiting the shipping distance to meet quick and frequent demands. Focusing on suppliers close to the assembly plant encourages those suppliers to reciprocate the dedication. It also incentivizes other suppliers to establish operations near the assembly plant.

FLEXIBILITY FOR MANUFACTURING SUPPLIERS

Flexibility in supply chains can be defined as the ability to respond to changes in demand, supply situations, or other external disruptions, as well as the ability to adjust to strategic and structural shifts in the supply chain environment. Flexibility, therefore, is a combination of agility and adaptability. It is described as a concept in which business processes effectively manage to react to changes with minimal penalties in time, cost, quality, or performance.

Since the beginning of the supply chain, suppliers have been expected to provide high speed and low cost. These factors have been important drivers for them. However, these suppliers often struggle to react to abrupt changes in company demands; in other words, they have a hard time being flexible.

Changes in market demand, varying lead times among suppliers, product quality issues, and information delays are sources of uncertainty that necessitate building flexibility. Suppliers who manage to be flexible are in a much better position than their rivals. This flexibility provides an advantage for companies as it fosters competitiveness among suppliers.

Flexibility for manufacturers is characterized into 3 components as explained by Hau L Lee

1. Adaptable: Adjust the supply chain's design to meet structural shifts in markets, and modify supply network strategies, products, and technologies.
2. Alignment: Create incentives among partners within the supply chain to achieve better overall performance.
3. Agility: The ability of a supply chain to respond quickly to short-term changes in demand or supply and handle external disruptions smoothly.

HYBRID AUTOMOTIVE ASSEMBLY

Hybrid vehicles can be built on the same or similar assembly lines as non-hybrid vehicles. However, hybrid vehicles have additional components that require extra steps during assembly. There are three main areas that need a different approach when assembling hybrid vehicles: the installation of the heavy battery, the inverter, and the regenerative braking system.

Other components of hybrid vehicles include a temperature management unit, an electric battery pack, an in-dash electrical outlet, power cables, electronic power assist steering, a DC-to-DC converter, an Atkinson-cycle engine, and an electronically controlled continuously variable transmission.

One of the main challenges is related to the complex wiring harness system. The controls and high-voltage power wiring are unique to hybrids, presenting assemblers with the challenge of performing these additional processes while the vehicle moves down the same assembly line. Quality testing at the end of assembly also needs to be very specific to hybrid vehicles.

The areas on the assembly line that accommodate these additional hybrid requirements are called bypass stations since non-hybrid vehicles simply bypass these stations. In the stamping department, unique processes are needed to make holes for wiring harness routings and various hoses required for the electrical system.

ASSEMBLY FLEXIBILITY

Flexibility in a system's behavior can be expressed in many forms, based on the system's desired characteristics. Many different types of flexibility have been proposed, including product, operation, process, volume, expansion, and labor flexibility. Broadly, it can be classified as external or internal. Statistical analysis has been used to measure flexibility, and it has been concluded that flexibility is determined by the manufacturing system's sensitivity to change: the lower the sensitivity, the higher the flexibility.

Current research focuses on investigating the relationships among flexibility and other manufacturing attributes such as cost, time, and quality. In studying the effect of flexibility on market adaptation, especially when dealing with fluctuating demands, it has been observed that establishing and maintaining the flexibility of a production system at a satisfactory level leads to sufficient market adaptation. In manufacturing, it has been noticed that many factors are influenced by flexibility. One important finding in automotive assembly is that flexibility decreases with an increase in robotic automation. This can be seen in the schematic below (Fig. 2).

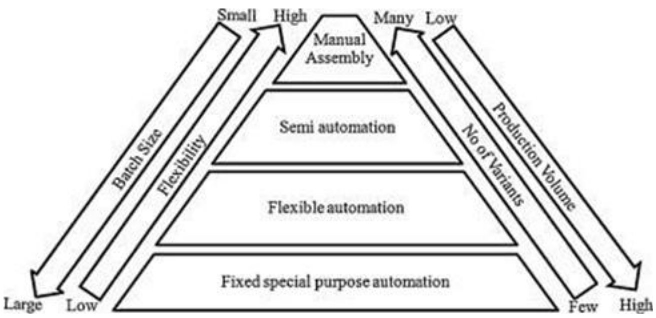

Figure 2: Relation between Flexibility & Automation | Source: [14]

In automotive manufacturing, the structure of an assembly plant generally comprises four stages: stamping, body shop, paint, and final assembly (FA). Most assembly operations occur in the body shop and FA. High levels of automation are seen during the assembly of the body-in-white, while hybrid (human and machine) systems are found at the final assembly stage. There are four approaches to the design of an assembly system, as shown in the figure above: (1) manual assembly, (2) flexible assembly, (3) semi-automated assembly, and (4) fixed assembly. In modern automotive assembly lines, different vehicles are typically assembled using the same assembly line, known as a mixed model assembly line (MMAL). MMALs are known for their ability to assemble different models of a given product without holding large inventories. One of the main challenges that modern assembly systems face is the cost-driven demand for faster and safer ramp-up processes. Due to enhanced innovations and the increasing number of new products and their variants, this goal is supported by the constantly rising number of ramp-ups. The recent trend followed by automotive OEMs is adopting standardization for products, equipment, and processes.

Lean manufacturing provides a common foundation for assembling a greater number of powertrain variants and an even larger array of vehicle models, including completely different models. For example, at Volkswagen plants, both Audi TT and Volkswagen Golf are produced on the same assembly line based on demand, employing a similar technique to the Kanban pull system. This approach also accommodates different model versions such as 3-door, 5-door, coupe, sedan, etc., and includes various features like navigation systems, heated seats, sunroofs, etc. Successfully managing this requires various production departments to be sufficiently flexible to handle such diversity.

Layout of pull system for multistage, multi powertrain Assembly

Below is the illustration of a Pull system for multistage, multi powertrain assembly (Fig. 3)

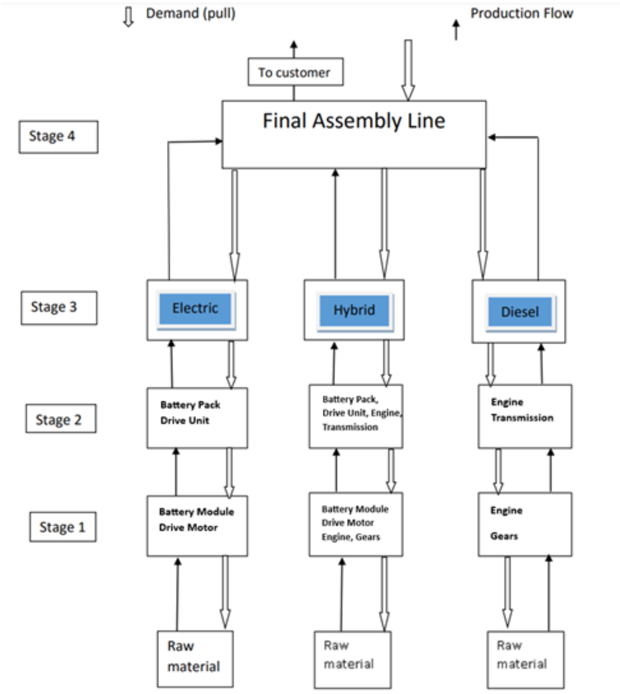

Figure 3: Block Diagram for Pull system

The figure below (Fig. 4) shows an example of different variants with flexibility adopted by various departments. The highest flexibility can be seen in the final assembly department. This flexibility is achieved with lower automation and a higher number of workers, as explained in the preceding section.

	Description	Department	Example
PLATFORM	Car of a different class	Body Shop	C-Class
MODELS	Different car model	Body Shop	Model 1 Model 2
VERSIONS	Different versions of the same model	Body Shop	3 door 5 door Coupe Sedan
OPTIONS	Options within versions	Final Assembly	Clima Navigation Heated Seats

Figure 4: Flexibility Adoption by Departments | Source: [14]

AUTOMOTIVE MANUFACTURING

The history of Automotive Manufacturing Systems has been intriguing and inspiring from the beginning. Henry Ford, the first industrial engineer, implemented the most effective production method of his time: the assembly line. Later, Toyota developed the most effective manufacturing system, the Toyota Production System (TPS), which has been the most successful production system in history. Nearly all major automotive manufacturers now follow its principles. Toyota, having been the first to implement it, continues to benefit and thrive from its continuous improvement, making it the most refined and effectively used system at Toyota.

Over time, all large companies have developed their own manufacturing systems based on TPS or lean manufacturing principles. Production systems found worldwide include the Honda Production System, Audi Production System, BMW Production System, Mercedes-Benz Production System, and others. These systems have evolved according to each company's specific circumstances and preferences, but their foundation remains rooted in TPS.

A. Mercedes-Benz Production Systems

The Mercedes-Benz production system has received praise for its effective modifications at the Vance facility in Alabama, USA. They assembled personnel from diverse backgrounds and perspectives who did not necessarily adhere to the traditional techniques of TPS, sparking motivation for new problem-solving approaches. They addressed specific issues related to cleanliness and safety, visual management, pull systems, standard methods and procedures, and continuous improvement.

One innovative implementation by Mercedes-Benz was addressing supply chain issues in the region. Given that suppliers were located at considerable distances from the assembly plant, they consolidated shipments from multiple suppliers onto the same trucks. This significantly improved inventory efficiency and supported smoother production, aligning with the Just-In-Time methodology.

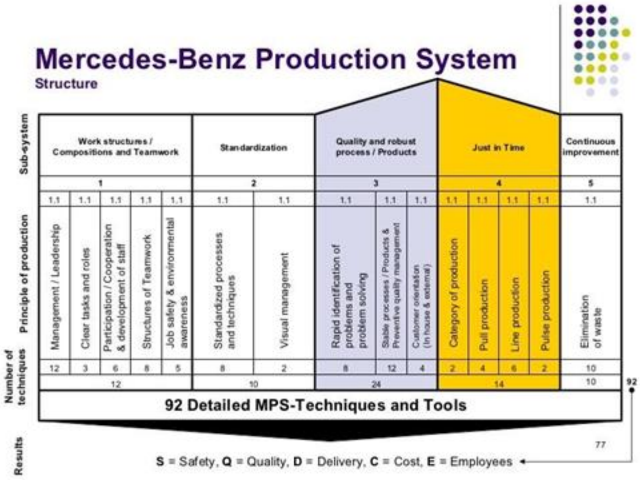

Figure 5: Mercedez-Benz Production System | Source: [15]

B. BMW Production System

On the other hand, BMW has similarly developed a pull system based on TPS or lean manufacturing principles. While they have evolved according to their specific production line challenges, BMW's production system is globally recognized for its flexibility on the assembly line. BMW showcases this capability at its plant in Dingolfing near Munich, Germany, a massive facility that produces over 340,000 vehicles annually, all on a single assembly line. This highlights the significant level of flexibility BMW's production system has achieved through years of refinement and improvement, also based on lean manufacturing principles.

C. Audi Production System (APS)

The Audi Production System (APS) is also among the renowned systems in the history of Automotive Manufacturing Systems. Derived and developed from Toyota's Lean Manufacturing principles, APS is recognized for its environmental friendliness and high flexibility, similar to BMW's approach. It efficiently utilizes minimal energy resources for the same manufacturing output. Audi's oldest plant, located in Ingolstadt, Germany, produces up to 650,000 vehicles annually with smooth and flexible production processes. As a subsidiary of the Volkswagen Group, Audi's APS is commonly implemented in Volkswagen plants, benefiting from Volkswagen's financial support and expanding Audi's global market reach.

D. Japanese Manufacturers

Most Japanese manufacturers have developed their production systems closely aligned with the Toyota Production System (TPS). This similarity can be justified by the fact that they operate in the same country, facing similar conditions and challenges. Toyota prioritizes customer satisfaction above all else, whereas Honda distinguishes between two types of customers: internal and external. According to Honda, they give equal priority to satisfying both the external customers and the workers within the organization, whom they refer to as internal customers.

ADVANTAGES & DISADVANTAGES OF IMPLEMENTING TOYOTA PRODUCTION SYSTEMS

A. Advantages

- Minimizes various types of waste, particularly the 7 wastes: Transport, Inventory, Motion, Waiting, Over-Processing, Overproduction, and Defects.
- Reduces production time, promotes less floor movement, and decreases chaos.
- Facilitates continuous improvement.
- Enhances product quality through Jidoka and Poka Yoke techniques.
- Maximizes resource utilization.

B. Disadvantages

- Initial complexity until achieving smooth operation.
- Significant investment requirements for productivity tools.
- Increased pressure on suppliers due to flexible demands and cost constraints.
- Lengthy implementation period.

CONCLUSION

Through detailed discussions on lean manufacturing, Just-in-Time (JIT) methodology, and value stream mapping, this paper underscores the critical role of efficient supply chain management and manufacturing flexibility in the successful deployment of TPS. It elaborates on the importance of agility and adaptability in supply chains, emphasizing how these attributes enable manufacturers to respond effectively to market fluctuations and external disruptions.

Moreover, the paper delves into the specific challenges and solutions associated with hybrid vehicle assembly, providing a nuanced understanding of the additional processes required. The examination of various manufacturing systems inspired by TPS, including those of Mercedes-Benz, BMW, and Audi, illustrates the adaptability of lean principles across different organizational contexts.

By exploring the advantages and disadvantages of TPS, this paper not only elucidates the practical benefits of minimizing waste and enhancing product quality but also addresses the complexities involved in its implementation.

Future research should focus on integrating emerging technologies such as artificial intelligence, IoT, and advanced robotics with TPS principles to further enhance efficiency and flexibility. Additionally, studies on the long-term impact of TPS on sustainability and environmental performance would provide valuable insights. Companies should also consider the development of customized training programs to ensure the workforce is well-versed in lean manufacturing techniques. Lastly, exploring the applicability of TPS in new and evolving industries could expand its benefits to a broader range of sectors, ensuring continued innovation and improvement in global manufacturing practices.

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