

**Texturing, Spackling, and Jointing: Strategies for
Helping Coordinate Product, Process, and Supply Chain Design**

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Abstract

We develop a framework for determining whether the production process should be designed as make-to-stock (MTS) and/or make-to-order (MTO), given the firm's assessment of market preferences for standard product designs and custom product designs and the firm's production capabilities in terms of efficient versus flexible production. These process and product design decisions can in turn impact supply chain design since standard products might typically involve retail outlets, while custom products can often be sold directly. If the firm chooses to offer only standard products we suggest considering a process strategy called texturing, if it offers both standard and custom designs we suggest considering a process strategy called spackling, and if it offers custom products we suggest considering a process strategy called jointing. All three strategies involve both MTS and MTO.

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1. Introduction

The advent of the Internet has heightened interest in the use of direct sales channels and in the design and production of custom, make-to-order (MTO) products. The Internet gives manufacturers direct access to customers and in turn gives customers direct access to information about products, creating a convenient means through which customers can configure and order their preferred products. In some cases manufacturers foresee using this direct channel to complement the customer's alternative of buying a standard make-to-stock (MTS) product from a traditional retailer, while in other cases the direct channel may fully displace the traditional channel. In yet other situations, the direct channel may be of no value – the manufacturer may choose to continue selling strictly through retail outlets to customers who prefer immediate delivery and visual inspection of the product.

Advances in production technologies also seem to be influencing methods by which products can be designed, produced, and distributed. For example, flexible manufacturing processes are becoming less costly and more capable. Supply chain management initiatives are reducing lead-times and inventory requirements. And tracking technologies are facilitating the smooth and efficient flow of goods. Thus manufacturers are faced with a changing landscape – creating a picture of both opportunity and challenge.

The firm must make some very basic, but strategic, decisions about its product designs, process designs, and supply chain designs. Should the firm's product designs include custom products, or standard products, or both? Should the firm's processes be designed as make-to-order, make-to-stock, or some combination of these alternatives? And should the supply chain

be designed to deliver products direct, or through a traditional retail channel, or both? We begin to address these relatively high-level decisions in a very general framework. We focus on the issues of product design type (standard versus custom) and process design configuration (MTO versus MTS), noting that direct supply chains seem quite amenable to the delivery of custom products while retail supply chains deal efficiently with standard products where quick delivery and fast inventory turnover are paramount.

The question of how best to match product design with process design is not a new one. Hayes and Wheelwright (1979a) developed the notion of the product/process spectrum to address a fundamental trade-off that firms face, between efficiency and flexibility. Flow shops typically mass-produce standard items in a steady, make-to-stock (MTS) fashion using dedicated resources to achieve efficient, low-cost production. However, a downside of flow-shop production is that output may not directly match customer demand in a couple of significant ways. First, the standard products may not exactly match each customer's needs. Second, achieving a steady flow of efficient output is difficult under stochastic demand; the manufacturing firm likely will produce too many items or too few and experience overage or underage costs.

At the other end of the spectrum from the flow shop is the job shop. A job shop can produce customized make-to-order (MTO) products using flexible resources and thereby exactly match both customer design preferences and demand volume. A possible supply chain design advantage is that the MTO manufacturer may be able to sell custom products directly to end users more easily than a traditional retailer could, and thus have a more streamlined supply chain. The downside of custom MTO items is that these products generally require less efficient, but flexible job-shop type resources. Further, the customer may experience a delay cost

in not getting the product immediately – many standard products are sold through retail outlets where the consumer takes immediate delivery of the product rather than incurring any delay.

The firm desires a process design based on flow-shop efficiency but also sees possible advantages from product designs that feature customizable MTO items and from streamlined supply chains that sell direct. How can the firm best manage these trade-offs?

The traditional answer to this management challenge has been to match the process design strategy with the product design strategy, as suggested by Hayes and Wheelwright (1979b). That is, if the product design is one of standard products produced in high volume, then the process design should be based on efficient flow-shop resources producing in MTS fashion (a process typically referred to as mass production), while if the design strategy involves one-of-a-kind custom products then the process design strategy should incorporate less efficient but flexible resources and a job-shop MTO environment. While recognizing that there are possible intermediate strategies of batch flow and line flow, this traditional response aligns product design for standard products with an MTS mass production process design, and product design for custom products with a flexible MTO process design.

We consider the possibility of further refining the firm's response to this challenge by using hybrid (i.e., dual) strategies that simultaneously take advantage of both MTS and MTO in non-traditional ways. In this paper we first develop a marketing model that determines whether the firm might be best served by offering custom products in addition to its standard products, or only custom products, or only standard items. We then present separate operations models for each of these three cases, to tie the results of the marketing analysis to three possible dual MTS/MTO strategies: the first is applicable to the case where the market preference is only for standard products (we call this a texturing strategy), the second should be considered when the

market preference is for both standard and custom products (we call this a spackling strategy), and the third might prove advantageous when the market preference is only for custom products (a jointing strategy). We show the conditions under which each of these hybrid strategies is preferred, as compared to more traditional strategies.

Our framework is depicted in Figure 1, and is comprised of a simple two-stage analysis. The marketing model first determines which row of Figure 1 the firm finds itself. That is, it establishes whether the firm should offer only standard products in retail channels, only customized products in a streamlined supply chain involving a direct marketing channel, or a mix of both, and establishes expected demand volumes.

Figure 1. Strategy is Determined by Market Preferences and Production Capabilities

		Production Capabilities	
		High	Low
Market Preferences	Standard Products	<p><u>Mass Production</u> Make std. products via MTS using efficient capacity</p>	<p><u>Texturing</u> Make std. prod. via 2 resources; MTS using eff. cap. & MTO using flex. cap.</p>
	Both Std. & Custom Products	<p><u>Focus</u> Make std. prod. via MTS using eff. cap.; Make custom prod. via MTO using flex. cap.</p>	<p><u>Spackling</u> Make std. prod. via MTS using flex. cap.; Make custom prod. via MTO using the same flex. cap.</p>
	Custom Products	<p><u>Postponement</u> Start custom prod. as MTS using eff. cap., finish via MTO using flex. cap. (most steps the former)</p>	<p><u>Advancement</u> Start custom prod. as MTS using eff. cap., finish via MTO using flex. cap. (most steps the latter)</p>

Using this marketing information, along with information regarding demand variability, the firm then uses an operations model to determine whether it is located in the left or right column of Figure 1. More specifically, the operations model determines the type, and level, of capacity to acquire, and determines whether to operate in MTS or MTO fashion. (We use the

term MTS to mean that production proceeds in anticipation of demand, with output being added to inventory, while MTO proceeds only after demand realization.) Capacity comes in two forms, “efficient capacity,” that can only produce standard products in MTS fashion, and “flexible capacity,” that can produce either standard or customized products, and can operate in either MTS or MTO fashion. That is, efficient capacity is associated with a relatively steady production schedule for a limited set of product configurations, where output is added to inventory. Flexible capacity, on the other hand, is associated with resources that can produce a wider configuration of products on relatively short order, within the capacity constraint, but at a higher cost.

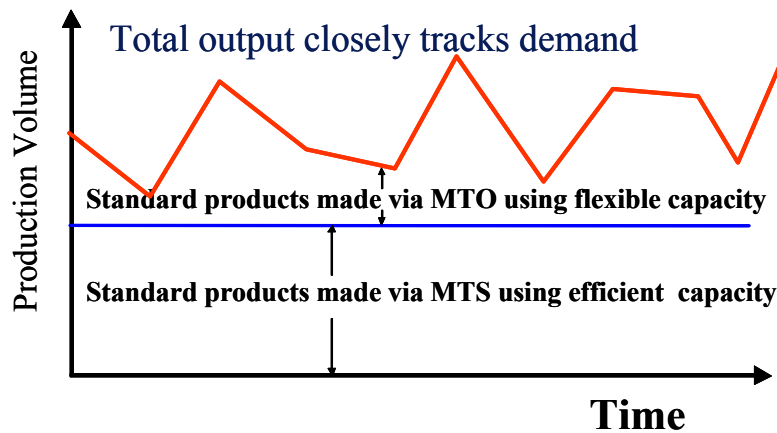
First, consider the case where the market demand is primarily for standard products (the top row of Figure 1). Traditionally, a firm might view this as a situation calling for efficient capacity and MTS, i.e., mass production.¹ Indeed, we find that to be the case, assuming there is a significant cost advantage for such production. However, if the penalty associated with flexible capacity is less imposing, then the firm may want to consider an approach we call *texturing*.

With the texturing strategy, the firm’s primary production comes from efficient capacity coupled with MTS production, but since MTS has the disadvantage of not exactly matching demand in a given period, the firm restricts its efficient capacity (its MTS output) to avoid building too much stock product. Concurrently, it holds some separate flexible capacity used in MTO fashion only if it realizes demand in that period exceeding MTS capacity. The result is that efficient capacity is utilized fully, while flexible capacity is used only if there is sufficient

¹ Technically, the term mass production may be appropriate only if the items are sold in large volume. However, even if volumes are small, producing standard items via MTS can likely be done in a relatively more efficient manner than making such items via MTO.

demand. If this scenario is repeated in a series of independent and identical periods, then varying levels of flexible capacity (MTO production) would be used from period to period based on each period's specific demand realization. This yields a total production level that is bumpy (it varies from period to period), but that closely matches the bumpy demand (see Figure 2). Our analogy here is to a textured (bumpy) wall or ceiling surface. Note that with texturing, the firm effectively operates two different production facilities, one equipped with efficient resources and the other with flexible resources.

Figure 2. Texturing Yields a Bumpy Stream of Standard Products, from Two Facilities.



An example of texturing involves a well-known semiconductor manufacturer. The firm produces a steady volume of standard computer chips in an efficient manufacturing fab, and supplements that capacity with flexible but expensive capacity that is generally used for R&D purposes. The R&D capacity is used for production purposes only if demand exceeds the fab capacity. See Cattani, et al. (2003a) for further discussion of the texturing strategy.

Next, consider the case where significant market demand exists for both standard and customized products (the middle row of Figure 1). In this situation, a firm might traditionally establish a focused strategy: one efficient facility (or production line) focuses on production of

standard products managed in MTS fashion, and a separate flexible capacity focuses on custom products operating as MTO. We indeed find this to be optimal if the cost premium for flexible capacity is high. However, in many situations the firm may also want to consider another dual MTS/MTO approach, which in this case we call *spackling*.

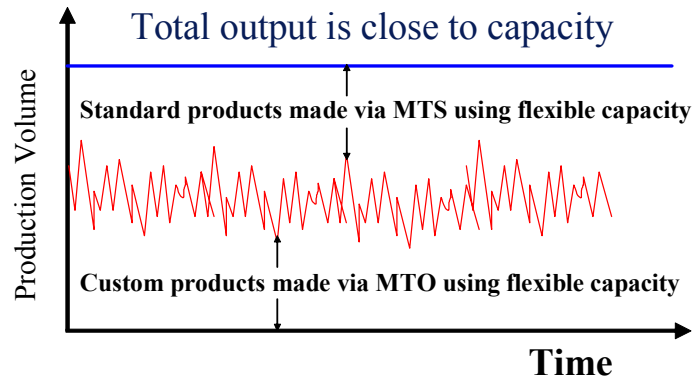
With spackling, the firm acquires only flexible capacity. Its first priority in any given period is to produce custom products via MTO. However, order patterns for custom products are bumpy (uncertain), yielding an undesirable production profile compared to smooth schedules that allow for higher capacity utilization (see Figure 3). Thus the firm uses the same (flexible) production capacity to produce standard products in MTS fashion, to smooth the production schedule. The result is that MTO production closely tracks demand for customized products in each period, while MTS output tracks demand for standard products, not over the short-run but rather over the longer-run, with some inventory build-up. In the spackling case, total production output from period-to-period is relatively smooth, or spackled.²

An example of where spackling might be considered is in the auto industry, where managers have been talking for a decade or more about the five-day car. With this concept, a portion of cars would be produced only after end-user orders are received, shipping within five days of the order. Manufacturers might deal with day-to-day demand uncertainty producing cars for stocking at dealers in the same plant where they make the five-day cars, using a spackling technique. The custom products would be produced first each day, and the remaining capacity would be used to produce for dealer stocks. Our model can help the firm determine the optimal

² The American Heritage® Dictionary of the English Language: Fourth Edition 2000 defines spackle as “A trademark used for a ... paste designed to fill cracks and holes in plaster before painting or papering. This trademark often occurs in lowercase and as a verb...”

capacity level and pricing strategy. The spackling strategy is discussed in more detail in Cattani, et al. (2003b).

Figure 3. Spackling Yields a Relatively Steady Total Output Stream, from One Production Facility.



Lastly, consider the case where demand calls primarily for customized products (the bottom row of Figure 1). While each end item is customized to the individual customer's tastes, the firm might still be able to make effective use of both efficient and flexible resources through a strategy we call *jointing*. To see how jointing works, consider Figure 4. In the setup of Frame A, twenty-six customers (A through Z) each buy a unique product design (configurations A through Z). For simplicity, assume production of each configuration requires exactly two process steps. Further assume that all configurations use the same raw materials. However, steps one and two are specific to each configuration – after each step, each configuration is different from all other configurations. Thus the product fans-out into its individual custom configurations at the point that raw materials are consumed – we refer to this as the product *fan-out point*.

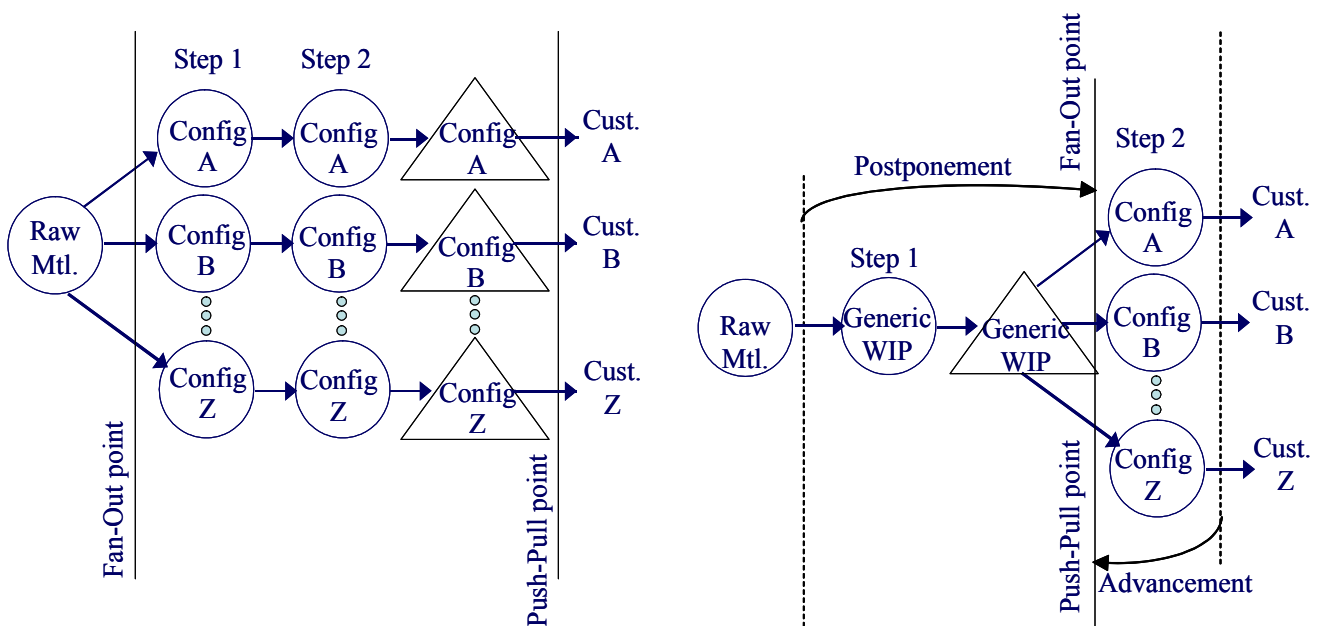
The *push-pull point* in Frame A of Figure 4 is positioned after step two. This point is so named because an item is pushed through production up to this point and then held in inventory

(as indicated by the triangle) until a customer purchases that specific item, figuratively pulling the item through the rest of the process (in this case, production is already complete at the push-pull point). Thus the approach depicted in Frame A is one where the firm produces all configurations (A through Z) and then holds them in inventory until consumer purchase.

Figure 4. Jointing Involves Postponing the Fan-Out Point and/or Advancing the Push-Pull Point.

Frame A: Original Setup

Frame B: After Product/Process Re-Design



Jointing involves merging of the fan-out and push-pull points at a common joint in the process, as illustrated in Frame B of Figure 4. In this example, the product is re-designed such that the first step is identical for all configurations. That is, a partially-completed product is generic through step one in that it can be finished into any one of the possible twenty-six configurations. The fan-out point now falls between process steps one and two. The push-pull point in Frame B has in turn been advanced one step to also fall between process steps one and two – items are now held in an unfinished state as generic work-in-process (WIP) until a specific

order is received, at which time process step two (specific to the configuration ordered) is executed and the product is delivered to the customer.

Thus jointing can be achieved through some combination of postponement (of the fan-out point) and/or advancement (of the push-pull point). One advantage of jointing is that only the generic product is inventoried, reducing underage and overage costs through pooling benefits. A second advantage of jointing is that efficient resources can still be used to produce the generic product in MTS fashion up to the joint where the fan-out and push-pull points meet (beyond that joint the product is finished in MTO fashion using flexible resources). If the cost premium for flexible resources is high, then jointing might best be pursued via postponement, while if the cost premium is low then advancement might be the preferred technique.

An example of jointing in the service industry is the walk-up rental of a room at an upscale hotel. The hotel room is cleaned and held in an almost-ready state up to the point where the walk-up customer arrives. Assuming this is a repeat customer, previous information regarding that customer is then accessed to customize the room to meet the preferences of that individual customer. For example, the staff may know that the customer prefers non-feather pillows, and can equip the room with these items at the last minute.

In this paper we develop a simple marketing model to assess market preferences. Using the results of the marketing model we synthesize and integrate into a common framework the three previously developed dual strategies of texturing, spackling, and jointing. In this way we show how these strategies can be used to help coordinate product, process, and supply chain design. We find that these dual strategies become more attractive as the cost premium for flexible production over that of efficient production decreases. We anticipate that this cost

premium will continue to diminish due to advances in operations management, increasing the viability and attractiveness of the texturing, spackling, and jointing strategies.

In § 2 we lay out a marketing methodology for determining whether demand is for standard, custom, or both types of products. In § 3, § 4, and § 5 we provide more detailed discussions of texturing, spackling, and jointing, respectively. We conclude in § 6.

2. Determining Whether Demand is for Standard, Custom, or Both Types of Products

We address product and supply chain design decisions by modeling the firm's decision to market standard MTS products, and/or custom MTO products. We assume the firm has already made related decisions regarding the exact product features to offer (i.e., what features to incorporate in the standard products and in the base custom products, and what options to offer in the custom products).

The effect of having two product types (standard and custom) is to segment the market. A second segment can generate incremental demand, but may also cannibalize demand for the first market segment. In other words, some customers are willing to switch between product types. We refer to those customers that would have bought the standard product if it was the only product offered but will switch to buying a customized product if both types are offered as "s-to-c switchers." Similarly, we refer to customers as "c-to-s switchers" if they would buy a custom product if that was the only type offered but will switch to a standard product if offered. The sizes of the s-to-c and c-to-s switcher categories are a function of customer preferences along with the prices for the standard and customized products. Pricing plays a crucial role because lowering the price for one model increases its sales by expanding the market but it also cannibalizes additional sales of the other model by increasing the number of switchers.

To determine the optimal prices, we begin by adopting the usual definition of a customer's reservation price, interpreting it as the most she is willing to pay for a product, and assume her reservation price for a customized product takes into account any delay cost that she might incur in having to wait for product delivery. Reservation price may be assessed, for example, through conjoint analysis and user design as described by Dahan and Hauser (2002).

Our focus is on the customer choice between a custom and standard product; in this paper we take as a given the feature levels the firm incorporates into its standard product and the menu of customizable features it offers.³ Let c_j denote product j 's cost and p_j its price, such that $m_j \equiv p_j - c_j$ denotes the firm's dollar markup on product j . Here, product j can be the standard product or any one of the custom products.

Let r_j^i denote customer i 's expected dollar-equivalent utility for product j , excluding price: we refer to r_j^i as customer i 's reservation price for product j . If viewed deterministically, then given the choice of buying product j or buying nothing, customer i buys at a price below r_j^i . Define $d_j^i \equiv r_j^i - c_j$ as the discriminating markup; it is the markup the firm could achieve in selling product j to customer i if it could perfectly price discriminate at the individual customer level (to the first degree), under deterministic customer choice. Customer i 's net utility (surplus) from buying product j at price p_j is $s_j^i = (r_j^i - p_j) = (d_j^i - m_j)$, since $d_j^i \equiv r_j^i - c_j$ and $m_j \equiv p_j - c_j$.

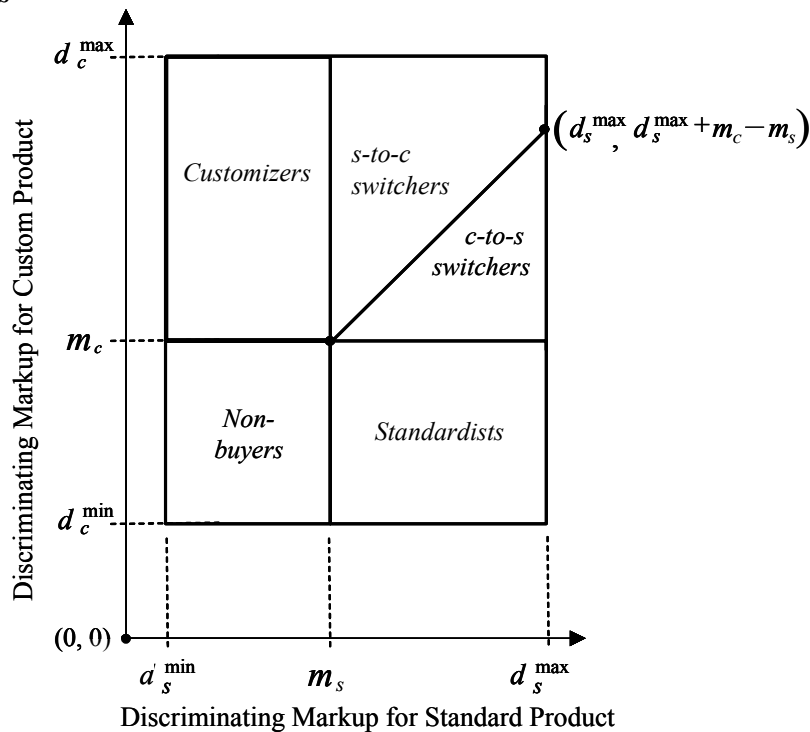
From here on, we consider only one custom product for each customer, her most preferred custom product. Thus for any given customer i we can restrict our consideration of product j to be either standard (s) or custom (c). Further, we assume the firm prices such that the absolute dollar markups for all configurations of the custom product are of constant magnitude

³ It is beyond the scope of this paper to determine the optimal set of product features to include in the standard products or to offer in custom products, but of course these decisions also impact profitability.

m_c . (This is accomplished by pricing all margin into a base configuration and then adding or deleting options at cost.) This assumption and its rationale are discussed in depth in Cattani, et al. (2003b), and have the effect of allowing us to compare the preference of a standard product to that of a custom product across customers without needing to know which specific configuration each customer has chosen.

We assume that customers have preferences such that these discriminating markups are distributed uniformly over the intervals $[d_s^{\min}, d_s^{\max}]$ and $[d_c^{\min}, d_c^{\max}]$. See Figure 5. We assume the customer buys at most one product from the firm; the product offering her the most surplus. See Schmidt and Porteus (2000) for similar methodology.

Figure 5: Market Segmentation Based on Preference for Standard versus Customized Products



As indicated in Figure 5, we categorize customers into several types: a segment of potential customers who don't buy (non-buyers), a segment who buys the customized product but who wouldn't buy the standardized product (customizers), a segment who buys the standard

product but wouldn't buy the customized product (standardists), a segment who would buy the standard if it had no choice but switches to the custom if a choice is offered (the s-to-c switchers), and a segment with the reverse preference (the c-to-s switchers). The size of each region depends on the prices (the markups) the firm charges for each product type. For example, increasing the markup of the standard product increases the number of non-buyers while reducing the number of standardists, and reducing the number of c-to-s switchers.

Since each customer's decision depends on markups, product pricing becomes a profit maximization calculation for the firm. We present below the solution for the case where $(d_s^{\max} - m_s) < (d_c^{\max} - m_c)$. The solution for the case where $(d_c^{\max} - m_c) < (d_s^{\max} - m_s)$ is found similarly. The firm's profit π is: $\pi = (\text{markup on standard}) \times (\text{standardists} + \text{s-to-c switchers}) + (\text{markup on custom}) \times (\text{customizers} + \text{c-to-s switchers})$

$$= m_c \left[(d_c^{\max} - m_c)(d_s^{\max} - d_s^{\min}) - \frac{1}{2}(d_s^{\max} - m_s)^2 \right] + m_s \left[(m_c - d_c^{\min})(d_s^{\max} - m_s) + \frac{1}{2}(d_s^{\max} - m_s)^2 \right]. \quad (1)$$

We find the optimal markups by deriving the first order conditions associated with the above profit function and solving simultaneously for m_s^* and m_c^* . The Hessian matrix can be checked for the negative definite property to determine whether optimality is assured. The general solution is not analytically elegant so we forego its presentation here. Given a specific set of minimum and maximum discriminating markups the solution is straightforward.

To gain basic insights we consider the special case where the minimum discriminating markups are zero, and the firm sets equal markups for standard and custom products, $m_s^* = m_c^*$.

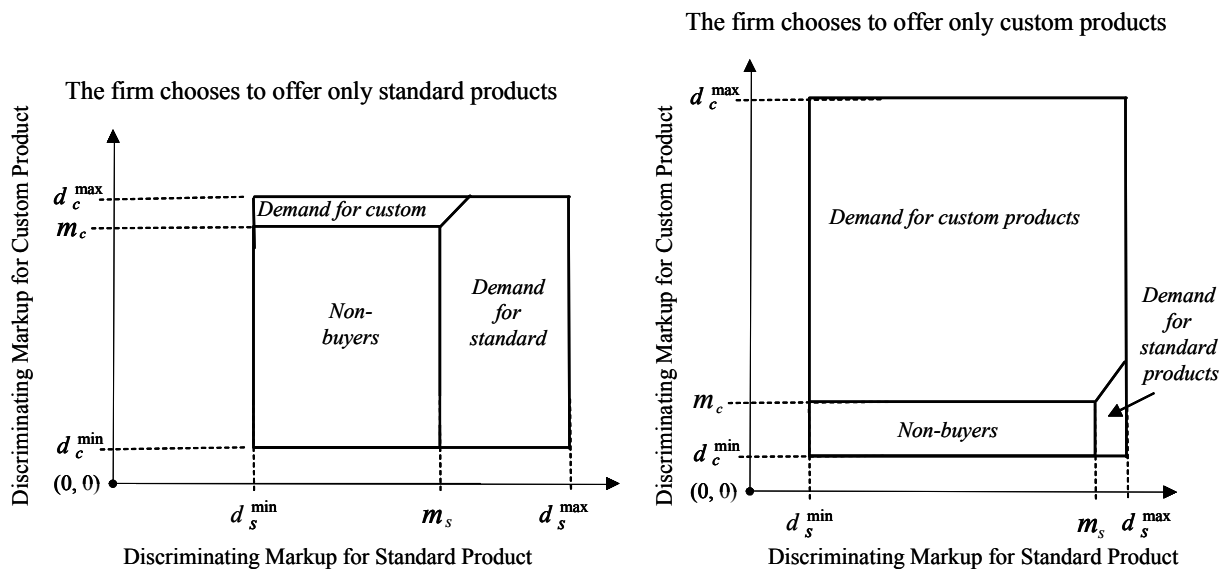
In this case, the solution reduces to:

$$m_s^* = \sqrt{\frac{d_c^{\max} d_s^{\max}}{3}} \text{ and the profit at } m_s^* \text{ is } \pi^* = \frac{2(d_c^{\max} d_s^{\max})^{3/2}}{3\sqrt{3}}.$$

The above equations suggest prices and profits increase as d_s^{\max} and d_c^{\max} increase, while higher unit costs drive prices up and profits down, as one would expect. Increasing the maximum reservation price for one product increases the prices of both products.

We have assumed that all costs are variable. In reality there likely are fixed costs associated with offering each type, such that the firm may choose to offer a type only if the projected incremental profit from offering that type (as calculated above) exceeds some threshold value. For example, Figure 6 illustrates the cases where the firm might choose to offer only standard or only custom products (the case where it likely chooses to offer both types was previously illustrated in Figure 5). In this paper we do not identify that threshold value but simply categorize the outcome of the marketing model into one the following three cases: 1) the firm chooses to offer only standard products since virtually all demand is for standard products; 2) the firm chooses to offer only custom products since virtually all demand is for custom; or 3) the firm chooses to offer both types since there is substantial demand for both. We proceed in §3, §4, and §5 to develop an operations model to address each of these three cases.

Figure 6: When it May Be Desirable To Offer Only Standard or Only Custom Products.



3. Process Design when Demand is Primarily for Standard Products (Texturing)

The operations model for the case where demand exists only for standard products follows that of Cattani, et al. (2003a), which we summarize in this section. To motivate the analysis, consider a semiconductor manufacturer who produces a computer chip in an efficient manufacturing fabrication plant, or fab. The chip is a standard item but will become obsolete quickly, such that the efficient plant effectively gets just one opportunity to set the production volume. To hedge against the uncertain demand volume, the firm also considers acquiring some relatively expensive, but more flexible capacity that can be used if demand exceeds the efficient capacity. Effectively, such flexible production would be make-to-order (MTO), in that production would commence only after demand is realized, even though the MTO-produced chips would not be customized in any way. Should the firm actually acquire this flexible capacity? More specifically, how much efficient capacity and how much flexible capacity should it acquire?

We employ a simple single-period model to address these questions. Demand is characterized as a non-negative, continuous random variable X with distribution $F(\cdot)$ and probability density $f(\cdot)$, and represents demand for one period (e.g., the season). The firm maximizes expected profit by setting its efficient and flexible capacities, denoted by K_E and K_F , respectively. Total capacity is denoted by $K = K_E + K_F$. The firm produces K_E units before observing demand (given our setup, the firm will fully use any efficient capacity that it acquires). If demand exceeds K_E , the firm fills this additional demand with output from the flexible capacity, up to its capacity level, K_F . Variable (per unit) costs are assumed to be constant over the volume of interest for each production type. The variable costs of producing one unit using efficient and flexible capacities are c_E and c_F , respectively. The selling price is p . We assume

lost sales, and at the end of the period any leftover units are salvaged at s . Each type of capacity incurs a fixed cost of θ_i per unit per period with $i \in \{E, F\}$ for efficient and flexible capacities. The cost of each type of capacity per period is thus $\theta_i K_i$.⁴

We make the following assumptions:

- (A 1) $c_F, c_E, \theta_F, \theta_E > 0$. All production costs are greater than zero.
- (A 2) $c_F > s, c_E + \theta_E > s$. Salvage value is less than the cost of production. There is no incentive to produce solely for the salvage market.
- (A 3) $c_F + \theta_F < p$ and $c_E + \theta_E < p$: We avoid trivial cases where the firm would never invest in MTS or MTO capacity, respectively.

The firm's optimal capacities K_E^* and K_F^* depend on the cost premium for flexible production, $((c_F + \theta_F) - (c_E + \theta_E))$. If MTO production (always associated with flexible capacity) is no more expensive than the efficient type, then the firm exclusively uses MTO. If MTO is more costly but "not too expensive," then the firm adopts the texturing strategy. By "not too expensive" we mean that it must be below Δ , defined as follows:

$$\Delta \equiv (p - (c_F + \theta_F))(c_F - s) / (p - c_F). \quad (2)$$

If the cost premium for flexible production exceeds Δ , then the firm produces only via MTS, which in this model is always associated with efficient capacity. We refer to the strict use of MTS using efficient capacity as a mass production strategy. More specifically, the optimal efficient capacity K_E^* and the optimal flexible capacity K_F^* are:

⁴ Since efficient production is produced to capacity once capacity is decided, each unit of capacity will incur both the fixed cost θ_E as well as the variable cost c_E , so these costs could be combined.

<p><i>Case A (strict MTO production):</i></p> <p>If $(c_F + \theta_F) - (c_E + \theta_E) \leq 0$, then</p>	<p>$K_E^* = 0$ and</p> <p>$K_F^* = F^{-1} \left[\frac{(p - c_F - \theta_F)}{(p - c_F)} \right]$.</p>	(3)
<p><i>Case B (textured production):</i></p> <p>If $0 < (c_F + \theta_F) - (c_E + \theta_E) < \Delta$, then</p>	<p>$K_E^* = F^{-1} \left[\frac{((c_F + \theta_F) - (c_E + \theta_E))}{(c_F - s)} \right]$, and</p> <p>$K_F^* = K^* - K_E^* = F^{-1} \left[\frac{(p - c_F - \theta_F)}{(p - c_F)} \right] - K_E^*$.</p>	(4) (5)
<p><i>Case C (mass production):</i></p> <p>If $\Delta \leq (c_F + \theta_F) - (c_E + \theta_E)$, then</p>	<p>$K_E^* = F^{-1} \left[\frac{(p - c_E - \theta_E)}{(p - s)} \right]$ and</p> <p>$K_F^* = 0$.</p>	(6)

In each case we find a newsvendor-type critical fractile solution. For a detailed interpretation of the results, along with comparative statics, see Cattani, et al. (2003a), where the model is also extended to the case of two products.

4. Process Design When Demand is for Both Standard and Custom (Spackling)

Our approach for the case where demand exists for both standard and custom products follows that of Cattani, et al. (2003b), which we summarize in this section. To motivate the analysis, consider Timbuk2, who makes messenger bags. The firm introduced an Internet site where a customer can order a customized MTO bag. This direct channel streamlines the supply chain, while complementing the firm's traditional retail channel where pre-configured (standard) MTS bags are sold.

Timbuk2 considered two alternative process design strategies: a focus strategy where an efficient offshore plant makes standard MTS bags at minimal cost while a flexible domestic plant makes custom MTO bags in a timely manner; and a spackling strategy where the firm makes both types of products (standard and custom) domestically in the flexible plant. Senior

management wondered what overall effect each strategy would have on manufacturing cost and ultimately, of course, on profitability.

We employ an operations model that maximizes profits by setting levels of flexible and efficient capacity, given the demand parameters for standard and custom products. We consider a single-period where demand is realized over T subperiods, with T being the lead time offered to retailers for delivery of standard products. The firm receives its orders for custom products at the beginning of each subperiod and must deliver them by the end of that subperiod. Separately, at the beginning of the first subperiod, the firm receives all orders for standard products, due at the end of the period. We do not account for holding costs.

Subperiod demands for custom products are assumed to be independently and identically distributed $F_C \sim N(\mu_C, \sigma_C^2)$. Here we present the simplified model that assumes demands for standard products are deterministic, with exactly $T\mu_S$ units due at the end of the period. Total period demand (the sum of demands for custom and standard products) is denoted by $F_T \sim N(T(\mu_S + \mu_C), T\sigma_C^2)$.

The firm implements either a strategy of focus or spackling. This choice is effectively one of setting production capacities for efficient and flexible resources, denoted by K_E and K_F , respectively (one unit of capacity can make exactly one unit of one product per sub-period). A focus strategy involves positive amounts of both capacity types, while spackling requires only flexible capacity. Let θ_E denote the fixed cost per subperiod for a unit of efficient capacity (used only with focus to make standard units) and θ_F be the fixed cost of flexible capacity (used with focus to make custom units, and with spackling to make both standard and custom units),

and let c_E and c_F denote their respective variable production costs per unit. Each unit sells for price p .

We assume that we can view a custom product to be some base product plus or minus a set of options and that each custom and standard product requires one unit of capacity. Without loss of generality, define such base product to be the standard product. We assume that we price to achieve the same markup on all custom products, such that we effectively sell all options at cost and simply set the markup on the base product. See Cattani, et al. (2003b) for rationalization of this assumption. Consistent with this marketing approach, here we assume θ_F and c_F apply to the base (standard) product.

At the beginning of the period (the first subperiod) the firm sets capacities K_E and K_F (if the firm chooses $K_E = 0$, i.e., to spackle, then flexible capacity $\equiv K$). Let X_{Ci} denote the realization of demand for custom units in subperiod i . In the case of spackling, K units are produced in total in each of the initial subperiods: X_{Ci} units of customized products and $K - X_{Ci}$ units of standard products. If demand over the T subperiods for customized products is less than $TK - T\mu_S$, the firm makes $T\mu_S$ standard units and then stops producing standard products for the remaining subperiods. If period demand for customized products is greater than $TK - T\mu_S$, there are lost sale of standard units. We assume $p, c_P, c_F, c_E, \theta_F, \theta_E > 0$ (all production costs are greater than zero), $c_F + \theta_F < p$ (we avoid the uninteresting case where flexible capacity is zero), and for spackling we assume $\mu_C \ll K$ (the firm has sufficient capacity each subperiod to meet customized orders, $X_i < K \forall i$).

Figure 1 suggested spackling is preferred if the cost premium for flexible production is “low.” Here we find “low” is anything below V :

$$V \equiv \frac{\sigma_C (T - \sqrt{T}) (z^* \theta_F + (p - c_F) L(z_F^*))}{\mu_S T} \quad (7)$$

where $z_i^* = \Phi^{-1}((c_P - c_i - \theta_i)/(c_P - c_i))$, the standardized variate for the given fractile $i \in \{E, F\}$, and $L(z_i^*)$ is the standard normal loss function.

More formally, optimal capacities are:

Case A (Focus): If $(c_F + \theta_F) - (c_E + \theta_E) \geq V$, then

$$K_E^* = \mu_S \text{ and} \quad (8)$$

$$K_F^* = \mu_C + z_F^* \sigma_C. \quad (9)$$

Case B (Spackling): If $(c_F + \theta_F) - (c_E + \theta_E) < V$, then $K_E^* = 0$ and

$$K^* = K_F^* = \mu_S + \mu_C + \frac{1}{\sqrt{T}} \sigma_C. \quad (10)$$

From (7) we gain the following managerial insights: spackling is most compelling when demand for custom products is more variable (σ_C is large), the lead-time for production of standard units is long (T is large), demand for standard products is low (μ_S is small), the penalty for lost sales is high (p is large) and, of course, when the premium for flexible production is small (when $(c_F + \theta_F) - (c_E + \theta_E)$ is small).

5. Process Design When Demand is Primarily for Custom Products (Jointing)

The description below follows Schmidt (2003). While this section covers the case where there is demand for (only) custom products, the principles discussed apply also to the production of custom products when offered in conjunction with standard products.

In this paper we do not determine the optimal positioning of the fan-out and push-pull points, or the optimal positioning of their common joint should the jointing strategy be followed, but offer a qualitative discussion of some of the issues.

The discussion surrounding Figure 4 provided definition of terms such as the product fan-out point and the push-pull point. Consider a firm such as Honda, that offers an assortment of options for its model S2000. These options cater to customers who differ in their preferences for color, sound system, and other features, and in their price sensitivity. However, from an operations perspective, offering product variety is generally more costly, since producing multiple configurations requires more expensive flexible resources, and since it may be difficult to match output with demand. For example, Honda may make more red cars and fewer silver cars than are demanded, or vice versa. How can Honda ameliorate this product variety dilemma?

One possibility is to implement a postponement strategy, as illustrated via the classic case of the Hewlett-Packard (HP) inkjet printer (see Lee, et al. (1993)). HP originally produced printers in make-to-stock (MTS) fashion (by this we mean printers were sold out of stock inventory), shipping numerous versions from its Vancouver plant to meet the needs of various geographic regions. HP redesigned the process to add the power supply locally, at multiple distribution centers, rather than at the factory (i.e., HP postponed the point at which the product fanned out into different configurations), thus reducing safety-stock requirements. Lee and Tang (1997) discuss some of the benefits of postponement in a more general setting. If Honda decided to similarly implement a postponement strategy of some type, how far should it postpone the fan-out point (i.e., when should a generic S2000 fan out into its various configurations)? Should Honda have the distribution center paint the car, for example? Or should they postpone some of the production steps all the way down to the dealer level, by offering dealer-installed options? In our terminology, if the firm ships the product to distributors before painting, for example, the firm delays or postpones the point at which the product “fans out” into its various colors. Thus

the degree to which postponement is practiced is effectively determined by the positioning of the product fan-out point – where should the fan-out point be positioned?

Alternately (or in combination with a postponement strategy), Honda might consider a strategy we call *advancement*. With advancement, the firm may initiate production but then holds the product in some unfinished state until the customer places an order, at which time production is completed. The auto industry has long discussed the idea of selling the bulk of its cars via MTO (currently most of the cars in the U.S. are bought off-the-lot). It has mentioned a 10-day car (meaning the car would be delivered 10 days after the order is received), or a 3-day car, or an “*x*-day” car. (See Jost (1994).) If Honda offered an *x*-day car, how much assembly should it initiate before receiving a customer order? At a minimum, it would probably have the engine, transmission, and other components already assembled. Should it initiate any final assembly before receiving individual orders?

Similar to the relationship between postponement and the fan-out point, there is a relationship between advancement and the push-pull point. The push-pull point is the point at which production is halted until receipt of an order – the item is pushed through production in make-to-stock (MTS) fashion, then held in inventory until a customer order pulls it through the rest of the way as a make-to-order (MTO) unit. A downside of more extensive forms of advancement is that lead-times become longer – rather than selecting a car off-the-lot, Honda’s customers would have to wait for its production and delivery. If Honda chose to pursue advancement, how far should the push-pull point be advanced?

Advancement is introduced here as a new term, but it is not a new concept. What the term is intended to convey is the notion that MTO production might in some cases mean starting from scratch in making the product, and in other cases it might mean simply “flipping a switch”

before shipping the product. In the first case, the push-pull point is at the start of the process, and in the latter it is at the end. Specifically, where should the push-pull point be? And where should it be relative to the fan-out point?

Conceptually, production can be divided into three stages, recognizing that the fan-out and push-pull points may not be delineated as cleanly as we imply in the current discussion. We assume here that the fan-out point precedes the push-pull point, as this seems likely to be the preferred sequence in most cases. Prior to the fan-out and push-pull points (stage 1), the firm makes generic items in continuous fashion. This can be accomplished using efficient resources (approaching those of a flow shop, for example), such that, qualitatively, the cost for completing any given process step is low (as compared to what it would cost to complete that step if it followed the fan-out and/or push-pull points). Between the fan-out and push-pull points (stage 2), the firm needs more flexible resources, as it is dealing with an assortment of products, but it can still make these in steady make-to-stock fashion, such that assembly cost is expected to fall within an intermediate range, relative to what it would cost to perform that step in stage 1, or in stage 3. Subsequent to both the fan-out and push-pull points (stage 3), the firm needs flexible resources, and needs to produce items on demand rather than at the firm's preferred rate of output. This implies poorer capacity utilization, such that the cost to perform a given process step is likely to be relatively more expensive. In addition to these cost issues, the firm should consider how design costs, inventory costs and product obsolescence costs are affected by advancement and postponement. And, very importantly, the firm should consider how customer preferences for variety and for immediate versus delayed delivery impact the firm's decisions.

For example, if customers are sensitive to time delays, then postponement seems to be a more attractive strategy because higher levels of advancement imply longer lead-times. With

postponement, the majority of the production steps can take place before demand is realized. If customers are seeking wider variety and customization of products then advancement might be more attractive, since it may be hard to achieve a wide variety of end-products from one generic nearly-finished assembly. On the production side, if the manufacturer can reduce lead-times through other means such as efficient scheduling, then advancement becomes more attractive while if commonality in design can be readily achieved then postponement seems desirable.

We further suggest that it may be attractive to merge the product fan-out point with the push-pull point, a strategy we call *jointing*. When using the jointing strategy, the firm holds inventory of a generic product at the push-pull point, instead of holding inventory of specialized products further downstream. Inventory costs should be lower, due to pooling benefits (the generic sub-assembly can be used to meet demand for any end unit), and there would not be any leftover units of the end product. However, there remains the question of *where* the joint (the merged point) should be located: if a product has n steps in its production process, there are $n + 1$ possible merged points (from before the first step to after the last). That is, should the firm primarily rely on postponement (positioning the joint far downstream) or advancement (putting the joint well upstream)? We expect that advancement is preferred when delivery delay can be minimized or tolerated, and when flexible production capacity is “inexpensive”. This intuition needs to be sharpened and quantified in future work. Also, in practice the process steps and process flow may be significantly more complex than suggested by our examples. The impact of this complexity needs to be assessed.

Further, while merging the fan-out and push-pull points is attractive, it may not always, or even generally, be optimal – the firm may want to stop short of jointing. Or, maybe there are

instances where the push-pull point should actually *precede* the fan-out point. Further work is needed to better understand these issues.

6. Discussion and Conclusion

In this paper we have developed a framework that links together certain elements of process design (namely, whether the firm implements MTS and/or MTO), product design (whether the firm offers standard and/or custom products), and supply chain design (whether the firm stocks products at retailers and/or sells direct). At its core, our framework is aimed at addressing a common trade-off: firms desire an MTS approach because it minimizes production costs but simultaneously desire an MTO approach because it eliminates overage and underage costs and can produce customized products.

To ameliorate the dilemma, we have outlined three possible dual strategies that make simultaneous use of both types of process design (both MTS and MTO). Each of these three strategies is matched with a specific product/supply chain design. When customer preferences call for standard product designs stocked at retailers, texturing is the dual strategy that may offer benefits, if customers demand both standard and customized designs then spackling is the dual strategy to be considered, and if customized products are offered then jointing may prove useful.

It is instructive to compare and contrast the strategies of texturing, spackling, and jointing. With texturing, the core (i.e., primary) process type is MTS, with MTO added as a texture to insure that production more closely matches the “bumpy” demand observed over multiple periods. Thus our strategy is similar to that suggested by the product/process spectrum (i.e., high-volume standard products call for flow shops that emphasize manufacturing efficiency and low cost) with the difference that even with standard products, an element of MTO may prove useful to reduce underage/overage costs.

With spackling, MTO production might be considered the core process design, since priority in every sub-period is given to the custom MTO products to insure timely delivery of items that cater to customers' specific needs. MTS production is layered on top to smooth out the production stream and thereby increase manufacturing efficiency. Again, our strategy is similar to that suggested by the product/process spectrum (i.e., specialized custom products call for job-shops that emphasize flexibility) with the difference that an element of MTS may prove useful to improve efficiency. At the same time, we note that the spackling approach as outlined herein is based on an assumption that demand for the two types of products is somewhat balanced. If the demand for standard products is significantly higher than that for custom products, then the firm may want to adopt a multi-layered spackling strategy involving two plants; an efficient plant producing the bulk of the standard products in MTS fashion, with the second flexible plant producing all the custom products and the remainder of the standard products, in spackling fashion.

With jointing, the process design that predominates, either MTS and MTO, depends on product design and supply chain design opportunities. For example, the product design may be conducive to postponement, or the supply chain may favor postponement because downstream supply chain members have the capabilities to perform certain manufacturing steps. On the other hand, advancement may be preferred if the production process is capable of being designed to achieve relatively shorter lead times.

In each of the texturing, spackling, and jointing strategies, our work points to the intertwined nature of product design, process design, and supply chain design.

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