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**TỪ JUST-IN-TIME TRUYỀN THỐNG ĐẾN JUST-IN-TIME THÔNG MINH
NHẪM TỐI ƯU HÓA CHUỖI CUNG ỨNG: NGHIÊN CỨU VỀ TOYOTA VÀ
CÁC ĐỀ XUẤT CHO NGÀNH CÔNG NGHIỆP Ô TÔ VIỆT NAM**

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Tóm tắt

Kỷ nguyên công nghệ đã thúc đẩy một sự chuyển dịch mang tính bước ngoặt từ mô hình Just-in-Time (JIT) truyền thống sang "JIT thông minh", với đặc trưng là việc tích hợp các công cụ hiện đại vào sản xuất và vận hành nhằm tối ưu hóa chuỗi cung ứng. Sự chuyển đổi này đặc biệt quan trọng đối với ngành công nghiệp ô tô - lĩnh vực đòi hỏi khả năng giám sát theo thời gian thực về thời gian, chi phí, nhu cầu và hàng tồn kho. Bài viết này làm rõ rằng tối ưu hóa chuỗi cung ứng không chỉ đơn thuần là cải thiện các công đoạn riêng lẻ, mà là tìm kiếm sự cân bằng chiến lược giữa các thông số có mối liên hệ chặt chẽ với nhau. Việc ứng dụng Bản sao số (Digital Twin) và Minh bạch dữ liệu (Data Transparency) trong sản xuất thông minh cho phép

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thu thập và truyền tải dữ liệu liền mạch, giúp các nhà sản xuất tối ưu hóa quy trình ra quyết định, tiết kiệm chi phí và đẩy nhanh tiến độ vận hành. Cuối cùng, nghiên cứu đưa ra các khuyến nghị chiến lược cho ngành sản xuất và lắp ráp ô tô tại Việt Nam nhằm thúc đẩy một chuỗi cung ứng linh hoạt và chuyển đổi số toàn diện.

Từ khoá: just-in-time, tối ưu hóa chuỗi cung ứng, bản sao số, minh bạch dữ liệu, Toyota

FROM TRADITIONAL JUST-IN-TIME TO SMART JUST-IN-TIME FOR SUPPLY CHAIN OPTIMIZATION: CASE STUDY OF TOYOTA AND RECOMMENDATIONS FOR VIETNAM'S AUTOMOTIVE INDUSTRY

Abstract

The technological era has compelled a paradigm shift from traditional Just-in-Time (JIT) to "Smart JIT", characterized by the integration of advanced tools into production and operations to optimize the supply chain. This transition is particularly vital for the automotive industry, which demands real-time visibility of time, cost, demand, and inventory. This study clarifies that supply chain optimization is not merely about improving separate stages but rather seeking a balance among interconnected parameters. By integrating Digital Twin, and Data Transparency, which is smart manufacturing, enables seamless data collection and transmission, as well as empower manufacturers to enhance decision-making, reduce costs, and accelerate processes. Finally, the paper proposes strategic recommendations for the Vietnamese automobile manufacturing and assembly sector to foster a resilient and digitally-transformed supply chain.

Keywords: just-in-time, supply chain optimization, digital twin, data transparency, Toyota

1. Introduction

1.1. Background

Supply Chain Management (SCM) is a key field of Vietnam's economy benefiting from geographical location, natural resources, labor resources, and government support. Foreign Direct Investment (FDI) contributes significantly to Vietnam's GDP, drawing particular attention and SCM development. The manufacturing and processing industry in Vietnam plays a crucial role in industrialization and modernization, with the automotive sector which is considered as a vital and fast-growing industry, leading to the increased demand for efficient and optimal supply chain systems.

Vietnam's SCM sector has recorded positive figures for growth rate and scale, becoming a crucial link in regional and global supply chains. However, some important problems still remain which are the low alignment between organizations' direction, limited real-time visibility of cost, and inventory, hesitant response to transformation, and low collaboration between departments in supply chain (KPMG, 2021).

The automobile industry requires an evolution of Supply Chains from "reactive" or traditional to "predictive" maintenance due to the digital age era (Amina R. & Lucas M., 2025). SCM focuses on flow of goods, service and information from points of origin to customers

through a chain of entities and activities that are connected to others (Lu LX & Swaminathan, 2015). While capacity, demand, and costs are known parameters, there are uncertainties arising from variations in customers' demand, supplies, transportation, organizational risks, and lead times (Seyedan & Mafakheri, 2020).

An influential approach to supply chain efficiency in this industry is the Just-in-Time (JIT) system, pioneered by Toyota. While Traditional JIT has delivered substantial efficiency gains, it relies heavily on physical cues, lean inventories and highly synchronized fragile networks whose vulnerabilities are exposed by global disruption (pandemics or supply shortages). In response, Smart JIT has been introduced to enhance resilience and decision-making by integrating digital technologies. Digital Twins is a key in the reduction of errors, uncertainties, inefficiency, and expenses (Maulshree Singh et al., 2021). Data Transparency enables firms to apply predictive analytics and scenario analysis, thereby improving their ability to respond quickly to supply chain disruptions (Kache & Seuring, 2017; Queiroz et al., 2023).

Within this context, Toyota Global Operations represents how Traditional JIT shifts to Smart JIT by leveraging Digital Twins and Data Transparency due to the crisis in 2021-2022. Particularly, this study also narrows down to the implementation of these technologies in Toyota Vietnam.

1.2. Problem Statement

Traditional Just-in-Time (JIT) systems, while efficient, often lack real-time visibility and flexibility, making them vulnerable to supply shocks and demand volatility. During the 2021 - 2022 crisis, the weakness became evident when the COVID-19 lockdowns in Southeast Asia, forcing enterprises to cut global production, leading to inventory depletion, delayed customer deliveries, and financial loss. The real-time technology was required to deal with production halts, increased costs, and lost competitiveness.

1.3. Research Objectives

There are five main objectives of this study:

1. To compare the implementation of Traditional JIT and Smart JIT. Highlighting the shifts from reactive to predictive model by the integration of advanced technologies for supply chain optimization.
2. To analyze a case study - Toyota from global to Vietnam to identify operational benefits and technical barriers of manufacturing and assembling automation in worldwide conditions and in Vietnam's context.
3. To evaluate the pros and cons of traditional JIT and Smart JIT that influences the automotive supply chain optimization.
4. To assess the current conditions of the automotive sector of Vietnam regarding technological readiness, infrastructure, and the quality of labor.

5. To propose recommendations for Vietnamese automobile manufacturers and government agencies to enhance the policies to digital transformation, thereby fostering a more resilient and transparent supply chain ecosystem in Vietnam.

1.4. Research Questions

There are four questions that are raised throughout the process:

1. How does Traditional JIT differ from Smart JIT in implementation, and which ways do technologies enable the transition from a reactive to predictive model?
2. What are the current conditions of supply chain management in Vietnam's automobile industry (such as technological readiness, infrastructure, etc), and how do these factors affect its position as an emerging hub in the regional value chain?
3. In the current situations of the global supply chain, which models provide higher agility for the automotive industry?
4. What strategic measures and policy adjustments should be implemented by manufacturers and the Vietnamese government to foster a resilient and digitally-transformed automotive supply chain?

1.5. Research Significance

Academically, this study contributes to extending the existing literature on SCM, with focus on Just-in-Time, digital transformation, and data transparency. It shows how traditional JIT systems can evolve into Smart JIT models by technological integration. Toyota Operation is used as a case study to bridge the gap between theory and practice, offering key insights to modify supply chain decision-making, resilience, and visibility.

Practically, these findings provide some actionable insights of manufacturers in the automotive sector to optimize their supply chain performance in the current conditions. This study is also expected to support firms in improving inventory management, reducing lead times, and strengthening supply chain transparency.

2. Literature Review

2.1. Traditional Just-in-Time (JIT)

Just-in-time (JIT) is the term used to indicate that a process is capable of instant response to demand without the need for any overstocking, either in expectation of the demand being forthcoming or as a result of inefficiencies in the process (David Hutchins, 1988). The core mechanism of traditional JIT is the “pull system”, operating by using Kanban to communicate requirements from the next stage to the previous one. Kanban production control is the policeman, which enforces compliance with stated objectives to identify and solve manufacturing system problems. (Harold Dyck et al., 1988).

On the other hand, there are many significant limitations of this system in the modern business environment. In the contexts of global pandemics or logistics crises, traditional JIT lacks inventory buffers and the ability to react quickly, which may lead to the risk of immediate production chain disruptions when even a small chain fails.

2.2. Smart Just-in-Time (Smart JIT)

The advent of the Fourth Industrial Revolution 4.0 has transformed JIT from a reactive to a proactive system, also known as Smart JIT (JIT 4.0), to mitigate the limitations of the traditional JIT. The Smart JIT uses technologies such as the Industrial Internet of Things (IIoT), the analysis of large volumes of data, real-time End-to-End planning and control, autonomous system, Cyber Security and the concept of “Digital Twins” (Gratiela Dana BOCA, Arzum ISITAN, 2021).

IIoT is defined as the use of certain IoT technologies – certain kinds of smart objects within cyber-physical systems – in an industrial setting, for the promotion of goals distinctive to industry (Hugh Boyes et al., 2018). IIoT systems replace traditional Kanban cards with digital signals - E-Kanban, which offers advantages such as real-time visibility across extended supply chains, faster signal transmission, and direct integration with Enterprise Resource Planning systems (Olga MAŘÍKOVÁ, 2008).

2.3. Digital Twin Technology

Digital Twin, defined as a virtual representation of a physical object, process or system, enables real-time monitoring, analysis, and optimization of supply chain operations (Tao, Cheng et al., 2018). By creating the digital replica of a physical asset or process, organisations can gain intelligence enabling responsiveness of the supply chains (Ivanov and Dolgu, 2020).

Digital Twin is used to run stress-testing in a virtual environment to detect potential system failures or "break points" before they actually occur in real life. In the manufacturing context, a Digital Twin can be used for monitoring, control, diagnostics, and prediction, other than just simulation (Yuqian Lu et al., 2019).

2.4. Data Transparency

E2E visibility is the capability of an organization to capture, track, and monitor products, information, and processes International Journal of Multidisciplinary Futuristic Development across the entirety of its supply chain, from raw material sourcing through production, distribution, and final delivery to end customers (Awe, 2021; Ejibenamet al., 2021). Traditional localized visibility which often focuses on internal operations or Tier 1 suppliers, E2E visibility encompasses all supply chain nodes, enabling organizations to achieve comprehensive situational awareness, real-time monitoring, and actionable insights across multiple tiers of suppliers and logistics providers (Adeshina et al., 2021; Ajayi and Akanji, 2021).

2.5. Supply Chain Optimization

An optimally designed supply chain should, through one or a variety of metrics, reflect the “best” configuration and operation of all elements (suppliers, manufacturers, and distributors) (Daniel J. Garcia, Fengqi You, 2015). Therefore, it is in industry's best interest to optimize their supply chains in some manner (Wassick, 2009). Optimizing the supply chain in the Industry 4.0 era is the process of using advanced algorithms and big data analytics to find the balance between cost, speed, and resilience.

In the context of Smart JIT, supply chain optimization helps determine Dynamic Safety Stock - a method of establishing a safety stock level that changes over time, based on actual fluctuations. Intelligence (or Smart) is revealed through cooperation in networks with other smart devices, which have the possibility to check the system updates and decide whether to act on them or not (Elvis, 2015). Thus, Smart JIT system can automatically calculate the necessary inventory level at any given time based on the actual consumption rate of the production line, instead of maintaining a fixed, wasteful safety stock level.

2.6. Conceptual Framework

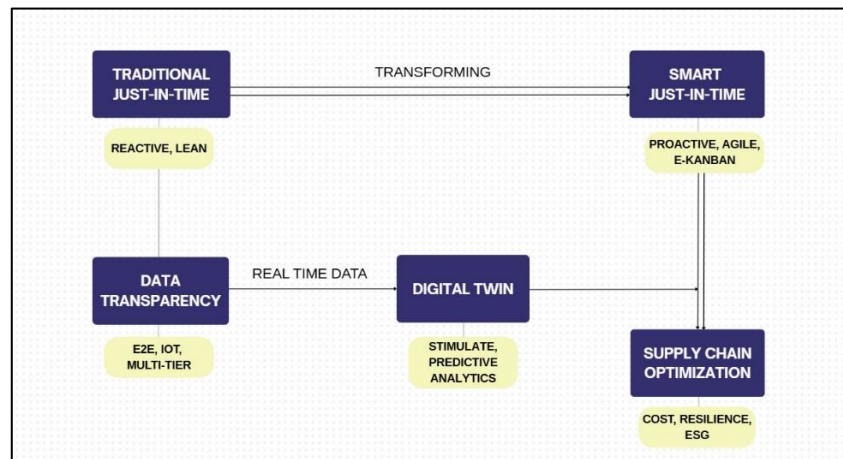


Figure 1: The Smart JIT's Framework

Source: Synthesized by the authors

2.7. Research Gap

Firstly, most existing studies about JIT only focus on their effectiveness under relatively stable production and supply conditions. However, the increasing complexity and volatility of global supply chains, especially during recent disruptions such as pandemics and logistics crises, have exposed several limitations of traditional JIT systems. In particular, the reliance on minimal inventory levels and reactive information flows makes these systems highly vulnerable when unexpected disruptions occur.

Secondly, at the same time, the emergence of Industry 4.0 technologies, including IIoT, Digital Twin, and real-time data analytics, has created new opportunities to enhance supply chain visibility and responsiveness. While these technologies have been widely discussed in literature, they are often studied separately rather than being examined as part of an integrated framework that can transform traditional JIT into a more adaptive and intelligent system.

Therefore, there remains a research gap in understanding how traditional JIT systems can evolve into Smart JIT by integrating digital technologies that enable real-time information sharing, predictive decision-making, and greater supply chain transparency. Addressing this gap is important for helping organizations maintain the efficiency benefits of JIT while improving resilience and responsiveness in increasingly uncertain supply chain environments.

3. Methodology

3.1. Research Design

This study adopts a qualitative research approach using an exploratory case study design (Yin, 2014). This method was to establish a detailed analysis of the complex transition from the traditional Just-in-Time system to the Smart JIT within the real context of Toyota.

3.2. Case Selection Criteria

Toyota was selected as the primary case for two reasons:

- **Pioneering Position:** Toyota originally developed the JIT system, its transition to Smart JIT represents the most advanced evolution of the model.
- **Relevance to Vietnam's Context:** Being one of the leading enterprises in Vietnam's domestic market, the digital transformation of Toyota Motor Vietnam serves as a benchmark for the entire Vietnamese automotive industry.

3.3. Data Collection and Triangulation

To ensure the validity and reliability of the research results, the study employed secondary data triangulation collected during the period 2021–2026:

- **Corporate Data:** Annual reports, technical whitepapers, and official digitalization roadmaps from Toyota Motor Corporation and Toyota Motor Vietnam (TMV).
- **Industry Benchmarks:** Statistics from the Vietnam Automobile Manufacturers' Association (VAMA) and global supply chain performance indicators.
- **Technological Frameworks:** Implementation documentation and system architectures from SAP S/4HANA and Synology's infrastructure solutions.

3.4. Analysis Procedure

The data analysis was conducted through a systematic three-stage process:

1. **Content Analysis:** Identification and extraction of key technological variables from corporate documentation.
2. **Comparative Analysis:** Comparison of Toyota's reactive operational performance during the 2021 - 2022 supply chain crisis with its predictive capabilities in the 2025 - 2026 period.
3. **Synthesis:** Integration of global technology trends with Vietnam's infrastructure and workforce constraints to formulate strategic recommendations.

4. Findings & Analysis (Case study: TOYOTA)

4.1. General Information of Toyota

4.1.1. Toyota Motor Corporation

Toyota Motor Corporation is a Japanese multinational automotive manufacturer based in Aichi Prefecture, Japan that operates globally, engaging in the design, manufacturing, and selling of passenger vehicles, commercial vehicles, engines, and parts.

Toyota's customer base includes: mass consumers, utility focused consumers, commercial consumers, eco-friendly consumers, and premium consumers.

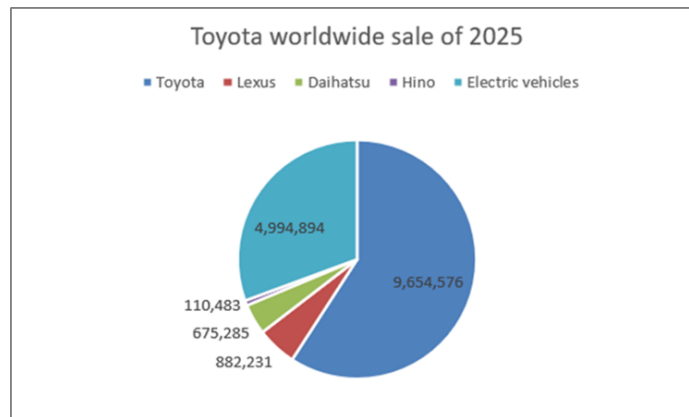


Figure 2: Toyota's total sale between all branches corresponding to customer bases

Source: Toyota's Official Report

Since the late 2000s, Toyota has become the world's largest automobile manufacturer by sales volume (Britannica, The Editors of Encyclopaedia, 2026). With its presence all over the global market, Toyota employs, maintains manufacturing, and sales operations in every noticeable market. Toyota Motor Corporation's net worth is approximately \$302 billion as of late January 2026 (Stockanalysis, 2026).

4.1.2. Toyota Motor Vietnam (TMV)

Toyota Motor Vietnam (TMV) was established in 1995 as a joint venture between Toyota Motor Corporation and VEAMCORP. Toyota was one of the first foreign automobile manufacturers to enter the Vietnamese market (Baolaodong, 2016). TMV has established a broad network of authorized dealerships and service centers across the country, reaching over 80 locations in dozens of provinces and cities, operating under the 3S/4S model.

Over its 3 decades venture, TMV's operation had reached 700,000 vehicles produced and 1.04 million vehicles sold (1995 - 2025) (Toyota, 2025; Vietnamplus, 2026).

TMV plays an important role in Toyota's operation in the SEA region. As an original function, TMV operates an automobile manufacturing plant in Vinh Phuc province, where it engages in assembly and production of vehicles. TMV also manages the sales and distribution of vehicles as a hub of information for a dealer network while providing customer support, and replacement parts.

As a regional manufacturer, TMV can provide parts exports, and supplier linkages, support ASEAN regional lean supply lines and adapt Toyota's strategy of production and distribution networks to local market conditions (Riza Noer Arfani & Awan Setya Dewanta, 2018).

4.2. Case study of the 2021 – 2022 crisis: How data gaps led to production halts during the 2021 – 2022 crisis

4.2.1. The Nature of the 2021–2022 Supply Chain Crisis

During 2021, widespread lockdowns and escalating COVID-19 cases in Southeast Asia severely impacted Tier 1 and Tier 2 suppliers. Operations at crucial plants producing wire harnesses and other essential components were suspended, shutting down Toyota’s assembly lines, since wire harnesses are essential and not easily substitutable within the JIT system. The inability to track these disruptions in real-time contributed to delayed responses and downstream production halts (Business day, 2021).

Toyota had been forced to make cuts to its planned output for September 2022 because of the spread of Covid-19 in South-East Asia and the ongoing shortage in the supply of semiconductors. As reported in August, the carmaker planned to cut production by 40%, equal to around 360,000 units. Further changes had been made and it was estimated to have cut production by a further 70,000 units, with 30,000 accounted for in Japan (Automotive logistic, 2021).

In fiscal 2022, Toyota reported a 25% drop in quarterly operating profit, 562.7 billion yen operating profit as opposed to expectations, attributed in part to the persistent parts shortage and related production cuts (Toyota’s official report, 2026).

4.2.2. Information Gaps and Data Blind Spots in Toyota’s Supply Chain

- **Limitations of Visibility:** When Toyota signals a need for materials, Tier 1 receives the order and begins assembly. To assemble, Tier 1 signals need for materials from Tier 2. When pandemic occurred, Tier 2 factories in Southeast Asia were suddenly shut down, resulting in Tier 1 still receiving orders from Toyota but lacking materials from Tier 2 production. JIT prioritizes lean inventory and synchronized deliveries based on real demand signals. However, the system relies on intermittent visibility beyond immediate suppliers, thus Tier 1 had no stock to continue producing. It revealed that Toyota’s ability to monitor multi-tiered supplier operations was limited, where restrictions disrupted operations without immediate notice to headquarters. Consequently, it became a data blind spot in anticipating cascading failures (Yang Sitong, 2022).
- **Real-Time Disruption Detection:** Sudden supplier production stoppages outpaced Toyota’s visibility and forecasting. When new variants break out in Southeast Asia, information about the Tier-2 plant can be periodically transmitted to Toyota. This means Toyota only discovers the disruption when the remaining components in its buffer stock are used up. At this point, finding alternative suppliers is late due to the long lead times. Integrating Big data analytics with AI allows the identification of potential disruption signals, enabling timely corrective actions (Federico Briatore et al., 2025). As real-time data management and predictive analysis allow the SC to quickly adapt to changes in market conditions or customer needs; the integration of IoT sensors and AI facilitates a more dynamic, responsive and resilient SC by identifying early warning signs of sudden disruptions. (Federico Briatore et al., 2025)

- Dependency on External Data Flows: Toyota's SC historically relied on periodic planning data, forecasts, and supplier reports, rather than continuous sensor driven or real time tracking across global networks. As the pandemic altered production capacity, demand patterns, and shipment timelines, the older planning and reporting cycles became insufficient. Gaps in continuous data exchange hindered Toyota's ability to proactively adjust production sequencing, reroute parts, or deploy contingency strategies at scale. This reflected a classic blind spot in extended supply chain visibility.

4.2.3. Consequences

The accumulation of unseen delays upstream eventually forced Toyota to adjust output globally. In late 2021, Toyota announced significant production cuts, reducing global output due to part shortages originating in Southeast Asia. These disruptions became visible to production planners only after inventories dwindled below critical thresholds, forcing reactive rather than proactive mitigation.

Information blind spots also manifested in downstream markets. Dealer inventories ran low, leading to empty showroom lots for some models and extended delivery wait times a direct consequence of upstream visibility failures and supply delays. The inability to accurately predict supply inflows contributed to inventory depletion and customer impact.

This shortage creates a domino effect which disrupts production plans, distributor allocations, and logistics schedules in many regions. In a report of July 2021, country-wide production fell 33% from the same period last year. Both production and selling fell heavily, dropping by 53% by September compared to the same period. Customer's orders and sellers' orders experience late deliveries, hitting TMV's annual profit (Tapchicongthuong, 2021).

4.3. Implementation of Data Transparency and Digital Twins at Toyota Manufacturing

4.3.1. Tier-N Connectivity and Data Transparency

- Tier-N connectivity: refers to the ability of a manufacturer to access and integrate data not just from direct (Tier-1) suppliers but also from secondary (Tier-2, Tier-3, etc.) suppliers, logistics partners, and internal systems. To accommodate new information requirements, Toyota has applied the following technologies:
- Supply Chain Data Sharing with ERP: Toyota Vietnam has implemented an SAP S/4HANA Enterprise Resource Planning (ERP) system, which centralizes core operations such as inventory, production planning, finance, and supplier tracking. This platform enhances internal data integration and transparency across functions, enabling managers to access real-time information for decision-making. The ERP acts as a primary digital backbone for collecting and sharing data within the organization and aligning operational activities with global Toyota systems (FTP IS, 2024).

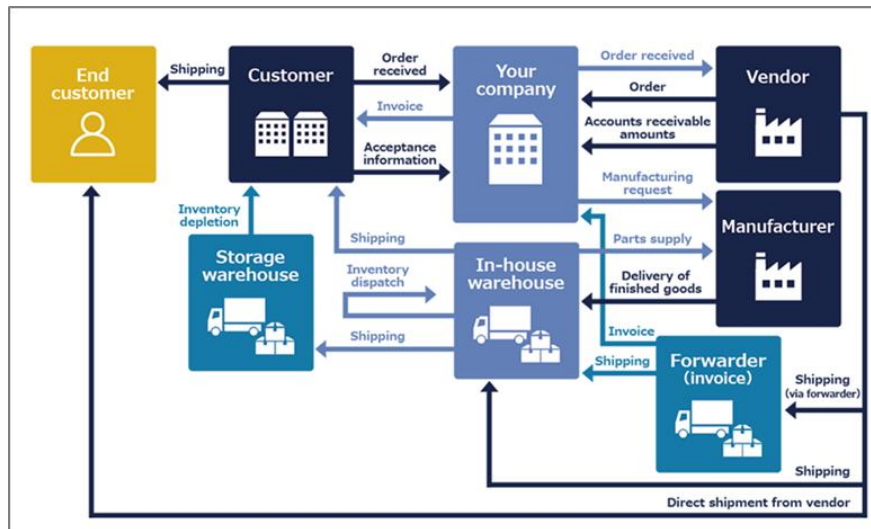


Figure 3: Template of a SAP S/4HANA Model in a Supply Chain

Source: NTTDATA

- IoT and Sensor-Driven Data Flows: Toyota globally leverages IoT sensors and industrial automation to capture equipment status, production metrics, and quality data in real time. Such sensor-driven datasets constitute a key component of visibility, providing the data streams necessary for both digital twins and early disruption detection (Toyota, 2023).

4.3.2. Digital Twin Simulations

Digital twins are virtual replications of physical systems (factories, production lines, or even supply networks) that can simulate, analyze, and predict operations under various conditions. Using real, static information, digital twin simulation can translate them into possible scenarios, applying new variables to examine multiple possibilities to gather information, prediction, and feasibility of actions.

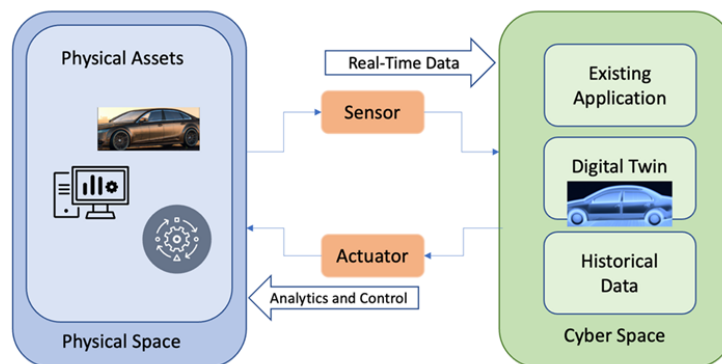


Figure 4: Model of Digital Twin Operation

Source: txOne

Toyota has publicly documented the use of digital twin technology in manufacturing environments, particularly in Europe, which could conceptually extend to other regional plants like Toyota Vietnam. These digital replicas allow production engineers to:

1. Study operational flows and ergonomic layouts before implementation in the physical factory.
2. Finding possible failures before they occur and supporting proactive decision-making.
3. Accelerate cross-site cooperation.

By creating a comprehensive virtual representation of its global supply chain, the company achieved remarkable operational improvements through an integrated platform that combined real-time IoT sensor data, predictive maintenance algorithms, and dynamic inventory management systems. The digital twin approach enabled Toyota to realize significant performance enhancements, including a 35% reduction in inventory holding costs, a 42% improvement in production line responsiveness, and enhanced predictive maintenance capabilities across its global logistics network (Oluwakemi Adesola Itunu Taiwo & Damilola David Adeyemi, 2025).

Digital twin simulation has been used for planning by the TMV, and possible application in Toyota Vietnam is being considered after the implementation of the SAP S/4HANA system.

4.3.3. Application of Synology system in TMV

From 2024, TMV has started operating within the Synology storage system to safely store hundreds of terabytes of data from operation each year. With high reliability and easy access, Synology system allows TMV to quickly recover from any blackout or disruption of the system faster than most other storage frameworks available.

Toyota uses Synology's enterprise-scale SAN system to centralize data storage across multiple levels, with petabytes of data handling ability. Implementing active-active SAN architecture ensures Toyota's ability to operate critical workloads, with a failsafe option to prevent disruption of the chain. At the same time, Toyota employs ActiveProtect DP7400 appliances to perform backups with immutable storage. This is applied to key servers and virtual machines, giving high resistance to data corruption or ransom attacks. In addition to its backup role, the ActiveProtect DP7400 also functions as a management server at headquarters, streamlining backup management for the infrastructure through a single interface (Synology, 2024).

For daily operation, TMV uses 150 VMs backed up directly to Synology SA3410. For enhanced protection, Snapshot Replication replicates VM backups from SA3410 to five remote Synology RackStation units, providing an extra layer of security and disaster recovery. This allows branches to get data from the headquarters quickly and separate critical data from the usual information flow, ensuring security of information.

4.3.4. Smart JIT in Manufacturing

To precisely pin-point where each implementation of technology creates a difference compared to the old model of production, we can cut down the TPS into 3 main layers of production, and within each, what has been improved.

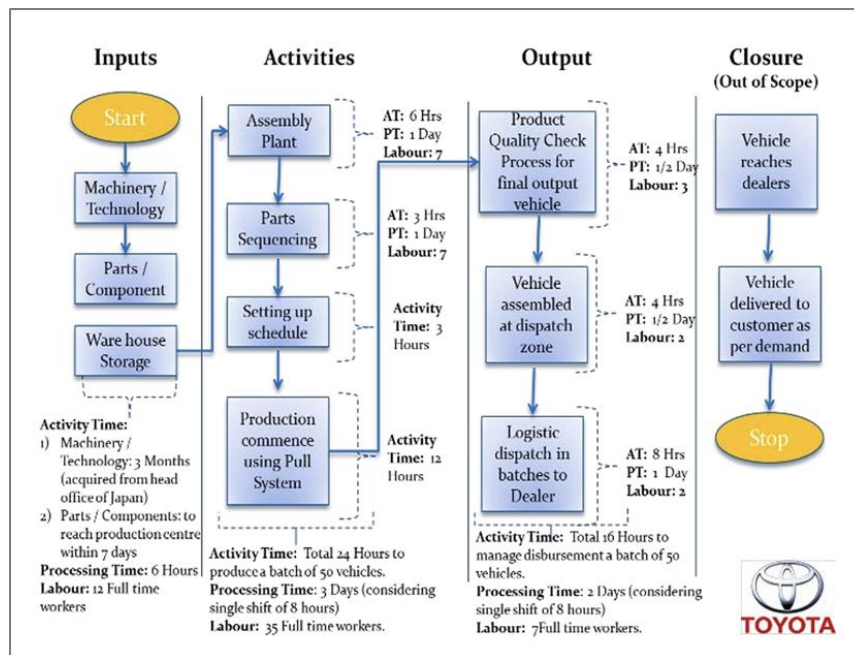


Figure 5: Toyota's Manufacturing Flow Analysis

Source: Osama Alshehri

a. Input Layer

Tier N Connectivity addresses the "visibility gap" that previously afflicted the JIT pillar at the input stage. Toyota had good communication with Tier 1 suppliers but little insight into the levels of raw materials or subcomponents, leaving the system to shocks from a distance. Toyota fortifies the JIT pillar by creating a transparent digital thread throughout all tiers, which guarantees that "pull system" is synchronized with the entire global network and the immediate supplier. Due to this connectivity, the supply chain is no longer reactive, Toyota only became aware of a shortage when a part did not arrive, but predictive, where possible delays are identified weeks in advance. This greatly enhances TPS resilience to variables in production.

b. Manufacturing Layer

The Jidoka pillar is strengthened on the factory floor by the interaction between IoT/Smart Sensors and the Digital Twin. When a flaw was discovered, Jidoka used mechanical stoppers or employees pulling a "Andon" cord to stop the line in the analogue TPS. These days, IoT sensors serve as Jidoka's "digital eyes," picking up on minute vibrational or thermal irregularities that are invisible to humans. A Digital Twin, which acts as a virtual testing ground for Kaizen, receives real-time data from these sensors. Engineers can now simulate thousands of variations in the digital space to find the most efficient flow, whereas prior to implementation, a change in line speed or layout required physical downtime for trial and error.

c. Output Layer

At this stage, Data Transparency and Digital Twins make sure that the finished car precisely satisfies TPS's "built in quality" requirement. Prior to these technologies, quality control frequently relied on post-production inspections or sampling, which could overlook sporadic errors. Every car now has a "digital certificate" that allows for 100% traceability of every part thanks to IoT data gathered during the vehicle's production on the assembly line. By guaranteeing that the system can immediately trace back to the precise sensor reading and machine state at the time of failure, this improves the Jidoka principle in the event that a defect is later found.

d. Closure Layer

The end result of this process is a move away from the detection of defects and instead the prevention of defects, so the output stage of the process maintains a "one piece flow" with zero rework or scrap, maximizing the value to the end customer.

4.4. Toyota's JIT Supply Chain Model

The Toyota Production System (TPS) combines attitudes, themes and specific techniques into an integrated socio-technical system for manufacturing. The main point of the TPS is to create a supply chain that is able to detect, and remove any waste during operation. The basic philosophy of the TPS is based on two main principles: Jidoka (automation with a human touch), and Just-in-Time, based on the concept of synchronizing production processes- making only what is needed, when it is needed, and in the amount needed.



Figure 6: Advantages of JIT Lean Manufacturing Production Line

Source: 6sigma

As the Just-in-Time Model has been updated and upgraded in order to meet the current demand and solve problems, here are some key points summarized to illustrate the differences of Traditional JIT Model and Smart JIT Model:

Table 1: Traditional JIT versus Smart JIT

Criteria	Traditional JIT Model	Smart JIT Model	Key changes
Kanban System	Physical kanban cards, strict 4 rules (pull from downstream, 100% defect-free, reduce kanban count over time)	Electronic kanban and SAP S/4HANA integration, maintains 4 rules with digital signals	From Paper to Digital backbone via ERP
Supply Chain Visibility	Intermittent Tier-1 visibility only, data gaps caused halts (Vietnam wire harness crisis)	Internal SAP and IoT sensors (Tier-1 focus, Tier-2/3 development phase)	From periodic reports to Real-time internal data
Disruption Response	Reactive - 40% production cuts when suppliers stopped	Proactive planning with Digital Twin simulations (Europe model), enhanced Jidoka	Simulation before halts
Data Storage & Resilience	Manual/legacy systems, vulnerable to blackouts	Synology SA3410 and ActiveProtect DP7400, 150 VMs backup, 5-site disaster recovery	75% IT protection cost reduction
Supplier Quality Control	Strict standards but no real-time Tier-2/3 monitoring	ERP-based supplier tracking and quality compliance via 4S/5S	From Compliance to Data-driven quality
Crisis Impact	33-53% production drop Vietnam 2021 due to blind spots	Strategic safety stock + improved multi-tier visibility	From Zero inventory to Calculated buffers

Source: Synthesized by the authors

4.5. Overview of Automotive Industry in Vietnam

In Viet Nam, car manufacture is considered as a key economic driver which has always received special care and support from the government. As a result, in recent years, Vietnam's car manufacture has several improving points, with the rise of insourcing and localization rate. However, the manufacturers do face some challenges.

4.5.1. Current Situation

First, the revenue of car manufacture in Vietnam in 2025 has great results. According to the latest data released by the Vietnam Automobile Manufacturers' Association (VAMA), sales performance among its member companies showed several positive signs. In particular, total industry sales reached 375,736 vehicles, representing a 10.5% increase compared to 2024, a growth rate considered encouraging given the prolonged period of stagnation previously experienced by the automotive market. In short, VAMA Sales Record Double-Digit Growth as the Market Accelerates Sharply Toward Year-End.

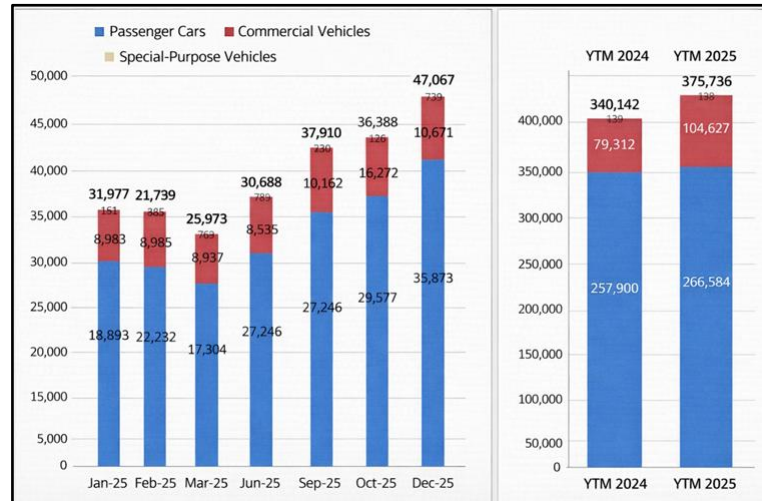


Figure 7: Total vehicle sales across the VAMA automotive market in 2025 increased by 10.5% compared with the previous year

Source: VAMA

Regarding market share, Vietnam automotive market share chart indicates that VinFast holds a dominant position with 29%, followed by Toyota at 12%, Hyundai at 9%, Ford at 8%, Mitsubishi at 7%, and Mazda and Honda at 5% each. This distribution reflects a highly fragmented market structure, also highlighting a clear shift toward electric and hybrid vehicles.

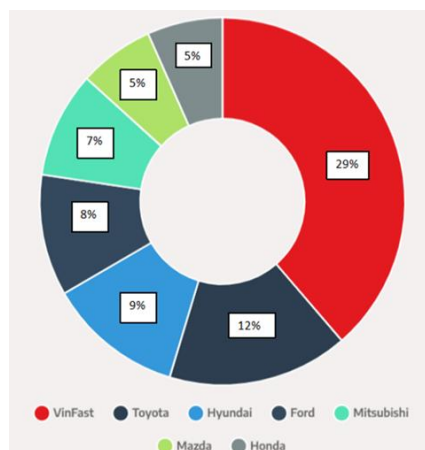


Figure 8: Market Share of Automotive Brands (2025)

Source: Vnbusiness

Focusing on Toyota, the company maintained a 12% market share with total sales of 71,954 units, outperforming both Ford (50,450 units, 8%) and Mitsubishi (44,107 units, 7%). The strong performance was largely the result of a 58% growth in hybrid vehicle sales, with the Veloz Cross and Innova Cross standing out as models well aligned with Vietnam's current infrastructure (Vietstock, 2026). As a result, Toyota achieved stable year-on-year growth of 8%, with relatively low dependence on tax incentives.

In addition, Toyota benefited from a more resilient supply chain, as its component sourcing from Thailand and Indonesia faced fewer disruptions. In contrast, competitors such as Ford and Mitsubishi were more affected by the global semiconductor shortage and a 20% rise in maritime logistics costs in 2025, factors that constrained deliveries. This supply stability enabled Toyota to meet delivery schedules consistently and maintain customer trust.



Figure 9: Automobile Sales and Growth by Brand (2025)

Source: Vnbusiness

4.5.2. Characteristics of Vietnam Automotive Manufacturing sector

In terms of Strength, the total revenue of automotive manufacturing experienced a 38.6% growth in 2025 with a high level of revenues in comparison with the previous period. Within strong government support, 2025-2045 policy and tax promotion for EV/ Hybrid car and 10% growth in FDI, many local brands won the race of revenue, utilizing smartly domestic production and insourcing. (Nguyen Thuy Tien, Vietnam Briefing, 2025)

However, there are some weaknesses in the performance result in 2025. Within 20-30% local utilization (Vietnam News, 2025), Vietnamese automotive manufacture still relied on outsourcing and importation, which leads to high production cost and limited scale. More importantly, manufacturers may face the risk of chain disruption (due to possible semiconductor shortages, logistics constraints, and geopolitical factors), longer lead times, making it difficult to respond quickly to market fluctuations.

Fortunately, opportunities are available in this case. Regional integration through frameworks such as ASEAN and RCEP helps reduce tariffs and allows manufacturers to diversify their supply sources more effectively. At the same time, foreign direct investment

plays a key role in supporting the development of local suppliers, which contributes to higher localization rates over time. In addition, the shift toward hybrid and electric vehicles has generated new demand for high-tech components, encouraging technological upgrading within the supply chain. Finally, long-term strategic partnerships with suppliers enable automakers to better control costs and maintain consistent product quality.

4.5.3. Trends of Vietnam Automotive Manufacturing sector in 2026

Within the forecasted challenges for 2026’s market (Beecham, 2026 Automotive Supplier Outlook, 2026), the automotive industry continues to face supply chain disruptions, as manufacturers remain heavily dependent on imported components, accounting for around 70–80% of total parts sourced mainly from China and Thailand (Vietnam News, 2025).

In addition, stricter fuel efficiency standards pose further challenges. The CAFC requirement of 4.83 liters per 100 kilometers in 2030 (Laodong.vn, 2025) has forced manufacturers to significantly expand hybrid and electric vehicle offerings. However, limited charging infrastructure and higher costs of green components have pushed vehicle prices up by 20–30%.

The market is also under pressure from intensifying foreign direct investment competition. Chinese automakers such as Chery and BYD are establishing manufacturing facilities, while low-priced Chinese vehicles are increasingly entering the ASEAN market, placing greater pressure on domestic production, where localization rates currently remain at only 20–30%.

Finally, high interest rates and weakening consumer purchasing power have constrained market growth, which is projected to reach only 6–8%. This slowdown has particularly affected the mass-market segment, where demand is more sensitive to financing costs.

5. Discussions and Recommendations

5.1. Evaluation of Smart JIT Implementation

Table 2: Evaluation of Smart JIT Implementation

Fields of Evaluation	Pros	Cons
Operational Evaluation	- <i>The integration of Tier-N Connectivity eliminates the “Bullwhip Effect”, allowing TMV to monitor the production schedules of local suppliers in real time and adjust the assembly line in Vinh Phuc’s factory. This directly results in the reduction of idle time by 15 - 20% (QA Logistics, 2021).</i>	- <i>High dependency on data integrity results from the essence of digital twin technology, a modeling environment requiring software synchronization (Belcan, 2023). Once a Tier-2 supplier inputs inaccurate production data into the shared ecosystem, the Digital Twin can generate "hallucinated" lead times, potentially causing line stops.</i>

Fields of Evaluation	Pros	Cons
	<p>- <i>The application of Digital Twin</i> brings about considerable improvement, including a 35% reduction in inventory holding costs, a 42% improvement in production line responsiveness, and enhanced predictive maintenance capabilities across its global logistics network (Adesola, 2025). In Vietnam, this supports the increase in the production process from the current 47,000 vehicles/year to 100,000 vehicles/year after the investment of 360 million USD into hybrids (JustAuto, 2025).</p>	<p>In the context of Vietnam, with the quantity of local suppliers up to 61 (Toyota Vietnam, 2025), this risk increases since the digital infrastructure is not uniform, making it difficult to synchronize on a large scale. This situation leads to digital inequality, limited system compatibility, difficulty in scaling and increased security risks due to legacy technologies. The lack of synchronization also leads to higher operation costs and slower digital transformation process</p>
Financial Evaluation	<p>- <i>Reduction in Working Capital:</i> By using digital simulations to replace physical safety stocks, TMV can minimize "capital traps" with funds tied up in idle inventory. Even a 5% reduction in inventory holding costs across Toyota's vast SKU range can bring about millions of USD in liquidity (Vilas, 2022). Combined with the hybrid tax-reduction policy effective from 2026 (Nhân Dân, 2025) TMV can put aside an additional 20–30% cost of imported green components (Vietnam Briefing, 2025).</p>	<p>- <i>High Initial CAPEX:</i> The cost of implementing IIoT sensors, Digital Twin software licenses (like Siemens or SAP), and training staff can be up to millions of USD (Karunaratne, 2025). The Return on Investment (ROI) is typically from 3 to 5 years, which may be challenging for smaller local partners in Toyota's supply chain. Specifically in Vietnam, this exerts a major obstacle in the context where the industry's localization rate is only 12–20% (Xuyen Dong, 2025).</p>
Feasibility Evaluation	<p>TMV can leverage Toyota's global initiatives such as "Woven City" and "Digital Factory", which have been successfully implemented at Toyota plants in Europe and Japan, delivering a 20–30% reduction in</p>	<p>Although Vietnam's national digital infrastructure is improving with broadband coverage reaching 99.3% of villages (Ministry of Science and Technology, 2024), a large number of</p>

Fields of Evaluation	Pros	Cons
	<p>predictive maintenance time (Toyota Global Newsroom, 2023). In Vietnam, this aligns with the National Digital Transformation Strategy to 2025, with a vision to 2030 (Decision No. 749/QD-TTg) and the plan for 2026, which considers 2026 as a breakthrough year for digital technology, featuring mobile broadband speeds of 170 Mbps and 5G coverage reaching 99% of the population (Du Lam, 2026). An investment of USD 360 million in a hybrid vehicle plant in Phuc Yen (Phu Tho) starting in 2025 will support the integration of IIoT and Digital Twin technologies, increasing capacity from 47,000 to 100,000 vehicles per year by 2028, while also promoting green transformation in line with the Net Zero 2050 target (Huy Hoang, 2025). Moreover, Smart JIT has strong potential for high-quality job creation since TMV currently generates 1,500 direct jobs and 76,000 indirect jobs through 61 local suppliers (VNA, 2025). This implementation will expand the ecosystem and support the localization target which delivers an attractive ROI for investors through cost reduction and productivity gains, while also supporting national policies on the development of supporting industries.</p>	<p>TMV's local suppliers still rely on manual Excel-based processes and lack ERP systems, creating risks for real-time data integration. Local suppliers are often reluctant to share cost and capacity data due to concerns about losing bargaining power with TMV which are highly dependent on FDI with approximately 70-80% imported components (Phuc Hau, 2025). Furthermore, Vietnam faces a serious shortage of talent in Lean Manufacturing and Data Science (Doanh nhân Sài Gòn, 2016). Despite progress through education and training partnerships factories primarily need staff who can interpret data and operate digital systems rather than highly advanced AI experts. This creates a mismatch between training supply and actual industry needs (Bao Anh & Bong Mai, 2026), potentially extending implementation timelines by 6–12 months without targeted upskilling programs.</p>

Source: Synthesized by the authors

5.2. Recommendations

With a clear understanding of the opportunities and challenges involved in adjusting the Just-In-Time (JIT) system according to Toyota's practices, car manufacturers in Vietnam, including Toyota Motor Vietnam (TMV), can gain a competitive advantage by applying the key recommendations from the study of Toyota's adjusted supply chain into their practices.

For Toyota Motor Vietnam (TMV), it is necessary to prioritize building a data-sharing network across the entire ecosystem and starting with a 12-month pilot program to reduce the "Bullwhip Effect" which cuts down on idle times and increases the localization rate. The integration of artificial intelligence (AI) into forecasting input material price fluctuations, combined with Digital Twin, will help decrease logistics costs, increase production line flexibility and eliminate the risk of global supply chain disruptions. Moreover, TMV should put more emphasis on developing green vehicle components, including batteries, energy management software, to reduce vehicle costs from imported components and take advantage of the hybrid tax exemption policy from 2026 and the CAFC standard of 4.83 liters/100km by 2030.

For the automotive industry in Vietnam, manufacturers need to establish a structured periodic market and demand assessment processes to promptly detect changes in consumer preferences, economic conditions, or external disruptions. Proactive planning processes are essential for the flexible adjustment of production capacity to regional demand fluctuations. Imported components must be maintained at safety stock levels to minimize the risk of delays due to geopolitical tensions, port congestion, or pandemic restrictions. Simultaneously, companies should gradually reduce physical inventory at dealerships by investing in advanced digital forecasting tools and real-time tracking platforms, therefore freeing up working capital and responding more quickly to end-consumer demand fluctuations.

For procurement, manufacturers should learn from Toyota's disciplined approach by minimizing purchases of non-critical components while ensuring a stable flow of high-value or bottleneck components. Domestic and regional supply sources are essential to be diversified to create buffers and reduce reliance on a single source. In terms of risk management, businesses need to adopt a hybrid inventory model, strategically positioning important goods while maintaining lean principles. A flexible production system with modular line design and a multi-skilled workforce is of significance to maintain continuous operations during sudden spikes in demand or supply disruptions. Workers need to be empowered to make decisions and to be trained in multiple skills and assigned roles that adapt to unexpected absences, reducing dependence on on-site personnel during crises while ensuring quality and safety.

Building trust and ecosystem cooperation is the foundation for sustainable success. Manufacturers should prioritize transparent communication with upstream suppliers and downstream distributors, sharing real-time operational data and jointly developing response protocols. Implementing customer-centric practices, relating to enhanced after-sales support, proactive quality feedback loops, and clear social responsibility initiatives, will strengthen brand loyalty and mitigate reputational risk. Developing and regularly testing a comprehensive

Business Continuity Plan (BCP), with clear escalation procedures, alternative supply lines, and recovery timelines for major disruption scenarios, is an essential step.

From the analysis of Toyota's strategic shift from traditional Just-In-Time to Smart JIT, Vietnamese automakers, from TMV to other enterprises, can transform potential weaknesses into strengths in resilience and efficiency. Selectively adopting Toyota's JIT philosophy to suit the local market will help businesses achieve higher cost competitiveness, superior supply chain flexibility, and sustainable growth in an increasingly volatile industry that is heavily reliant on digital technology and green transformation in 2026.

6. Conclusion

In conclusion, the utilization of Smart Just-in-Time is not a complete replacement of traditional Just-in-Time method, it is a more helpful, flexible technology companion for manufacturers to meet the demand of unpredictable changes in automotive manufacturing in Vietnam and the world, in general.

By applying real-time data transparency together with Digital Twin technology, Toyota Vietnam is able to reduce its reliance on physical safety stock and instead depend more on predictive capabilities. Digital Twins support more proactive decision-making by simulating potential risks such as port congestion or supplier delays, which allows production plans to be adjusted in a timely manner. In the context of Vietnam's automotive industry, where manufacturers still depend heavily on imported components, face increasing competition, and are under growing environmental policy pressure, Smart JIT provides a supply chain model that is more flexible and better able to adapt to change.

All in all, Smart JIT can be seen as a natural next step in Toyota's Lean philosophy, as it allows the company to keep costs under control, maintain stable operations, and respond more effectively to changes in both the domestic and global markets.

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