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ORIGINAL ARTICLE

# Just-in-time for supply chains in turbulent times

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**Abstract**

The Covid-19 pandemic and other recent disruptions in the early 2020s led to sections in the business press blaming just-in-time (JIT) practices for operational failings. Consequently, there are calls for moving away from JIT toward holding more inventory as preparation against future disruptions, which is referred to as just-in-case. The academic community is also divided. Some scholars argue that JIT is not resilient, while others maintain that JIT can continue providing superior performance even with disruptions. Motivated by this debate, we discuss various misconceptions about JIT that underlie this debate. Furthermore, we present different ways to adapt JIT for turbulent environments and argue that companies can improve their supply chain performance if JIT supply chain segments are chosen fittingly—even more so—during disruptions.

**KEYWORDS**

disruptions, inventory, JIT, just-in-time, supply chain resilience

## 1 | INTRODUCTION

Disrupted supply chains have been a hot topic in the early 2020s, with shortages resulting from Covid-19 and related lockdowns. Then came the post-pandemic consumer demand surge. At the same time, the supply of commodities and gas was disrupted by the Russian invasion of Ukraine and western countries' sanctions on Russia. Popular media have blamed just-in-time (JIT) practices in various sectors for these systemic disruptions.[1,2,3] For example, the business press has singled out JIT for the semiconductor chip shortages in the auto industry[4] along with disruptions to other sectors.[5] Worldwide auto production losses were estimated to be $210 billion for the year ending in September 2021.[6] Therefore, there is movement in the industry to retreat from JIT to just-in-case, with Toyota's pre-pandemic stockpile of chips often cited as an example.

Could it be that JIT practices are suitable only for "stable" but not "turbulent" times, or does JIT have to be adapted to fit different circumstances? We answer this question by revisiting the JIT concepts in the context of turbulent global supply chains. Our approach as a group of co-authors was to "debate a phenomenon of interest" (MacInnis, 2011, p. 138) as topical experts from different academic backgrounds and industry experiences. Individually, we endorsed or rebutted the comments of the business press regarding JIT and the successive disruptions in the early 2020s.

In this article, we revisit JIT against the background of disruptions and the related criticisms of JIT. Section 2 briefly reviews the origin of JIT in Toyota to set the scene. In Section 3, we tackle five common misconceptions of JIT in the literature and practice. In Section 4, we characterize JIT in terms of its fit with the *supply chain*—not just the plant—and what would be needed to extend JIT to turbulent conditions. Section 5 then presents different ways JIT can be—and is being—adapted for such situations in the supply chain. Finally, Section 6 concludes with some areas of further research.

## 2 | BACKGROUND

JIT is a management philosophy first developed within the Toyota Motor Company as part of its Toyota production system (TPS) (Ohno, 1988; Sugimori et al., 1977). The

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philosophy emerged after World War II with Japan's need to rebuild after the devastation caused by the war and strengthen its industrial base. It is focused on increasing product quality, reducing lead times, and reducing inventory and manufacturing costs. When proposed in the literature during the 1970s, scholars and practitioners viewed JIT as a radical new approach to manufacturing processes (Sugimori et al., 1977; Sepehri, 1986). In the 1980s and 1990s, JIT gained worldwide prominence as companies in different sectors adopted it (Schonberger, 2007). Indeed, the approach has led to impressive benefits in manufacturing, including significant reductions in operating costs, improved quality, and increased customer satisfaction. Companies such as Honda, GE, Boeing, Lockheed Martin, Hewlett-Packard, IBM, McDonald's, Volvo Group, Zara, and many others have credited part of their success to JIT.

Although there is no universally accepted definition of JIT, we can understand it from its origins at Toyota. Indeed, there is a great deal of scholarly and practitioner literature, and our intent is not to summarize it here. Instead, as a working definition, we start with the description of JIT found on Toyota's global webpage, which matches well with authoritative sources on JIT and the TPS (e.g., Cusumano et al., 2021; Liker, 2004; Monden, 2010; Ohno, 1988; Sugimori et al., 1977):

> Producing quality products efficiently through the complete elimination of waste, inconsistencies, and unreasonable requirements on the production line (known, respectively, in Japanese as *muda*, *mura*, *muri*). In order to fulfill an order from a customer as quickly as possible, the vehicle is efficiently built within the shortest possible period of time by adhering to the following: (1) When a vehicle order is received, production instructions must be issued to the beginning of the vehicle production line as soon as possible. (2) The assembly line must be stocked with the required number of all necessary parts so that any kind of ordered vehicle can be assembled. (3) The assembly line must replace the parts used by retrieving the same number of parts from the parts-producing process (the preceding process). (4) The preceding process must be stocked with small numbers of all types of parts and produce only the numbers of parts that were retrieved by an operator from the next process.[7]

What is remarkable about this description is that it discusses JIT only as an intra-logistics concept for assembly production lines. It describes how Toyota ensures all parts needed for assembly are present at the right place, at the right time, and in the right quantity and quality, and is the essence of JIT. Applying JIT to a stable mass production system in a homogenous market is simple; it becomes more complex when there is variation in products, processes, and demand. Although challenging, JIT is the philosophy that has enabled Toyota to produce different car models with millions of variants on the same production line—faster and cheaper than its competitors.

To achieve JIT in its assembly factories, Toyota uses a range of supporting principles and practices. For example, to help synchronize manufacturing and logistics processes, Toyota calculates and enforces *takt times* in their operations. Because having a defective part at an assembly station violates the JIT philosophy, Toyota builds quality into processes with practices such as error-proofing (*poka-yoke*) and visual management. Because parts must arrive at the assembly station on time, Toyota developed the *kanban* system for robust material replenishment. Because stockpiling large batches of components at the point of use is not JIT supply, Toyota developed the quick die-change system, which surfaced errors early and reduced lead times for individual parts. Because manufacturing errors are bound to happen, Toyota developed the *andon* system to call for all necessary help instantly and use problem-solving practices to find and eliminate the root causes of errors. As a practical framework to recognize and reduce obstacles to JIT in the system, Ohno (1988) developed the *seven waste* model, including (1) transportation, (2) inventory, (3) motion, (4) waiting, (5) overproduction, (6) overprocessing, and (7) defects as wastes. It is critical to understand that the key to Toyota's success was not the deployment of any of these practices in isolation but the coherent deployment of these supporting principles and practices in unison (Liker, 2004).

From the start, Toyota integrated its first-tier suppliers into the JIT concept and propagated the philosophy in its upstream supply chain. For example, you will hardly see any seats when you visit the Toyota Camry plant in Georgetown, Kentucky. The underlying reason is not that the inventory is simply pushed back to Johnson Controls, its seat supplier, to hold. Instead, Johnson Controls produces the seats needed *and* delivers them to the Toyota plant JIT through kanban, with only the necessary in-transit inventory. Implementing JIT allows more than just eliminating inventory. It enables workers to discover and solve problems faster and more comprehensively than if there were large amounts of inventory. JIT also reduces the opportunities and slack for quality errors because it makes manufacturing defects visible; in contrast, large-batch production makes any defects harder to find.

The two main differences between using JIT in the external supply chain versus logistics within the plant and its co-located suppliers are that JIT in the supply chain typically involves (1) coordination between self-governing companies (Baudin & Netland, 2022) and (2) greater geographical distance. As with the Johnson Controls seat plant near the Toyota plant, the automotive industry has generally sought first-tier suppliers' plants right next door or, at most, within a few hours' drive from the assembly factories. This supply chain configuration, however, is not typical in other industries, which makes geographic distance an essential factor to consider when implementing JIT practices. In addition, given the lack of direct ownership and control in upstream entities in the supply chain, Toyota reduces potentially opportunistic supplier behavior by developing close and supportive buyer–supplier relationships (Shih, 2022a).

## 3 | MISCONCEPTIONS ABOUT JIT

Several misconceptions arose as other companies implemented JIT, including in other sectors. For example, one misperception is that JIT is about lowering inventory, which makes it susceptible to disruptions, as observed during the pandemic. High levels of just-in-case stock could tide over occasional shortages and prevent a systemwide disruption. Hence, managers perceive the need to move away from JIT by building up inventory when they can, *in case* a disruption requires inventory to tide things over. However, such thinking misses the essence of the JIT philosophy, as we shall clarify. Next, we summarize five recurrent misconceptions of JIT that have resurfaced during the Covid-19-affected period from 2020 to 2022:

1. JIT can be implemented piecemeal, à la carte;
2. JIT means no inventory;
3. JIT is the cause of shortages;
4. more inventory, not JIT, is a solution for resilience; and
5. JIT is the best operating model.

### 3.1 | Misconception 1: JIT practices can be implemented piecemeal, à la carte

The operations literature has conceptualized JIT alternatively as a *manufacturing philosophy* (Upton, 1998) or a *set of practices* (e.g., Shah & Ward, 2003; White et al., 1999). It was always unclear what JIT really is (Goyal & Deshmukh, 1992; Shah & Ward, 2007). Consequently, individual firms (and their consultants) interpreted the philosophy and practices, the latter being easier to put into practice. Indeed, in their haste to see results, companies implemented a single or few JIT practices in isolation. However, *JIT is a manufacturing philosophy manifested in a system of practices linked to superior performance only when implemented in a cooperative spirit*.

The empirical operations literature linking JIT to performance has viewed JIT in several ways: (1) as a single-dimensional construct (e.g., Bortolotti et al., 2013; Shah & Ward, 2003; Swink et al., 2005; Ward & Zhou, 2006), (2) as a multidimensional construct (e.g., Ahmad & Schroeder, 2001; Cua et al., 2001; Fullerton & McWatters, 2001; Matsui, 2007), or (3) as multiple constructs corresponding to selected individual JIT practices (e.g., Avittathur & Swamidass, 2007; Inman et al., 2011; Ketokivi & Schroeder, 2004; Narasimhan et al., 2006). Given the lack of a generally accepted conceptualization of JIT in the literature, we consider a metastudy in which Mackelprang and Nair (2010) use 10 JIT practices in their meta-analysis, following Mehra and Inman (1992) and Sakakibara et al. (1993) (Table 1).

The idea pursued in most of the survey- and audit-based research is that researchers can measure each practice by the extent to which the company follows that practice, independently from the other practices. Unfortunately, such measurement has the unfortunate consequence of engendering and reinforcing the idea that JIT is a menu of practices companies can implement à la carte. What is measured is what gets management, and it is easier to administer a research survey with 10 items and ask respondents to score each on a Likert scale than to present them with a causal-loop diagram representing JIT practices. Likewise, companies may find it easier to audit factories and units on the adherence to a set of practices than on the interplay among them.

However, the practices (Table 1) are intertwined and need to be implemented together for successful JIT implementation. For example, one can only have smaller lot sizes through preventive maintenance and reduction of setup times. JIT deliveries from suppliers require a JIT link with them and kanban, which also ensures the pull system. Likewise, the repetitive nature of the master schedule enables daily schedule adherence, which keeps lot sizes small. To ensure, implementing some practices, such as setup time reduction, will help in themselves. However, we should see JIT as enabling the flow of production processes to occur as smoothly as possible; having one bottleneck may not be much different from having many, which all the practices together could eliminate.

### 3.2 | Misconception 2: JIT means no inventory

Another common misconception about JIT is that it means low or zero inventory.[8] Unfortunately, in a rush to implement JIT, the broader philosophy was reduced to inventory reduction. Indeed, searching on the web, we find blogs and other articles describing JIT as "inventory management"[9] with the intent to lower costs, "inventory processes" to lower working capital and enhance cash flow,[10] or a method that "focuses on keeping as little inventory at hand as possible."[11] As a result, companies implementing JIT focused on their inventory levels, and JIT became synonymous with low stock levels. To facilitate this singular focus, many companies off-loaded their inventories from their balance sheets to their suppliers, for instance, with a vendor-managed inventory.

Why did this reductionism to inventory management happen? Inventory is the most easily spotted and routinely targeted "waste" in improvement projects. However, the original intent of the JIT philosophy was to attain high-quality and short lead times rather than to reduce inventory per se. While reducing inventory could free up capital and be presented as cost savings, especially when interest rates are high, it missed the essence of JIT and has fueled a widespread misconception that skirts the fundamental conditions Ohno developed at Toyota. Some early influential books on JIT, *Zero Inventories* (Hall, 1983) and *Non-Stock Production* (Shingo, 1988), and many subsequent studies also equated JIT with reducing inventory or increasing inventory turns (e.g., Schonberger, 2007). Consultants further propagated

**TABLE 1** JIT practices (*source*: Mackelprang & Nair, 2010).

| No. | JIT practice | Description |
|---|---|---|
| 1 | Setup time reduction | Extent to which the plant is reducing setup times in production |
| 2 | Small lot sizes | Extent to which the plant is utilizing or working toward using small lots in production |
| 3 | JIT delivery from suppliers | Extent to which the plant is receiving shipments from vendors on a JIT basis |
| 4 | Daily schedule adherence | Extent to which the plant is producing to schedule as well as utilizing time buffers to guard against unexpected stoppages in production |
| 5 | Preventive maintenance | Extent of proper maintenance of machinery such that the production machinery downtime is limited |
| 6 | Equipment layout | Extent of use of cellular manufacturing design, including proximity of machinery |
| 7 | Kanban | Extent to which operations in the plant utilize the concept of Kanban |
| 8 | JIT link with customers | Extent to which the plant provides JIT deliveries to customers |
| 9 | Pull system | Extent of the existence of a pull production system and the related supporting systems |
| 10 | Repetitive nature of master schedule | Repetitive nature of master schedule: Extent of consistency of production scheduling, as well as the variation in product volumes |

this myth with a superficial presentation of JIT, presenting inventory as pure waste for which a company's customers would be unwilling to pay. However, inventory could offer value for customers through product availability and reduced purchasing costs (Baudin & Netland, 2022).

Inventory can be helpful when considering the reality of a supply chain. The focal company having JIT links with its suppliers who are similarly linked with their suppliers, and so on, can extend JIT upstream only to a point before lead times become so high and variable that JIT is no longer feasible. At this point, we need inventory to de-link the upstream from the downstream parts of the supply chain that have different order cycle times. Even Toyota has yet to eliminate inventory in its global supply chains: the company maintains necessary work-in-process and finished goods inventory located at various points. For instance, Toyota often stocks completed cars to protect its production from fluctuating market demands. In construction supply chains, builders mix concrete using sand or gravel that can be delivered but not extracted JIT.

Indeed, companies have not set up their global supply chains to run in a "pure" or canonical JIT mode. Even in the automobile industry, global supply chains are, for the most part, not JIT, with Toyota provided as an example earlier. Typically, OEMs establish large consolidation centers for components and materials they need globally or regionally. Then, they supply the regional assembly factories from these warehouses JIT, even in sequence. Third-party service providers operate these centers, which offer sequencing and frequent delivery of parts to geographically close plants (Wagner & Silveira-Camargos, 2012). Examples are Barrett Distribution and Syncreon.[12] However, parts inbound to these centers from distant locations are shipped in bulk to optimize transportation and administration costs.

## 3.3 | Misconception 3: JIT is the cause of shortages

A third misconception is that JIT is the primary culprit for the shortages experienced, not only in the auto industry for chips and other components but also in other sectors.[13] In reality, shortages and disruptions occur in spatially complex supply chains extended globally (Bode & Wagner, 2015). JIT encourages co-location and close relationships with suppliers. However, due to increased and variable lead times between order and delivery, geographically dispersed supply chains naturally require extra inventory—even for those that follow the JIT approach. Inventory results from the large batch sizes dictated by the shipment mode as most products and components are shipped worldwide in large containers on increasingly larger ships. Such shipments were never the intention of JIT but were necessary to make JIT functional in global supply chains. Moreover, there are many reasons for lowering inventory for financial reasons that have nothing to do with JIT.

Consider the following example. There was a lot of press coverage about the toilet paper shortage during the early months of the pandemic, possibly linked to retailers' JIT purchasing. In the Netherlands, Prime Minister Mark Rutte announced on public television in March 2020 that the country has stockpiles of toilet paper enough for 10 years to reduce public panic buying and hoarding.[14] However, toilet paper supply chains have never operated in JIT mode, so how could it be blamed for the shortages?

## 3.4 | Misconception 4: More inventory means better supply chain resilience

Yet another misconception is that more inventory is the ultimate solution for building supply chain resilience.[15] The flip side is that high inventory levels also risk creating stagnant supply chains bloated with inventory and high costs. Holding more stocks *can* be one of several ways to tackle supply and demand shocks, depending on *what* the company keeps and *where* it stores it. However, inventory is no guarantee of resilience in a supply chain, and the capacity to build inventory and even the capability to build capacity may be needed (Li et al., 2023).

Just-in-case inventory was effectively the norm before JIT in the 1970s and earlier. Under this norm, plant managers ran their workstations to keep machine utilization high, piling up inventories that stayed on their books as assets. They also maintained "rainy-day" stocks hidden away that may or may not get back into production. Such an uncoordinated approach results in inventories created haphazardly, potentially resulting in a shortage of necessary items and an excess of noncritical ones when a disruption occurs.

Any inventory for disruptions can only last for a finite period if there is no other recourse for recovery, whether it is just-in-case or an adaptation of JIT. Even Toyota's famed stockpile of semiconductor chips, built after the Fukushima disaster, was eventually depleted during the global chip shortage from September 2020 onward. At this point, Toyota was in the same situation as other auto manufacturers.

## 3.5 | Misconception 5: JIT's traditional view is the best operating model

The fifth misconception is that implementing JIT in its original form is a surefire way to gain competitive advantage and other related performance gains regardless of context (Claycomb et al., 1999; Fullerton & McWatters, 2001). Many proponents of JIT and lean hail JIT as a desirable model to implement—always. However, in its pure form, JIT is often not the best economic model.

Take, for example, the paper products sector with products that include toilet paper and packaging materials. The industry does not have assembly-based plants, so implementing JIT here would not work. Setup times are very high; therefore, product runs are very long, resulting in large inventories. Much of the raw material, pulp, is made from trees that take years to grow. The total lead time can be excessively long unless there is inventory at different production stages. Closer to assembly production, we can consider remanufacturing. In any case, the high uncertainty of component and raw material availability would preclude the use of JIT. For example, Canon disassembles, recovers, and reuses parts from its old products into new devices and refurbished products.[16] In this situation, holding additional buffer inventory is the only option to ensure continued operations. However, needing inventory does not imply that JIT as a *philosophy* is infeasible in this setting. Instead, the conclusion should be that there are better alternatives from an economic perspective than a canonical JIT implementation.

# 4 | THE NEED TO ADAPT JIT TO SUPPLY CHAINS

JIT worked well in Toyota's assembly lines, which extended into the suppliers' plants located nearby. Therefore, the next logical step was to connect the (Tier-1) suppliers' plants to the Tier-2 suppliers and those in turn to Tier-3 suppliers. Each link upstream in the supply chain requires adaptation to procedures while retaining the overall goals expected from JIT.

## 4.1 | JIT and supply chain fit

A JIT implementation does not entail a binary decision in terms of a company either applying JIT or not, as sometimes implied by the popular press. As discussed above, JIT entails numerous JIT practices, each of which the company must adapt from a within-plant setting to a supply chain. How JIT practices are implemented in a supply chain largely depends on the product to be handled and the environmental conditions for each link between and within supply chain entities. Overall, the adaptation ties in closely with the notion of "supply chain fit," as introduced by Fisher (1997) and Lee (2002) and empirically validated by Wagner et al. (2012).

"Fit as matching" (Venkatraman, 1989) implies that there is no one-size-fits-all ideal form of JIT. Instead, JIT can be implemented to a certain degree to match the given conditions of the product or the environment. For instance, when a company faces more uncertainty from customers, the product yield, or the environment, its supply chain needs to be more responsive. Hence, buffers in appropriate places in supply chains may be required to protect downstream operations from upstream volatility, so a "pure" JIT across the entire supply chain is not practical. In contrast, JIT is suitable in its canonical form if the supply uncertainty is low, the demand is stable, and components of acceptable quality are readily available. The result would be a highly effective supply chain.

The literature on supply chain fit suggests that matching supply and demand under uncertainty can lead to different supply chain designs on the efficient–responsive spectrum (e.g., Fisher, 1997; Lee, 2002; Gligor, 2017; Prajogo et al., 2018; Wagner et al., 2012). Therefore, we extend the question of supply-chain design to link JIT to the conditions under which the focal company must match supply and demand.

Dynamic environmental conditions push ideal JIT implementation for a supply chain fit toward more responsiveness on the *cost-efficiency*-to-*responsiveness* spectrum. The problems JIT allegedly caused during the pandemic when environmental conditions had extremely high uncertainty arose because JIT implementation was oriented more toward cost-efficiency than responsiveness. With the increased uncertainty that firms experienced during the Covid-19-related disruptions of 2020−2022, companies need to alter supply chains by changing their JIT practices toward more responsiveness.

Toyota and other companies pioneered JIT for repetitive production systems characterized by relative stability and certainty. However, two factors have changed the context for JIT and thus require adapting it. One is supply chain turbulence, and the other is the buyer–supplier geographic distance. We discuss these below.

## 4.2 | Supply chain turbulence and JIT

JIT assumes a relatively stable environment, enabling closer collaboration. However, with turbulence and day-to-day variability in the supply chain, Toyota shelters its manufacturing plants and those of its Tier-1 suppliers by using buffers upstream (e.g., stockpiles of chips) and downstream (i.e., finished cars) while retaining traditional JIT practices in its plants. Although these inventories may be costly, they enable the suppliers' and Toyota's plants in a JIT supply chain to capture as much of the JIT's boost to performance as possible. With increasing potential turbulence, there would be more need (1) to find supply chain segments vulnerable to turbulence and (2) to design the buffers at supply chain points where these segments start.

In general, supply chain turbulence is a challenge for JIT systems. Turbulence caused by Covid-19, geopolitical conflict, or natural disasters contrasts with the stable environment that traditional JIT assumes. Turbulence leads to increased inventory directly to cover the possibility of disrupted supplies or demand spikes. Turbulence also indirectly leads to holding more stocks as forecasts become less accurate and behavioral issues become more prominent with purchasing managers overriding algorithms. As a result, the bullwhip effect becomes more pronounced (Lee, 2002; Lee et al., 1997), and inventory becomes inevitable.

Consider the demand changes during the Covid-19 pandemic. The work-from-home lifestyle impacted consumer buying patterns with online shopping of athleisure wear, home office equipment, and self-care products. However, the slowdown in the pandemic, coupled with economic stimulus and suppressed consumers, unleashed a desire for travel and glamour. As a result, retailers placed orders for goods from their suppliers based primarily on analytics and data. However, retailers who were successful during the pandemic began ballooning inventories after the second wave of Covid-19 as customers' preferences and shopping habits changed yet again. The rapid increase in consumer demand after the second wave of Covid-19 caused whiplash to the retail supply chains that could not provide desired goods and services and suffered longer lead times than before Covid-19.

Another reason for the shortages of many products is cross-industry competition for components, labor, and shipping containers. For example, the global chips shortage during 2020−2021 was due to pent-up demand as the auto industry geared up after plant shutdowns with consumer electronics and other sectors competing for the same parts or raw materials. Moreover, companies' efforts to build just-in-case inventories resulted in much larger orders than they needed in the near term, exacerbating the shortage (Shih, 2022b).

## 4.3 | Buyer–supplier geographical distance and JIT

Buyer–supplier geographical distance has become an increasingly problematic issue. JIT implementations assume buyers and suppliers were co-located or located nearby to guard against some of Ohno's waste from building up. Co-location shortens transportation time. Additionally, employees from both companies are likely to meet in person more frequently to share problems and solutions.

Many supply chains today are global in being physically distributed and geographically dispersed. So, personal interaction and relationship building get more complicated, and the impact of any supply chain disruption gets exacerbated. In such supply chains, it may take weeks before anyone notices something the company needs to fix. For example, a product can be shipped in bulk on a sea route across the globe only to be found defective during inspection three months later. The need to send parts and products efficiently leads these suppliers to produce and export large batches with long lead times, without takt time or just-in-sequence synchronization. Not surprisingly, products in shortage during the pandemic had to travel long distances, including components such as semiconductor chips and household goods.

In summary, geographically dispersed supply chains require extra transit inventory due to long lead times between order and delivery and even more so with varying shipping times and shipment in large containers on massive cargo ships. A larger batch size could also magnify the proportion of undetected defects in a produced batch.

# 5 | ADAPTING JIT TO SUPPLY CHAINS

Therefore, implementing JIT in a supply chain needs more nuanced exploration and understanding when considering turbulence at the scale experienced in the early 2020s. Canonical JIT, which may be well suited to an *assembly plant*, may or may not be the best approach for a *supply chain* with its inter-organizational relationships and spatially distributed actors. We must understand how to adapt JIT to supply chains and what method to use for which part of the supply chain. Our core idea here is not to apply JIT piecemeal to the supply chain as a monolith but to adjust JIT differently for the different supply chain links. Doing so will ensure a better "fit" of JIT to the supply chain. The focal company may also need to reconfigure the supply chain to reduce the risk of disruptions (Chopra & Sodhi, 2014) in various supply chain links to ensure a better "fit."

The different links in the supply chains may have different start times, takt times, or buffers. Moreover, such variation could become more significant in turbulent conditions. Therefore, JIT will only be successful in a supply chain if JIT is applied suitably, segment by segment, with only specific links in the supply chain having a canonical JIT implementation. The companies in the supply chain, including the focal company, must have visibility of all pertinent upstream suppliers' real-time status. They must use buffers—including inventory, capacity, and capability (Sodhi & Tang, 2021). Finally, the focal company must manage its buyer–supplier relationships well and encourage this in the upstream entities.

## 5.1 | Buffers

Toyota re-evaluated its supply chain in Japan after the hurricane and the Fukushima tsunami and found that semiconductors were the most vulnerable aspect of the supply chain. As a result, they decided they would need to hold 6 months of inventory for all chips required in manufacturing their cars. Six months of inventory may appear to be excess inventory rather than JIT or waste elimination. However, the actions taken by Toyota reflect its understanding of its supply chains, vulnerabilities, risks, and strategic goals. The company understands that its inventory placement needs to align with its strategic objectives and its JIT production. They know that *heijunka* requires the continuity of supply, which is facilitated by this excess supply of chips.

Indeed, we can take buffers beyond inventory to include capacity and capability (Sodhi & Tang, 2021). Companies can readily use inventory in the supply chain's next stage, including supplying finished goods to customers. Additionally, they can use production capacity to convert raw materials or semifinished goods into finished goods inventory, making it available for the next stage of the supply chain. Finally, they can use their capability to create such production capacity inhouse or at suppliers. Such buffers could be at the boundaries of supply chain segments operating under JIT, generalizing the idea of using inventory at a push–pull boundary (Sodhi & Choi, 2022).

Another buffer type is using *commons*, which are the resources shared between companies (Chopra et al., 2021). Small and medium enterprises (SME) do not have the buying power of larger firms and must resort to carrying more buffer stocks (Aksoy et al., 2022), nor can they compete against large buying companies for scarce upstream inventory, as was evident during the early days of the pandemic in China (Choi et al., 2020). However, if they shared resources, SMEs could run efficiently without carrying excess capacity or inventory. For instance, defense SME suppliers pool their resources together in a manufacturing network to respond to calls for proposals from large defense contractors (Wu & Choi, 2005).

## 5.2 | JIT segments

The conditions for a JIT segment include minimum fluctuations in demand, matching manufacturing cycle times across the nodes in the segment, and proximity of these nodes, which makes short transit times and close collaboration possible at various levels of the companies in the link (Sodhi & Choi, 2022). Some segments may consist of just a single plant, while others may encompass suppliers across two or more tiers. The differences in the production cycles of upstream and immediately downstream segments should determine the size of the buffer, whether it is inventory or production capacity. One idea to enhance cost-effectiveness is using a single buffer to service two different JIT segments that face upstream risks. For example, if one product line is vulnerable to geopolitical risk and another to natural disasters, both would be better off with a single buffer (rather than two separate ones). This buffer would cushion the downstream JIT segments of these product lines from disruptions in their respective upstream sources. Such a buffer could be a warehouse with a stockpile of components for either a product line or a single flexible plant that can make the components. Another idea is to ensure that different product lines in adjacent JIT segments have as many shared parts as possible and create a buffer for these parts, whether of inventory or capacity to produce them.

## 5.3 | Visibility

Visibility of all pertinent upstream suppliers' real-time status is a vital issue. The use of digital technologies such as supply chain software, blockchain, the Internet of things, and artificial intelligence can benefit JIT supply chains in various ways (Holmström et al., 2019; Sodhi et al., 2022). Digital technologies are instrumental for supply chain visibility and transparency (Choi et al., 2023; Wagner and Postel, 2022). Furthermore, forecasting is necessary for each JIT segment due to the lead times involved. Digital technologies can help us better forecast end-product demand—and share the translated forecast upstream—enabling *heijunka* at the right level and visibility of in-transit inventory. Software platforms shared by the buyer and supplier can transact new orders faster using smart contracts, cutting the lead time. Better traceability with blockchain systems across many tiers of suppliers would ensure reliability (Hastig & Sodhi, 2020). Digitalization can also reduce the different kinds of waste, especially waiting time, by enhancing connectivity and visibility across the supply chain. Digital technologies can allow foundational JIT concepts to thrive in a turbulent environment giving the operating system the ability to anticipate through better forecasting and respond through visibility and collaboration.

## 5.4 | Buyer–supplier collaboration

As discussed, JIT implementations assume that the buyer and supplier collaborate closely. For example, Toyota works closely with its local supplier to improve quality and reduce costs for the benefit of both firms (Shih, 2022a). However, buyer–supplier relationships in the supply chain will take on many shades, ranging from outright adversarial to close cooperation. The Kraljic matrix shows other purchasing relationships possible besides the strategic ones, with issues of power and interdependence (e.g., Caniëls & Gelderman, 2007). Relationships across the adversarial–collaborative and the trustworthy–untrustworthy axes provide researchers an opportunity (1) to identify supply chain segments that need to be sheltered from adversarial relationships and (2) to design the buffers, possibly by way of collaborative relationships between the company and its suppliers. Third-party logistics providers or purchasing organizations could provide such a role.

## 6 | CONCLUSIONS

We have tried to debunk misconceptions underlying the arguments in the popular press that promote just-in-case inventory over JIT while presenting a more nuanced view of JIT in the supply-chain context. The problems experienced by companies since the disruptions of 2020 and beyond were not because of JIT practice but because companies had *moved away* from the original tenets of JIT, including the focus on the lead time between order and delivery. Specifically, delivery and consumption became even more tightly coupled while the variance in lead times increased, intensifying any disruption in the supply chain and the impact on the end consumer. The popular press targeted JIT as a scapegoat for global supply chain shortages, but this is unjustified.

During the pandemic, unexpected competition from disparate supply chains increased the intensity of disturbances, as seen in the shortage of electronic chips. The push–pull tug, where a vast majority of the supply chain had been moving away from JIT while other parts had become more tightly coupled, could only lead to frequent and more intense disruptions. If JIT is indeed a firm's idealized goal, the key would be to go back to the basics by developing a closer, collaborative relationship with suppliers (and customers) and minimizing distances where possible. Moreover, firms should consider other mechanisms, such as excess inventory to counter long lead times or pooled inventory to reduce supply uncertainty—making inventory reduction the goal is not JIT.

We are seeing more re-regionalization of global supply chains in response to geopolitical risks (Madhok, 2021). For example, car manufacturers are reorganizing their supply chains to reduce "their reliance on Chinese factories for goods sold overseas, while retaining a secure local supply chain for their own plants inside the country."[17] By doing so, these firms might reduce supply chain turbulence and buyer–supplier geographical distance, creating new or better conditions for JIT to work. Indeed, the intersection of geopolitics and JIT is a fruitful area for future research.

Additionally, three potential future research questions go beyond the setting of turbulent conditions. First, how could small- and medium-sized enterprises (SMEs) be part of JIT? Typically, JIT does not apply to SMEs as it does to large companies such as Toyota because they lack a focal company's leverage. Yet, SMEs compete against large companies for parts and raw materials and need to hold more inventory in proportion to sales. Thus, buffering mechanisms, such as additional safety stock, capacity, or some combination, would be helpful for the JIT implementation at SMEs. As mentioned earlier, one buffering mechanism for SMEs to run efficiently would be to create shared commons (Chopra et al., 2021).

Second, how could JIT be considered for environments where turbulence comes from innovation and novelty within the supply chain rather than disruptions? Browning and Sanders (2012) studied JIT implementation in the production system for Lockheed Martin's F-22 Raptor. The environment was complex and novel and had an innovative product and process design. Unfortunately, the initial implementation of JIT in its traditional form resulted in increased costs for the company and aggravated the problems related to novelty and complexity in the production system. Future research may consider modifying JIT for such environments while staying true to the philosophy.

Third, researchers can continue to build theories for JIT for different scopes of application: grand theories that are the most general, mid-range theories, and empirical statements of some findings in a narrow setting (Freese, 1980; Swamidass, 1991). While Swamidass (1991) considers even "JIT principles" as a grand theory applying to a broad context, we believe scholars can be more successful when aiming to build JIT theory at the mid-range level (Busse et al., 2017). Mid-range theory development on JIT can examine JIT practices (what), relate these practices to performance (how), and attempt to explain the causal mechanism between rehearsals and performance (why) (e.g., Fullerton & McWatters, 2001; Mackelprang & Nair, 2010). The literature in this domain has yet to incorporate disruptions, particularly continual disruptions in turbulent times, leaving ample opportunities for future research.

In conclusion, we need more JIT, not less, to build resilience in supply chains for performance. Certainly, reverting to just-in-case may only mean a loss in performance without a gain in strength. If adequately implemented, JIT creates a close relationship between suppliers and buyers who collaborate regularly and have digital technologies that allow communication and visibility. In contrast, a haphazardly implemented just-in-case approach would place inventories across the supply chain and take us back to the time before JIT.

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