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COLLECTION-BASED SUPPLY CHAIN DESIGN (CBSD): A STRATEGIC FRAMEWORK FOR ALIGNING PRODUCT ARCHITECTURE, CUSTOMER EXPECTATIONS, STRATEGIC INVENTORY RESERVATION, AND DYNAMIC LEAD-TIME POLICY IN HIGH-VARIANT MANUFACTURING

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ABSTRACT

The increasing complexity of high-variant manufacturing challenges the static planning assumptions of traditional supply chains. Industries like architectural lighting operate with extensive customization, global networks, prolonged replenishment cycles, and diverse service expectations. Assigning static lead times and treating all physical inventory as immediately available often results in excessive stock, production instability, expedited freight, and inconsistent service. This paper introduces Collection-Based Supply Chain Design (CBSD), an integrated framework linking product architecture, customer expectations, inventory positioning, and manufacturing capability to lead-time policy. CBSD treats lead time as a dynamic planning decision driven by order quantity, collection characteristics, replenishment strategy, and allocation priorities. Central to CBSD is Strategic Inventory Reservation (SIR), which distinguishes physical stock on hand from stock protected to sustain recurring demand throughout replenishment cycles. Modular architecture and postponement strategies are shown to enhance operational efficiency and sustainability. Two contrasting architectural lighting case studies demonstrate how identical corporate goals require distinct strategies based on customer expectations and configuration. CBSD provides a practical methodology for high-mix manufacturers where static policies fail.

Keywords: Collection-Based Supply Chain Design; High-Variant Manufacturing; Strategic Inventory Reservation; Dynamic Lead-Time Policy; Postponement Strategy

1 INTRODUCTION

For most manufacturers, the world has changed. Over the last twenty years, supply chains have become incredibly complex as companies chase customization, shorter product lifecycles, and faster response times. While global sourcing and new technologies make it possible to offer thousands of configurations, they also create a planning nightmare that traditional methods just aren't built to handle.

Look at the architectural lighting industry. A single product platform can now spin off thousands of unique versions based on finishes, optics, and mounting options. Designers and architects now expect this level of customization with the same speed they get from standard consumer goods, putting immense pressure on the production line.

This explosion of variety changes how we have to plan. Demand is no longer a predictable pattern. Instead, manufacturers have to juggle small replenishment orders, highly custom projects, and massive commercial installations all at once. These different needs often fight for the same resources, but they require very different strategies to fulfill.

The problem is that many companies still use outdated planning policies. For example, they often assign one static lead time to a product, regardless of the order size or supply chain constraints. They also treat all warehouse stock as immediately available, ignoring the strategic need to protect inventory for future recurring demand.

These shortcuts might make ERP systems easier to manage, but they don't reflect reality. A one-unit order follows a completely different path than a hundred-unit order. While a small order might come off the shelf, a large project often requires reserved capacity and new material from suppliers. Giving both the same lead time creates false expectations and chaotic production schedules.

The costs of these policies are high. To hit unrealistic deadlines, organizations often overstock inventory or rely on expensive overtime and air freight. This reactive approach doesn't just hurt the bottom line; it also undermines sustainability by increasing energy use and transportation emissions.

Traditional inventory management has a similar blind spot. Most systems view inventory as a binary: it's either there or it isn't. This assumes all physical stock is up for grabs, but that view is dangerous when you face long replenishment cycles and constant market demand.

Imagine a product that takes five months to restock. If one massive order wipes out your entire supply, you're stuck with months of stock-outs for everyone else. You might have satisfied one customer, but you've damaged your reputation with the rest of the market. The short-term win isn't worth the long-term cost.

This shows that inventory has two jobs: fulfilling immediate orders and preserving market availability. Because these goals often conflict, we shouldn't assume that physically being in the warehouse means a product is strategically available for every order. This paper argues that lead times and inventory levels should be strategic decisions, not static settings. I propose Collection-Based Supply Chain Design (CBSD), a framework that connects five key dimensions of manufacturing strategy:

- Product collection characteristics and manufacturing architecture;
- Customer expectations regarding responsiveness and customization;
- Order quantity and resulting production behavior;
- Strategic inventory reservation throughout replenishment cycles; and
- Sustainable capacity utilization and production planning.

Instead of one-size-fits-all policies, CBSD recognizes that different product lines need different approaches. A simple, modular fixture meant for quick shipping shouldn't be managed like a custom chandelier meant for a long-term construction project. Their customers, costs, and constraints are fundamentally different.

This paper introduces a dynamic way to set lead times that reflects how manufacturing actually works. Central to this is Strategic Inventory Reservation (SIR), which separates physical stock from the stock we intentionally protect to keep the market running. We will also show how smart product architecture and postponement strategies can cut inventory costs while making production more stable and sustainable.

The goal isn't to replace tools like MRP or S&OP, but to give them a better foundation. By aligning customer promises with manufacturing reality, CBSD gives manufacturers a practical way to balance service, cost, and sustainability in an increasingly complex world.

2 LITERATURE REVIEW

2.1 Evolution of Supply Chain Strategy in High-Variant Manufacturing

Supply chain management has shifted dramatically over the last thirty years. It used to be all about logistics efficiency; now, it's a strategic core balancing customer needs, operational costs, and the need for organizational resilience.

The architectural lighting industry exemplifies this transformation. Modern lighting manufacturers rarely produce standardized products in isolation. Instead, individual product platforms often generate hundreds or thousands of commercial configurations through combinations of optics, lumen packages, drivers, mounting systems, finishes, controls, and regional certification requirements. Simultaneously, manufacturers serve a diverse customer base that includes distributors, architects, electrical contractors, interior designers, and commercial developers, each exhibiting distinct purchasing behaviors and service expectations.

This combination of extensive product variety and heterogeneous demand creates planning challenges that extend beyond traditional inventory optimization. Manufacturing organizations must determine not only what inventory to hold, but also which products should be stocked, where inventory should be positioned within the value stream, how customer lead times should be established, and how manufacturing resources should be allocated across competing demand profiles.

This mix of variety and demand makes planning incredibly difficult. It's no longer just about deciding what to keep in stock. You have to decide:

- What products are worth stocking?
- Where should that inventory sit in the value stream?
- How do we promise lead times without breaking our capacity?
- How do we balance resources across dozens of competing order types?

As Christopher [1] notes, competitive advantage now comes from responsiveness, not just lower costs. The best supply chains aren't just good at recovering from disruptions—they are designed to anticipate and absorb variability before it even hits the production floor.

This is especially critical in high-variant manufacturing. Unlike commodity markets, where uncertainty might just be a blip in the economy, high-variant manufacturing deals with structural complexity. Every customization or engineering constraint adds another layer of variability. If your planning policies assume that every product behaves the same way, you're likely using a system that doesn't reflect your actual shop floor.

2.2 Lead Time as a Strategic Supply Chain Capability

We usually think of 'lead time' as a simple number—the elapsed time between an order arriving and it being shipped. In most ERP systems, it's just a static setting used for scheduling and promising orders. But this approach assumes that lead time is a fixed feature of the product itself, which is rarely true in a real manufacturing environment.

The reality, as explained in Factory Physics [2], is much more fluid. Lead time is actually the result of how a factory is running—it's driven by how busy the shop floor is, the variety of the work, batch sizes, and queue lengths. As a system gets closer to full capacity, wait times and total lead times don't just grow; they often skyrocket. In short, lead time isn't a fixed product attribute; it's a dynamic outcome of how the production system is performing.

Similarly, Simchi-Levi et al. [3] emphasize that effective supply chain design isn't about setting one number. It's about balancing responsiveness and efficiency by coordinating decisions on inventory, sourcing, and production. Lead time is really the cumulative result of all those operational choices.

Yet, despite this, most ERP systems still treat lead time as a static value attached to a SKU. While this makes administrative work easier, it often ignores the reality of the shop floor.

Think about a configurable lighting fixture with a six-week lead time. The system applies that same time whether a customer orders one unit or a hundred. But in reality, those orders are handled completely differently. A single-unit order might pull from existing stock or a quick sub-assembly, while a 100-unit project might require raw material orders, capacity reservations, and an engineering review.

When the administrative lead time doesn't match the operational reality, things break. Companies often react by hoarding inventory, paying for premium freight, or pushing overtime just to meet artificial deadlines. This approach hurts the bottom line, creates a chaotic shop floor, and wastes resources.

The takeaway? We need to stop treating lead time as a static 'master data' field. Instead, it should be an adjustable, strategic planning mechanism that actually reflects the current conditions of your manufacturing floor.

2.3 Product Variety, Manufacturing Complexity, and Demand Heterogeneity

It's no secret that offering more variety makes manufacturing harder. But there's a trap: many companies think that adding 10% more product options just adds 10% more complexity. In reality, that complexity often grows exponentially.

When you offer a highly configurable product—with different finishes, optics, and electrical specs—you aren't just selling more SKUs. You're creating a web of dependencies. Even if two products are built on the same line, their journey through your shop floor, their supplier requirements, and their finishing steps can be totally different.

Ulrich [4] famously pointed out that how you design your product determines how you can run your factory. If you build with a modular architecture—using interchangeable parts—you can wait until the last minute to finish the product. You keep stock of the common parts and only customize when you have a real order. It's flexible and smart. On the flip side, integrated products force your hand. Because everything is tied together, you have to commit your materials and labor way earlier, which kills your flexibility and piles up inventory risk.

In the lighting world, this is a massive differentiator. If your fixture is modular, you can swap out a housing or a lens at the final assembly stage. If it's integrated, you're building a whole, unique unit from scratch. This choice isn't just an engineering detail; it defines your entire planning strategy—from where you hold inventory to how you schedule your lines.

Then, you add customer demand to the mix. Fisher [5] split products into 'functional' (steady demand) and 'innovative' (uncertain demand). That's a helpful starting point, but most lighting manufacturers deal with both at the same time. You might have a simple wall sconce that needs to be on a shelf ready to ship, and a massive custom chandelier that's part of a construction project six months away.

Even if those two products look technically similar, they live in different worlds. The sconce buyer expects instant gratification; the chandelier project manager expects reliability. Because their expectations are totally different, applying the same planning logic to both is a mistake. Traditional supply chain models often ignore these 'customer expectations' as a variable, but in a high-variant business, it's actually one of the most important factors.

2.4 Postponement and Modular Manufacturing: The Power of Waiting

One of the most effective strategies in modern supply chain management is postponement. At its core, it's simple: you delay final product customization until you actually know what the customer wants. Instead of finishing a product and hoping it sells, you keep your components 'generic' for as long as possible. This lowers your risk and keeps your options open.

This isn't just theory—it works. The classic example is Hewlett-Packard, which famously localized its printers by adding regional power cords and manuals only at the very end of the process, rather than creating separate stock for every region.

But postponement only works if your product is designed for it. If you have a modular product—where parts can be swapped easily—you can delay differentiation until the last minute. If your product is 'integrated' (all one piece), you have to customize it early, which locks up your inventory and kills your flexibility.

Surprisingly, most of the research on postponement focuses on internal efficiency, not on how it impacts the customer. But the two are tied together. Postponement means you don't have to hold a mountain of finished goods to offer fast delivery. It changes how you commit to orders. It's not just a manufacturing trick; it's a core supply chain strategy that dictates your lead times, your inventory, and how you schedule your floor.

2.5 Inventory Strategy: Why 'Available' Doesn't Mean 'Allocated'

We rely on standard inventory math—reorder points, economic order quantities, and service levels—to keep things running. These formulas are the backbone of most ERP systems, and for a long time, they've worked fine. But they start to show their age when supply chains get complex.

Most companies use 'Available-to-Promise' (ATP) to check stock. It tells you, 'Yes, we have 100 units on the shelf, so we can sell them.' It's great for speed, but it has a blind spot: it tells you if the inventory exists, but it doesn't tell you if it's strategically smart to sell it to the first person who asks.

Some systems use 'Capable-to-Promise' (CTP) to factor in manufacturing capacity, which is a step up. But even then, the system is just checking if it can be done, not if it should be done.

Neither ATP nor CTP explicitly considers the strategic value of preserving inventory to maintain continuous market availability throughout lengthy replenishment cycles.

This distinction becomes increasingly important in industries characterized by extended supplier lead times and highly variable order sizes. Consider a manufacturer maintaining inventory for a product requiring approximately five months to replenish. Historical demand indicates consistent monthly sales that collectively consume the majority of inventory during the replenishment period. If a single project order exhausts available inventory immediately, the manufacturer may remain incapable of serving routine customers for several months despite having satisfied one large transaction.

From the perspective of ATP, the decision was entirely correct because inventory physically existed. From the perspective of long-term supply chain performance, however, the decision may have weakened customer service, disrupted distributor confidence, increased future expediting costs, and reduced market availability. This observation suggests that physical inventory and strategically allocable inventory should not necessarily be considered equivalent.

2.6 Moving Beyond 'Where' to 'Who'

For years, we've obsessed over 'decoupling points'—the spot in your supply chain where you stop building for a forecast and start building for a specific order. This is a great way to reduce risk and stay flexible.

However, the question used to be: 'Where should we hold this stock?' Today, the question is much harder: 'Who should we reserve this stock for, and when should we let it go?'

Inventory has to do too many jobs at once. It fulfills orders, handles demand swings, stabilizes the factory, and keeps customers happy. These goals often fight each other. You can't just allocate inventory based on who emailed their PO first. We need to start viewing inventory as a strategic asset for the long-term health of the product line, not just a commodity to be dispensed.

2.7 Sustainability: It's a Planning Problem

We usually talk about sustainability in terms of green materials, recycling, or more efficient trucks. These are important, but they often treat the symptoms of bad planning rather than the root cause.

Take expedited air freight as an example. We call it a 'logistics problem,' but it's usually a 'planning problem.' We're paying for a plane because we made an unrealistic delivery promise, or because our production schedule was too chaotic to handle a real order.

When your planning architecture is flawed, the waste is everywhere:

- Too much inventory piling up.
- Work-in-process sitting stagnant.
- Overtime and emergency shifts.
- Material waste.

The best way to be sustainable is to have a planning system that works. When you have a solid structure, you don't need to force-fit production or panic-ship goods. Improved planning architecture can simultaneously reduce inventory investment, work-in-process, transportation emissions, premium freight, manufacturing variability, material waste, and labor instability. Sustainability isn't just about the environment; it's about having an efficient, predictable business.

2.8 The Missing Variable: Customer Expectations

Supply chain literature loves operational variables—demand, capacity, throughput. But it rarely talks about the customer's mindset.

In the real world, customers have totally different expectations. A contractor replacing a broken light needs it now. An architect designing a high-end lobby six months from now expects reliability, not immediate shipping.

Currently, we barely mention these expectations in our planning. We try to provide the same 'service level' for everyone, which is usually a mistake. We end up hoarding inventory for products that don't need it, or we lose competitive ground on products that do. We need to bring 'what the customer expects' out of the sales team's heads and into our formal planning logic.

These differing expectations significantly influence appropriate inventory strategy. Maintaining finished-goods inventory for products whose customers naturally expect extended project lead times may create unnecessary working

capital investment without materially improving customer satisfaction. Conversely, failing to maintain inventory for products whose customers expect immediate fulfillment may reduce competitiveness even when manufacturing lead times remain technically acceptable.

2.9 The Research Gap

The research on supply chain management is excellent. We have solid theories on lean manufacturing, postponement, product architecture, and inventory optimization. But there's a gap.

We're missing an integrated view. We treat lead time as a static number in a spreadsheet. We treat postponement as an internal manufacturing choice, not a customer-facing one. We treat ATP as a 'yes/no' switch rather than a strategic decision.

We need a framework that ties this all together—one that doesn't just look at manufacturing in a vacuum, but balances architecture, customer needs, inventory, and sustainability all at once. That's what this paper proposes with Collection-Based Supply Chain Design (CBSD). We aren't just looking at SKUs; we're looking at entire collections and asking how to keep them sustainable, reliable, and efficient.

3 COLLECTION-BASED SUPPLY CHAIN DESIGN (CBSD): A FRAMEWORK FOR DYNAMIC SUPPLY CHAIN PLANNING

3.1 From Static Planning to Dynamic Planning Architectures

The literature shows we have plenty of sophisticated tools for forecasting, inventory, and scheduling. The problem isn't the tools—it's that we use them in rigid, static ways. We set a lead time once when a product launches and rarely change it, even when the market shifts or our capacity changes. We treat inventory as a SKU-level problem, ignoring that products actually live in collections. We understand customer expectations in our heads, but that rarely makes it into the actual planning logic in our ERP systems.

As complexity grows, these old habits are failing us. Manufacturers aren't 'one-size-fits-all,' so why are our plans? We need to move away from using static 'settings' and start designing adaptive architectures that actually reflect how different product families behave.

This is where Collection-Based Supply Chain Design (CBSD) comes in. Rather than treating lead time, inventory, and production strategy as separate, independent decisions, CBSD integrates them. It forces us to align our manufacturing capability with what the customer actually expects, creating a system that's built for the real world, not just a spreadsheet.

3.2 Definition of Collection-Based Supply Chain Design

So, what is Collection-Based Supply Chain Design (CBSD)? Simply put, it's a planning framework that moves us away from rigid, one-size-fits-all rules. Instead of managing every product as an isolated SKU, we plan based on the 'operational personality' of the entire product collection.

In this framework, a collection is more than a marketing category; it's a planning entity defined by shared operational DNA:

- How is it built? (Architecture)
- What components are shared?
- How complex is the supply chain?
- How do customers actually buy it?
- What are the real expectations for service?

This distinction fundamentally changes our perspective. We stop asking, 'What lead time should Product X have?' and start asking, 'What planning architecture best supports this collection?' The answer doesn't come from a formula; it comes from how the product lives in the real world—how it's manufactured, where inventory provides the most value, and how we balance speed with long-term sustainability.

3.3 The Five Pillars of CBSD

The proposed framework consists of five interdependent planning dimensions:

Pillar 1 – Collection Classification: Most traditional systems group products by item numbers or marketing categories, but that misses the most important part: how the product is actually made. CBSD changes the perspective by classifying products based on shared 'operational DNA.'

Pillar 2 – Dynamic Lead-Time Policy: We're used to lead time being a static setting in the system. CBSD treats it as a flexible decision. Lead time should change based on what's actually happening: How big is the order? How much capacity do we have? Is the inventory protected for someone else?

Pillar 3 – Strategic Inventory Reservation (SIR): This is one of the biggest changes in CBSD. We have to stop assuming that 'physically available' means 'available to sell.' We need to reserve some inventory—what we call Demand-Protected Inventory (DPI)—to keep the market running while we wait for the next batch to be produced.

Pillar 4 – Product Architecture and Inventory Positioning: How your product is designed dictates where you should hold your inventory. If it's modular, you can keep generic parts on hand and only finish the product when an order arrives (postponement).

Pillar 5 – Customer Expectation Mapping: Supply chain planning often ignores the customer's mindset. We need to map these expectations explicitly to avoid wasting money trying to be 'fast' for a customer who values 'flexibility.'

Accordingly: $LT = f(C, Q, I, P, E, R)$ where LT = Customer Lead Time, C = Collection characteristics, Q = Order quantity, I = Inventory eligibility, P = Production capacity, E = Customer expectation, and R = Replenishment status.

3.4 Integrating the Pillars

The real power of CBSD isn't in any one pillar; it's how they connect. Think of it as a decision chain: You start by classifying the collection, which tells you how to map customer expectations, which determines your architecture, and eventually leads to your inventory and lead-time policies. When you see these as a single, connected system rather than a bunch of separate tasks, you stop playing 'whack-a-mole' with production problems and start building a stable, predictable business.

3.5 CBSD as a Planning Philosophy

To be clear, CBSD isn't a replacement for the tools you already use (like S&OP, MRP, or ATP). It's the layer above those tools. You still need your ERP system to track parts and schedules, but CBSD provides the blueprint for how to configure those systems.

4 CASE STUDIES: CBSD IN THE REAL WORLD

4.1 The Goal of These Case Studies

Frameworks are just theory until you use them to make real decisions. The two collections below come from an architectural lighting manufacturer. They use the same factory, the same suppliers, and share the same corporate goals. But because their 'personalities' are different, their supply chain strategies have to be completely different, too.

4.2 Collection A: Modular, Fast, and Stocked

Collection A consists of standard wall-mounted lights used in everyday commercial and residential projects. These are relatively inexpensive, and customers buy them in small, frequent batches. Customers here expect speed. Instead of hoarding every finished configuration, we looked at the architecture: we stock the 'engines' (electrical/optical parts) and painted shells, assembling them quickly when a customer orders.

4.3 Collection B: Custom, High-End, and Built-to-Order

Collection B is the total opposite: large, high-value custom fixtures for major commercial projects. Architects pick these out months before installation. Our strategy here is build-to-order: we don't stock finished goods at all, keeping common raw materials on hand and building the final product only after an order is confirmed.

4.4 Comparing the Two

Table 1: Comparison of Collection A and Collection B Strategies

Planning Dimension	Collection A	Collection B
Customer Expectation	Needs it now	Scheduled delivery
Architecture	Modular (Easy to swap)	Integrated (Built as one)
Strategy	Postponed assembly	Build-to-order
Inventory Goal	Fast service	Flexibility

4.5 Strategic Inventory Reservation (SIR): Why 'Available' is a Trap

Imagine we have 120 units in stock for Collection A. Historical demand shows we sell 25 units a month, and it takes four months to get a new batch. A big project wants all 120 units today. A standard ERP system says 'yes'. But under SIR, Demand-Protected Inventory = (25 units/month × 4 months) + 20 units safety stock = 120 units. That inventory is protected for recurring market demand, and the big project is offered a lead time matched to a new production run.

5 IMPLEMENTATION, SUSTAINABILITY, AND FUTURE DIRECTIONS

5.1 How to Actually Implement CBSD

Implementation starts with a mindset shift: treat your 'product collections' as the primary way you organize your planning. You don't need to rebuild S&OP or MRP—just change the parameters inside them.

5.2 Making Your ERP Work for You

Modern ERPs are flexible: use quantity bands for lead times, set parameters at the collection level, segment inventory, and flag risky orders automatically.

5.3 Sustainability: Why Better Planning is the Best 'Green' Strategy

Solid planning naturally reduces inventory waste, stabilizes production, minimizes premium air freight, and improves batch manufacturing efficiency.

5.4 Beyond Lighting

CBSD applies to any industry managing high-variant, configurable products, including medical devices, furniture, industrial equipment, and electronics.

5.5 A Practical Note

SIR calculations are dynamic decision-support tools rather than rigid laws, and should be calibrated to your specific demand profiles.

6 CONCLUSION

CBSD bridges the gap between static traditional planning and the realities of modern manufacturing by managing entire product collections, preserving market continuity, and fostering sustainable operations.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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