

# Leveraging Additive Manufacturing for Inventory Optimization: A Dual-Sourcing Model for Cost and Performance Enhancement in Retail Supply Chains

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**Abstract:** This study examines the integration of additive manufacturing (AM), specifically 3D printing (3DP), into retail supply chains to optimize inventory costs while maintaining high service levels (CSL  $\geq$  95%). A dual-sourcing inventory model is developed, balancing demand between traditional suppliers and in-house 3DP production. The model, solved using Microsoft Excel Solver, incorporates economic order quantity (EOQ), economic production quantity (EPQ), and reorder points to minimize total costs. Experimental results show that hybrid sourcing with 3DP reduces inventory costs, particularly at higher demand levels, while capacity constraints limit full adoption. Findings suggest that retailers should invest in AM expansion to maximize cost efficiency. This study provides a data-driven framework for hybrid inventory strategies and highlights future research directions in demand uncertainty, queueing effects, and advanced optimization techniques.

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## 1. INTRODUCTION

In today's dynamic retail environment, optimizing inventory management is essential for maintaining cost efficiency and high service levels. Traditional supply chain (SC) models rely on external suppliers, often leading to challenges such as lead time variability, demand uncertainty, and elevated holding costs (Simchi-Levi et al., 2021). To mitigate these risks, retailers seek innovative strategies that enhance flexibility and responsiveness. One emerging approach is the integration of additive manufacturing (AM), commonly known as 3D printing (3DP), as a complementary in-house production method.

A key advantage of AM is its ability to pool demand by using a common raw material—such as polymer filament or metal powder—for various products, unlike conventional manufacturing, where raw materials are often product-specific. This structural shift affects inventory management by enabling on-demand production, reducing lead times, and minimizing stockholding costs. Moreover, AM's localized production model enhances SC resilience, offering retailers a competitive advantage in fulfilling customer demands promptly (Molcho, 2020). However, despite its benefits, integrating AM into SCs requires a careful evaluation of cost trade-offs, production constraints, and demand allocation strategies.

Recent studies underscore the transformative role of AM in SC management (SCM). For example, Molcho (2020) highlights AM's potential to reduce SC complexity and improve responsiveness, while Ekren et al. (2023)

demonstrate that integrating 3DP into e-commerce SCs enhances both cost efficiency and service levels. However, the majority of existing research focuses either on pure AM models or traditional inventory systems, without addressing hybrid sourcing frameworks that combine both approaches. Furthermore, most studies fail to consider the implications of queueing effects, capacity constraints, and raw material cost structures, which fundamentally shape the feasibility of 3DP integration.

This study addresses these gaps by proposing an analytical inventory optimization model that integrates 3DP with traditional retail SCs. Specifically, the model determines the optimal allocation of customer demand between external suppliers and in-house AM production, aiming to minimize total annual inventory costs while maintaining high customer service levels (CSL). Unlike conventional inventory models, this framework explicitly considers:

1. The impact of demand pooling in AM on cost efficiency and inventory dynamics.
2. The absence of queueing effects, by applying a pre-defined production rate for 3D printer production capacity.
3. The cost implications of hybrid sourcing across varying demand scenarios, lead times, and holding costs.

By bridging theoretical insights with practical applications, this study provides retailers with data-driven guidelines for leveraging 3DP as part of their inventory management strategy. The remainder of this paper is structured as follows: Section 2 reviews the literature on inventory

management and AM integration in SCs. Section 3 formulates the research question (RQ), emphasizing the role of hybrid sourcing strategies. Section 4 outlines the proposed optimization model, detailing cost components and methodological assumptions. Section 5 presents experimental results comparing traditional-only and hybrid sourcing models under different demand and cost conditions. Finally, Section 6 discusses managerial implications, study limitations, and directions for future research.

## 2. LITERATURE REVIEW

Inventory optimization has long been a focal point in SCM, with research primarily centring on minimizing costs while maintaining high service levels. Traditional inventory models rely on deterministic and stochastic approaches, such as the Economic Order Quantity (EOQ) model and reorder point systems, to balance demand uncertainty with cost-efficient stock replenishment (Abayomi et al., 2014). However, these models predominantly assume a single-source supply chain, where inventory is sourced externally from suppliers, without considering the implications of in-house production.

### 2.1 Traditional Inventory Management and Dual-Sourcing Strategies

Dual-sourcing strategies, where demand is split between external suppliers and an alternative in-house production method, have been extensively studied in inventory control. Chopra and Meindl (2021) highlight that diversifying supply sources mitigates risks associated with lead time uncertainty and demand fluctuations. Similarly, Ekren and Ornek (2015) develop inventory control policies that balance cost efficiency and stock availability in single-echelon SCs. These models, however, do not account for the distinct characteristics of AM, where raw material pooling and on-demand production fundamentally alter inventory cost structures.

Several studies have explored the impact of production flexibility in SC resilience. For example, Ekren and Arslan (2019) optimize lateral transshipment policies to reduce costs in multi-echelon SCs, demonstrating the benefits of dynamic inventory redistribution. However, these studies focus on traditional manufacturing settings, where production lead times and raw material requirements differ significantly from AM-based systems. The role of 3DP as a dynamic, cost-effective alternative to external suppliers remains largely underexplored.

### 2.2 Additive Manufacturing in Supply Chains

The advent of AM—commonly referred to as 3DP—has introduced a paradigm shift in SC operations. Unlike traditional manufacturing, which requires product-specific raw materials and batch production, AM standardizes raw material usage across different product types, significantly reducing inventory complexity (Molcho, 2020).

Research on AM integration in SCs highlights its potential to improve responsiveness and cost efficiency. Molcho (2020) emphasizes that localized, on-demand production

reduces lead times and minimizes stockouts, offering retailers greater agility in managing fluctuating demand. Similarly, Afshari et al. (2020) explore the role of eco-innovation in AM adoption, finding that sustainability considerations and supply chain resilience are key drivers of 3DP implementation. More recently, Ekren et al. (2023) demonstrated that AM integration in e-commerce SCs enhances cost efficiency and service levels, particularly in scenarios where product customization is essential.

Despite these advancements, most studies focus on either purely AM-based models or traditional SCs. The impact of hybrid sourcing strategies, where 3DP complements traditional suppliers in a retail context, remains largely unexplored. Additionally, few studies quantify the effects of AM's unique cost structure, including:

- **Raw material pooling effects**, which reduce purchasing complexity compared to conventional manufacturing.
- **Demand consolidation**, where AM's flexibility allows businesses to produce multiple product types from a common material source, minimizing waste and excess stock.
- **Capacity constraints**, which determine the feasibility of large-scale AM adoption.

### 2.3 Research Gaps and Motivation for Hybrid Sourcing Models

While prior research establishes AM's benefits in inventory reduction and SC flexibility, critical gaps remain in understanding how AM integrates with traditional sourcing models in retail settings. Specifically, existing studies do not fully address:

- **Cost Structure Differences:** i) Traditional SCs involve fixed ordering costs, bulk purchasing discounts, and high holding costs. ii) AM enables on-demand production, reducing stockholding but introducing variable production costs.
- **Capacity Limitations Effects:** i) Most AM models assume infinite capacity, disregarding the constraints of printer availability and production speed. ii) This study explicitly excludes queueing effects, however it aligns with real-world applications where retailers invest in limited 3DP capacity.
- **Practical Retail Applications:** i) Existing studies rarely identify specific industries or product categories where hybrid sourcing is viable. ii) This study provides retail-focused insights, demonstrating how AM can complement low-volume, high-margin products in inventory management strategies.

To address these gaps, this study develops a dual-sourcing inventory optimization model that integrates AM with traditional suppliers, balancing cost efficiency and service levels. By quantifying the cost trade-offs between external procurement and in-house 3DP production, this research contributes to a more nuanced understanding of AM's role in modern retail SCs.

### 3. RESEARCH GAP and RESEARCH QUESTION

Despite the growing body of research on inventory optimization and additive manufacturing (AM) integration, critical gaps remain in understanding how hybrid sourcing strategies impact inventory costs and operational efficiency in retail supply chains. The existing literature primarily focuses on two distinct streams:

- **Traditional Inventory Models:** i) These models optimize order quantities, reorder points, and holding costs under single-source or dual-supplier scenarios (Chopra & Meindl, 2021). ii) However, they do not account for the unique cost structure and demand pooling effects introduced by AM.
- **AM-Based SCs:** i) Research highlights AM's benefits in reducing lead times and improving supply chain agility (Molcho, 2020). ii) However, these studies typically assume standalone AM-based production, without considering hybrid models where AM coexists with traditional suppliers.

To the best of our knowledge, no comprehensive study has examined:

- How retailers should optimally balance demand allocation between traditional suppliers and in-house AM production.
- The impact of AM's raw material pooling effect on inventory costs.
- The role of capacity constraints in hybrid sourcing models.

This study directly addresses these gaps by developing a dual-sourcing inventory optimization model that integrates 3DP with conventional SCs, quantifying its cost and service level implications.

#### 3.1 Research Question and Objectives

To fill this gap, the following RQ is proposed: **“How can an inventory model be developed by integrating a 3DP production centre into a traditional retail SC to optimize inventory costs while maintaining high CSL?”**

This RQ encompasses three core objectives:

1. **Cost Optimization:** i) Develop a dual-sourcing strategy that minimizes total annual inventory costs by optimally allocating demand between traditional suppliers and AM. ii) Explicitly model raw material procurement costs, holding costs, and 3DP production costs, capturing AM's distinct economic factors.
2. **Customer Service:** i) Ensure the proposed model achieves a CSL of at least 95%, minimizing stockouts and lead time disruptions. ii) Assess how AM's reduced lead time affects overall inventory efficiency and fulfilment rates.
3. **Operational Feasibility and Scalability:** i) Evaluate the model's performance under varying demand levels, lead times, and holding costs, ensuring scalability for different retail applications. ii) Explicitly assume no

queueing effects, however retailers invest in limited capacitated 3DP in meeting demand.

#### 3.2 Research Methodology Overview

To address the RQ, an analytical inventory optimization model is developed, utilizing Microsoft Excel Solver to determine the optimal allocation of customer demand between traditional suppliers and a 3DP production centre. Sensitivity analyses are conducted to examine:

1. **Scenario 1:** A retailer relying exclusively on traditional suppliers ( $X = 1$ ).
2. **Scenario 2:** A retailer implementing a hybrid sourcing strategy, where demand is split between external suppliers and in-house AM production ( $0 < X < 1$ ).

The study quantifies the impact of AM integration by comparing:

- Total inventory costs (TC)
- Average inventory levels (AIL)
- Customer service levels (CSL)

The results offer actionable insights for retailers, helping them assess when and how to integrate AM into their SC strategy.

### 4. ANALYTICAL OPTIMIZATION MODEL

This section presents the mathematical framework for optimizing inventory management in a retail SC integrating AM. The proposed model minimizes total annual inventory costs (TC) by optimizing the allocation of demand between two sourcing options:

1. Traditional supply channel (external supplier)
2. In-house 3DP production centre

The decision variable ( $X$ ) represents the proportion of daily customer demand fulfilled through traditional sourcing, while  $(1-X)$  represents demand allocated to the 3DP center.

#### 4.1 Supply Chain Configuration

Figure 1 illustrates the SC structure integrating AM and traditional sourcing. The model considers a dual-sourcing retail SC, consisting of:

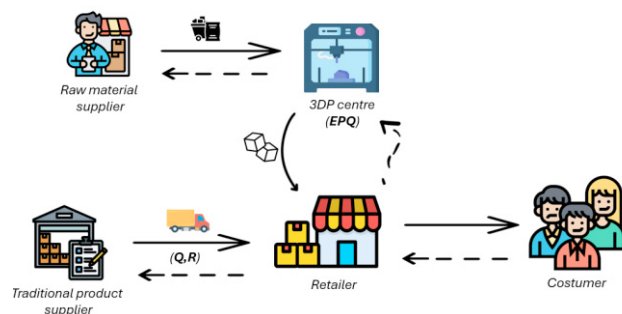


Figure 1: Structure of the SC involving dual sourcing

1. **Traditional Supplier** - External supplier fulfilling demand through periodic bulk replenishments.
2. **3DP Production Centre** - In-house facility producing goods using AM, with on-demand.

- 3. **Raw Material Supplier** - Provides polymer filament (or other AM-compatible materials) to the 3DP centre.

#### 4.2 Model Assumptions

The model operates under the following key assumptions:

##### Demand and Inventory Policies

- Daily demand ( $D_d$ ) follows a normal distribution with known mean and standard deviation.
- Continuous review ( $Q, R$ ) inventory control policy is used for traditional suppliers (EOQ-based replenishment).
- Economic Production Quantity (EPQ) model governs 3DP production batches, optimizing production frequency.
- Target  $CSL \geq 95\%$  ensures minimal stockouts.

##### Cost Structure Considerations

- *Traditional sourcing costs*: purchase, holding, and ordering costs.
- *3DP centre costs*: production, holding, setup, and raw material costs.
- *Raw material inventory*: managed separately for 3DP production.

##### Capacity Constraints & Lead Times

- Lead times are normally distributed across all SC nodes.
- No queueing effects considered: The model assumes production rate for 3DP capacity in meeting demand allocations.
- 3DP centre production capacity ( $C$ ) must exceed the allocated demand portion to avoid backorders.

#### 4.3 Model Formulation

The objective function minimizes total annual inventory costs (TC), consisting of cost components from both sourcing channels.

##### 1- Traditional Supply Channel Costs:

- Annual purchasing cost ( $TC_p$ ) is calculated by (1):

$$TC_p = D \cdot X \cdot C_p \quad (1)$$

where  $D$  is annual demand,  $C_p$  is the unit purchase price, and  $X$  is the proportion of demand met by the traditional supplier.

- Annual holding cost ( $TC_h$ ) is calculated by (2):

$$TC_h = H \cdot AIL_{tr} \quad (2)$$

where  $H$  is the holding cost rate and  $AIL_{tr}$  is the average inventory level, calculated by (3):

$$AIL_{tr} = \frac{EOQ}{2} + SS_{tr} \quad (3)$$

where  $SS_{tr}$  is safety stock and EOQ is computed by (4):

$$EOQ = \sqrt{\frac{2 \cdot D \cdot X \cdot S}{H}} \quad (4)$$

- Annual ordering cost ( $TC_o$ ) is calculated by (5):

$$TC_o = S \cdot \frac{D \cdot X}{EOQ} \quad (5)$$

where  $S$  is the ordering cost per order.

##### 2- 3DP Production Centre Costs:

- Annual 3DP cost ( $TC_{3DP}$ ) is computed by (6):

$$TC_{p,3DP} = D \cdot (1-X) \cdot C_{3DP} \quad (6)$$

where  $C_{3DP}$  is the cost per unit produced via 3DP.

- Annual holding cost for 3D printed products ( $TC_{h,3DP}$ ) is computed by (7):

$$TC_{h,3DP} = H_{3DP} \cdot AIL_{3DP} \quad (7)$$

where  $H_{3DP}$  is the 3DP holding cost rate, and  $AIL_{3DP}$  is the average inventory level which is computed by (8):

$$AIL_{3DP} = \frac{1}{2} \cdot \left( \frac{D_d \cdot (1-X)}{C} \right) \cdot EPQ \quad (8)$$

$C$  is the daily production capacity of the 3DP centre (units/day) and  $EPQ$  is the Economic Production Quantity.

- Annual setup cost for 3DP ( $TC_{setup}$ ) is computed by (9):

$$TC_{setup} = K \cdot \frac{D \cdot (1-X)}{EPQ} \quad (9)$$

where  $K$  is the setup cost per batch.

- Annual raw material cost ( $TC_{raw}$ ) is computed by (10):

$$TC_{raw} = C_{raw} \cdot D \cdot (1-X) \cdot CF \quad (10)$$

where  $C_{raw}$  is the cost per unit raw material, and  $CF$  is the conversion factor.

- 3D printer investment cost ( $TC_{3DP}$ ) is computed by (11):

$$TC_{3DP} = N_{3DP} \cdot I_{3DP} \quad (11)$$

where  $N_{3DP}$  is the total number of 3D printers at the centre and  $I_{3DP}$  is the unit cost of 3D printer.

##### 3- Raw Material Holding Costs:

- Annual holding ( $TC_{h,raw}$ ) and ordering costs ( $TC_{o,raw}$ ) for 3DP raw materials are calculated using similar expressions for  $EOQ$  and reorder points, accounting for the 3DP centre's demand.

Finally, the total cost ( $TC$ ) is computed by (12):

$$TC = TC_p + TC_h + TC_o + TC_{p,3DP} + TC_{h,3DP} + TC_{setup} + TC_{raw} + TC_{3DP} + TC_{h,raw} + TC_{o,raw} \quad (12)$$

#### 4.4 Optimization Approach

The optimization model seeks to determine the value of  $X$  that minimizes  $TC$ . Additional outputs include the optimal reorder quantities ( $Q, R$ ) for the traditional supplier and the optimal production batch size ( $EPQ$ ) for the 3DP centre which are computed by (4), (13)-(14) respectively.

$$R = L \cdot D_d \cdot X + z \cdot \sigma_L \quad (13)$$

$$EPQ = \sqrt{\frac{2 \cdot D \cdot (1-X) \cdot K}{H_{3DP}} \cdot \frac{C}{C - D_d \cdot (1-X)}} \quad (14)$$

where  $L$  is the lead time for traditional supply (days);  $z$  is the service level coefficient,  $\sigma_L$  standard deviation of demand during lead time which is computed by (15).

$$\sigma_L = \sqrt{L \cdot (SD_{D_d} \cdot X)^2 + (SD_L^2) \cdot (D_d \cdot X)^2} \quad (15)$$

$SD_L$  is standard deviation of lead time and  $SD_{D_d}$  is standard deviation of daily demand. Note that  $\frac{C}{C - D_d \cdot (1-X)}$  in (14)

adjusts for the interaction between production rate and daily demand, ensuring inventory replenishment is gradual as production occurs. Here, the condition  $C > D_d \cdot (1 - X)$  must hold; otherwise, the production capacity will be insufficient to meet daily demand, leading to backorders or delays.

5. EXPERIMENTAL STUDY

This section presents the experimental setup used to evaluate the proposed inventory optimization model. The study examines the cost and performance implications of integrating 3DP production centre into a traditional retail SC, comparing two distinct sourcing strategies:

- 1- **Traditional Supply Only:** All customer demand is fulfilled via the external supplier.
- 2- **Hybrid Model:** Customer demand is dynamically allocated between the traditional supplier and the in-house 3DP centre to minimize total costs.

5.1 Objectives

The experimental study aims to:

1. Quantify the *TC* for both sourcing strategies.
2. Assess the impact of key design factors (demand levels, holding costs, and lead times) on the hybrid model’s performance.
3. Identify conditions where 3DP integration is most beneficial, balancing cost efficiency and service levels.

5.2 Experimental Design

The experiments are conducted using synthetic data representative of retail operations. The input parameters and their values are outlined in Tables 1 and 2.

**Table 1. Input Design Factors and Levels**

Parameters	Low Level (L)	High Level (H)
Daily customer demand ( $D_d, SD_{D_d}$ )	$N(60, 30)$ (unit/day)	$N(120, 60)$ (unit/day)
Product Holding cost $H$	\$2.5/unit/year	\$7.5/unit/year
3DP product Holding cost $H_{3DP}$	\$1.5/unit/year	\$4.5/unit/year
Lead time product supplier ( $L; SD_L$ )	$N(5, 2)$ (day)	$N(10, 8)$ (day)
Daily 3DP centre production capacity $C$	48 unit/day (3 printers)	96 unit/day (6 printers)

Note: 3DP production capacity ( $C$ ) is based on one-hour printing time per product and two work shifts per day.

**Table 2. Fixed Model Parameters**

Parameters	Value
Working Days ( $W$ )	250 days
Traditional Unit Cost ( $C_p$ )	\$25/unit
3DP Unit Cost ( $C_{3DP}$ )	\$15/unit
3DP Setup Cost ( $K$ )	\$50/batch
Raw Material Cost ( $C_{raw}$ )	\$15/kg
Conversion Factor ( $CF$ )	0.5 grams/unit
Order Cost ( $S$ )	\$100/order
3DP Printer Investment ( $I_{3DP}$ )	\$5,000/printer

5.3 Optimization Approach

For each experimental case, Microsoft Excel Solver is used to determine:

1. **Optimal  $X$**  – The proportion of demand fulfilled via the traditional supplier.
2. **Optimal Economic Order Quantity (EOQ)** – For traditional supplier replenishments.
3. **Optimal Economic Production Quantity (EPQ)** – For in-house 3DP production batches.

**Key Performance Metrics Evaluated:**

- **Total Inventory Cost (TC)** – Sum of purchasing, holding, ordering, and 3DP-related costs.
- **Average Inventory Level (AIL)** – Inventory maintained across both sourcing channels.
- **Customer Service Level (CSL)** – Percentage of demand fulfilled without stockouts ( $CSL \geq 95\%$ ).

Eight experimental cases are optimised based on combinations of low and high levels of experimental design given in Table 1. Note that it is assumed that for low levels of demand, only the low  $C$  option is available, whereas for high levels of demand, the larger  $C$  is employed.

5.4 Results & Analysis

The following table presents optimal values of  $X$ ,  $EOQ$ ,  $R$ , and  $EPQ$  for the hybrid scenario:

**Table 3. Optimum  $X, EOQ, R, EPQ$  Values for the Hybrid Model**

Ex	$D_d$	$H/H_{3DP}$	$L$	$C$	$X$	$EOQ$	$R$	$EPQ$
1	L	L	L	48	0.46	748	246	1,265
2	L	H	L	48	0.46	432	246	730
3	L	L	H	48	0.46	748	656	1,265
4	L	H	H	48	0.46	432	656	730
5	H	L	L	96	0.33	895	350	2,828
6	H	H	L	96	0.33	516	350	1632
7	H	L	H	96	0.33	895	936	2828
8	H	H	H	96	0.33	516	936	1632

The values of  $TC$  corresponding to the optimal solutions of  $X$  for the two scenarios are presented in Table 4. Note that for the first scenario, as there is no option to source from the 3DP centre,  $X = 1$ . Table 5 presents results for Scenario 2 (Hybrid Model) when the capacity constraint ( $C$ ) is removed, allowing the 3DP centre to fulfil all demand without limitations (i.e.,  $X = 0$ , meaning the retailer does not rely on the traditional supplier at all).

**Table 4. Comparison of Total Inventory Costs**

Ex.	Scenario 1 (3DP unavailable)			Scenario 2 (3DP available)		
	$X$	$AIL$	$TC$	$X$	$AIL$	$TC$
1	1	774	378,304	0.46	690	373,954
2	1	542	381,440	0.46	443	376,296
3	1	1352	379,750	0.46	960	374,860
4	1	1121	385,780	0.46	713	380,015
5	1	1227	755,005	0.33	834	735,278
6	1	900	760,100	0.33	545	739,906

7	1	2384	757,896	0.33	1220	736,821
8	1	2056	768,780	0.33	930	744,536

**Table 5. Hybrid scenario results under unlimited C**

Ex	X	TC	Ex	X	TC
1	0	364,920	5	0	723,326
2	0	366,906	6	0	726,192
3	0	365,354	7	0	724,195
4	0	368,208	8	0	728,796

From Tables 3-5, the findings are summarized as below:

1. *Hybrid Model Outperforms Traditional Sourcing* – Across all cases, total inventory cost (TC) is lower in the hybrid scenario, demonstrating the cost-effectiveness of integrating 3DP.
2. *Demand (D<sub>d</sub>) is the Primary Factor Influencing X* – At higher demand levels, more production is allocated to 3DP, reducing reliance on external suppliers.
3. *Holding Costs and Lead Times Have a Limited Effect on X* – TC is mainly driven by purchasing and 3DP production costs, making demand the dominant variable.
4. *Higher Lead Times Increase Reorder Points (R)* – To maintain  $CSL \geq 95\%$ , higher lead times result in larger reorder points, ensuring stock availability.
5. *3DP Capacity (C) is a Key Constraint* – Without capacity limits, the model would fully shift to 3DP ( $X = 0$ ), highlighting the need for investment in additional 3DP capacity for scalability.

## 6. CONCLUSIONS

This study investigates the integration of AM, specifically 3DP, into traditional retail SCs, proposing a dual-sourcing inventory optimization model. The model determines the optimal allocation of customer demand between an external supplier and an in-house 3DP production centre to minimize total annual inventory costs (TC) while maintaining a high customer service level ( $CSL \geq 95\%$ ).

Through analytical modelling and experimental analysis, this study provides the following key insights:

1. **Hybrid Sourcing Reduces Inventory Costs**
  - o Across all scenarios, integrating 3DP leads to cost savings, demonstrating that 3DP complements traditional sourcing by reducing holding costs and lead time risks.
  - o The extent of cost reduction depends on demand levels ( $D_d$ ), with higher demand increasing reliance on 3DP.
2. **3DP’s Cost Advantages Are Driven by Demand Pooling and On-Demand Production**
  - o Unlike traditional manufacturing, where raw materials are often product-specific, 3DP enables demand pooling, improving cost efficiency.
  - o On-demand production minimizes holding costs, as inventory is only produced when needed.
3. **Capacity Constraints Limit Full 3DP Adoption**

- o In practical scenarios, 3DP capacity limitations (C) prevent full demand allocation to in-house production.
- o When C is removed (Table 5), total cost (TC) decreases further, proving that 3DP is the most cost-effective option if capacity is unlimited.
- o However, real-world constraints such as printing speed, raw material availability, and equipment costs require retailers to maintain a hybrid sourcing strategy.

## 4. Traditional Suppliers Are Used Primarily Due to Capacity, Not Cost

- o The model shows that traditional sourcing is only necessary when 3DP capacity is insufficient, not because of cost advantages.
- o This insight suggests that retailers should invest in expanding 3DP capacity whenever feasible to maximize savings.

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