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Betting on Pre-Assembly for Mitigating Uncertainty: Lessons Learned from a Global Jewelry Company

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Abstract: *In the realm of fashion, the jewelry industry is characterized by volatile trends and significant demand instability, calling for highly responsive supply chains to navigate this challenging context. To manage this uncertain environment, firms can adopt various mass customization approaches such as pre-assembly, aiming to ship products immediately upon receiving customer orders. However, there is a noticeable gap in research on the development and outcomes of this strategy in the fashion industry with a focus on product availability. This paper addresses this gap by conducting a case study in a multinational jewelry company, examining the impact of pre-assembling on product availability by integrating qualitative and quantitative analysis. Findings from the research indicate that pre-assembled products adopt better to customer needs while maintaining healthy inventory levels. Additionally, the study identifies several prospects for enhancing the AS-IS strategy of the company. The paper contributes to the field of mass customization by exploring an under-researched subject and suggesting future research directions within the domain.*

Key Words: ***Pre-Assembly, Availability, Uncertainty, Fashion***

1. INTRODUCTION

The fashion industry's supply chains are full of uncertainty and unpredictability (Lo et al., 2008), being forced to accept uncertainty while also develop a strategy that enables them to still match supply and demand (Christopher & Towill, 2001). In this way, fashion firms aim to simultaneously minimize supply shortages, which result in lost sales opportunities, and excess supply, which increasingly decreases in value (Fisher & Raman, 1996). In addition, fashion markets are characterized by high impulse purchasing, where many buying decisions are made at the point of purchase, hence the critical need for product availability (Christopher et al., 2004). Companies in this sector have been increasingly addressing mass customization requests, managing shorter product seasons, targeting specific customer needs, and offering a wide range of products (Christopher et al., 2004).

To this end, these firms must develop an agile supply chain that can be responsive to the needs of such a volatile market (Christopher, 2000). A pre-requisite to agility is lead time reduction (Naylor et al., 1999), as the lead time from supplier to customer plays a major role in an agile supply chain (Mason-Jones & Towill, 1999).

In this dynamic context, the traditional make-to-stock (MTS) policy may not be the best supply chain strategy since the uncertain demand of individual product variants makes it hard to avoid stockouts and excess simultaneously (Daie & Li, 2016). They face the challenge of planning their production based on unreliable forecasts. Thus, MTS companies within the fashion industry are interested in closing the gap between their traditional approach with Assemble-to-order (ATO) or Make-to-order (MTO) approaches.

A common practice of mass customization to close this gap is the postponement strategy (Daie & Li, 2016), which was firstly introduced by Alderson (1950). Form postponement (FP) was the term that Zinn and Bowersox (Zinn & Bowersox, 1988) used to refer to the already defined concept of delaying the commitment to the final assembly of a product as long as possible (Alderson, 1950; Heskett, 1977). Even though it was originally applied as relocation of inventories (Bucklin, 1965), postponement can be applied along the entire supply chain (Van Hoek et al., 1999), including the repositioning of several activities like labeling, packaging, assembly and manufacturing (Zinn & Bowersox, 1988). Manufacturing postponement aims at delaying final manufacturing until customer orders are received (Van Hoek, 1998). Thus, the idea behind postponement is to delay the point of commitment of work-in-process inventory into final products, allowing for more efficient use of assets in a rapidly changing and unpredictable environment (Venkatesh & Swaminathan, 2002). Accordingly, postponement leads with uncertainty by moving the differentiation nearer to the time of purchase (Alderson, 2006). Holding inventory at a generic level imply lower inventory levels, greater flexibility and variety of end products with the same components, more accurate forecasting, and higher level of variety at a lower total cost, enabling strategies of mass customization to be pursued (Van Hoek, 1998). In essence, FP serves as a design strategy in operations to alleviate the adverse effects of product variety on operational efficiency (Aviv & Federgruen, 2001; Feitzinger & Lee, 1997; Swaminathan et al., 1998; Van Hoek et al., 1999; Waller et al., 2000).

Forza et al. (2008) identify three distinct types of Form Postponement (FP): Type-I (from forecast to order driven), which involves postponing activities until after orders are received, potentially increasing delivery time; Type-II (forecast driven), which entails performing activities based on forecasts but closer to the order time, possibly extending delivery time; and Type-III (order driven), which involves conducting activities based on orders as close to the delivery time as possible, combined with flexible manufacturing. Remaining-forecast-driven FP (Type II) is often used in environments with high demand volatility where having end products readily available on selves is crucial for securing customer orders (Forza et al., 2008). Remaining-forecast-driven FP maximizes supplier's sales revenue when customers demand high responsiveness but accept low choice and do not require adaptability or reconfigurability (Trentin & Salvador, 2023). As this aligns with the context of the study, we will focus on this type of postponement.

A practical implementation of Remaining-Forecast-Driven FP in manufacturing is pre-assembling or postponement assembly, where the units are built without the variety of features and options, and when the customer orders come in, the final assembly takes place (Thomopoulos, 2014). Hence, the production time is shortened by using some semi-finished forms of the product (Swaminathan et al., 1998). This strategy provides the manufacturer with more flexibility and effectively reduces the production time in the selling season (Zheng et al., 2022). While the pre-assembly of semi-parts is done based on forecasts, the final assembly is not started before the demand order arrives. With this strategy, companies ensure products are ready to ship nearly immediately upon receiving customer orders. This strategy is well-demonstrated in the fashion world by Zara., which embraced dyeing fabrics until closer to final demand to quickly adapt to market changes, reduce inventory risks, and enhance supply chain efficiency (Ferdows et al., 2004).

Previous studies on pre-assembly mostly focus on its positive impact on efficiency, scalability, and cost savings, while its influence on availability, a critical measure in the fashion sector, has been overlooked. Thus, in this paper, we seek to explore the pre-assembly strategy within this context, addressing the following research question:

Is pre-assembly an effective strategy for enhancing product availability while maintaining healthy inventory levels in fashion companies that offer high product variety?

To answer this, we conducted a single-case study in a jewelry company that develops a forecast-driven pre-assembly strategy. Findings show that pre-assembling supports availability, but they also highlight a significant potential for refinement.

The paper is structured as follows. In **Section 2**, we describe the methodology followed to address the hypothesis previously introduced. In **Section 3**, we present the findings from the conducted case study, which are then discussed in **Section 4**. Finally, there is a conclusion in **Section 5**.

2. METHODOLOGY

The selected case company is a leading jewelry brand, operating beyond 100 countries through more than 10,000 points of sale and employing over 30,000 workers. In the past two years, their annual production exceeded 100 million pieces of jewelry, recording an annual turnover above 3 billion euros. The company owns production, distribution, and retail of jewels.

2.1. Research design

The study deployed a mixed method approach, integrating both qualitative and quantitative methods to get a comprehensive understanding of the impact of the pre-assembly strategy within the given context. For that purpose, the selected Mixed Methods Design (Creswell & Plano Clark, 2006) was the Exploratory Sequential. Thus, the first phase of the study employed semi-structured interviews, providing insights to allow a deeper comprehension of the pre-assembly strategy implemented by the company. This was followed by a quantitative phase aimed at measuring the effectiveness of the strategy.

2.1.1. Qualitative analysis

The objective of the qualitative analysis is to fully understand how the pre-assembly strategy is being implemented in the company. For that purpose, employees involved in the pre-assembly process were interviewed, from which insights were generated. The interviews had a semi-structured format, involving guiding questions but allowing flexibility for follow-up based on participant responses. The topics covered in the interviews dealt with a basic understanding of what these pre-assembled items consist of and the motivation behind them, followed by the justification for their selection, and ending with an explanation of the process. According to the discussion topic, questions were addressed to members of different departments, as listed in **Table 1**.

Table 1. *Discussion themes and interviewed personnel*

Main theme	Interview topic	Interviewed staff roles	Interview duration
Motivation	-Challenge -Opportunity	-SP[1] -SP	-1h -1h
Objective	-Strategy aim -Strategy concept	-SP -SP	-1h -1h
Selection criteria	-Criteria based on sales forecast -Criteria based on sales history	-DP[2] -AP[3]	-0,5h -0,5h
Selection constraints	-Manufacturing constraints	-NP[4]	-1h

[1] *SP: Supply Planning*
[2] *DP: Demand Planning*
[3] *AP: Assortment Planning*
[4] *NP: New Product Introduction Planning*

Manufacturing process	-Manufacturing steps	-MP[5]	-2h
Planning process	-Process flow -Time horizons	-SP -S&OP[6]	-1h -1h
Decision impact	-Strategy downsides	-SP	-1h
Investigation	-Selection success -Strategy success	-SP -SP	-1h -1h

Data from the interviews was gathered by written notes, which are outlined in **Section 3.1**.

2.1.2. Quantitative analysis

To perform the quantitative analysis, the DMAIC methodology (Pyzdek & Keller, 2001) was used, conducting the following steps:

1) Define - As with the qualitative analysis, we initially defined the objective of the quantitative analysis, which, in brief, is to measure if the strategy brought successful results to the company. For that purpose, items following the pre-assembly strategy (pre-assembled) needed to be compared with items not following it (standard).

2) Measure - To make this comparison, we determined the key metrics to be included in the analysis. On the one hand, three key metrics were chosen to assess the item selection success: sales turnover and sales units during the first 6 weeks after launch and share of the launch pack that was consumed after week 6 after launch. To evaluate the strategy success, four other metrics were selected: availability (% of items available at the DCs), Fill rate on time (FROT, % of items shipped from DCs to market on time), First hit (FH, % of items shipped from DCs to market in the first order), and Excess rate (% of items presenting more than 26 Weeks of Cover at the DCs). Following the scope, we gathered the average values of these metrics during the first 6 weeks after launch for each product.

The selection and specification of these metrics was based on the inputs gathered in the qualitative analysis. The first three are useful to measure how well the company selected the items to be pre-assembled, while the rest are Key Performance Indicators (KPIs) to assess if the pre-assembly strategy was successful.

3) Analyze - Once selected the criteria measures, the comparison analysis between pre-assembled and standard items could be made. A database was built by gathering from the company´s internal records the product identifiers, launch campaigns, and product type (pre-assembled or standard) of the products introduced in the launch campaigns of 2022 and 2023, as well as data on the measures for each of the products. The aim in this stage was to investigate any significant differences to ascertain if they could be attributed directly to the pre-assembly strategy. For that, we formulated a hypothesis for each of the measures defined, as outlined in **Table 2**.

Table 2. *Variables and Hypothesis for testing*

Measure	**Expected outcome**	**H0**
	Items selected for pre-assembly...	*There is no significant difference between Pre-assembled and Standard items...*
1. Turnover	...drive high revenue within the initial weeks of launch (if selected accurately)	...in the turnover they generate within the initial weeks of launch
2. Sales units	…trigger high demand within the initial weeks of launch (if selected accurately)	...in the sales units they trigger within the initial weeks of launch
3. Pack consumption	…consume a significant portion of their launch pack after the initial weeks of launch (if selected accurately)	...in the share of launch pack that was consumed after the initial weeks of launch
4. Availability	…feature a high availability within the initial weeks of launch (as it allows on-time replenishment at DC)	...in the availability they present within the initial weeks of launch
5. FROT	…feature a high FROT within the initial weeks of launch (as it allows on-time replenishment at stores)	...in the FROT they present within the initial weeks of launch
6. FH	…feature a high FH within the initial weeks of launch (as it allows on-time replenishment at stores)	...in the FH they present within the initial weeks of launch
7. Excess	…feature higher excess rates within the initial weeks of launch (as it might experience a rebound effect from the sales betting)	...in the excess rate they present within the initial weeks of launch

To select the statistical method most appropriate to assess these hypotheses, we first identified if the data points followed a normal distribution for each measure, for both pre-assembled and standard items. Normality was checked for both standard and pre-assembled items separately because the analysis involves comparing these two groups. For that purpose, the Shapiro–Wilk and the Anderson-Darling Normality Tests were conducted. As the data didn't follow a normal distribution, the comparison was conducted by the Mann-Whitney U test, which is a non-parametric test useful for comparing differences between two independent groups for non-normally distributed data. This test was also appropriate for this case study because it can be used with small sample sizes, so that having only a few pre-assembled items launched per cycle is not an obstacle. The software used to assess the normality of the data and then conduct

[5] *MP: Master Planning*

[6] *S&OP: Sales and Operations*

the Mann-Whitney U test was R. We set the confidence level to 95%. The results of this comparison are outlined in **Section 3.2**.

4) Improve - Once the statistical analysis had been conducted, we identified areas where the pre-assembly strategy could be improved or expanded. These are discussed in **Section 4.2**.

5) Control - Finally, some control measures were proposed to ensure that the suggested improvements would be sustained, which are listed in **Section 4.3**.

3. RESULTS

We carried out an Exploratory Sequential mixed method approach in the case company, aiming to answer if pre-assembly is an effective strategy for enhancing product availability while maintaining healthy inventory levels. Findings from the qualitative analysis are summarized below, followed by the results from the quantitative one.

3.1. Qualitative analysis

The semi-structured interviews gave relevant input to understand how the pre-assembly strategy is being employed at the company. The key points are outlined below, following the main themes listed in **Table 1** in **Section 2.1.1**.

Pre-assembly motivation - The company launches new products annually across seven cycles. Every cycle, more than 150 distinct SKUs are launched on average. Back in 2021, the company identified that, within every launch cycle, some of the campaign offerings were highly overperforming within the initial weeks of launch. Due to the high replenishment lead times, the company could not avoid having stockouts with these items on these crucial time periods. This challenge originated the ideation of a pre-assembly strategy on campaign products.

Pre-assembly objective - The goal of the pre-assembly strategy is to increase the responsivity of the items so that they are able to respond quicker when they over-perform and capture potential commercial upside. By pre-assembling the items, the fully assembly lead time is reduced by 50% when the manufacturing process takes place. This means building semi-finished goods inventory on specific items allow for shorter lead time between the factory and the Distribution Centers (DCs), which enables to send the items faster from the DCs to the market.

Pre-assembly selection criteria - Within every new campaign launch, there is a small portion of the assortment that is pre-assembled. Items selected for the pre-assembly strategy are products with high demand uncertainty and high potential revenue upside. The uncertainty is measured by comparing the difference of the forecast done by the Global Demand Planning team half a year in advance with the forecast conducted at market level one month later. When this difference is notable, high demand uncertainty is estimated for the given item. The revenue upside potential is based on historic sales performance of items with similar characteristics.

Pre-assembly selection constraints - However, not all items can be selected for the pre-assembly strategy, as there are some manufacturing restrictions to consider. There are some fixed constraints that immediately discard gold and plated items, limited editions, one-time push, or highly seasonal items, as well as contract manufactured products. Moreover, Material management may dissuade planners from selecting certain items due to raw material availability and potential supplier constraints. On top of that, feedback from the production site discourages the selection of items with high lead times, high sourcing complexity, or high risk of quality issues. Not only there are some limitations on the selection of pre-assembled items, but also on the allowed volume. Not more than 10% of the overall drop can be selected as Agile, and from those, only 10% of their production volume can be pre-assembled.

Pre-assembly manufacturing process - To comprehend this 50% lead time reduction, we need to revisit some concepts described in **Section 1**. By pre-assembling items, the process is moving from MTS, where all items are produced based on forecast, to ATO, where items are fully assembled once the order is placed. The pre-assembly process consists of the standard front-end manufacturing steps, including the casting, cleaning and cutting processes of the jewels. Then, the pre-assembled items are stored in the production site as intermediate parts. From there, the items can be fully assembled by conducting the finishing steps, such as polishing or stone setting. It is important to understand that the process does not affect the development phase, but just the time horizon in which the manufacturing steps are conducted. Thus, even though the production steps are the same, the products can be finalized and shipped in half the usual time upon receiving orders from the market.

Pre-assembly planning process - The orders of the pre-assembled items are placed slightly differently from the standard ones, creating a simultaneous parallel process. After the list of products of a given cycle is communicated to the planners sitting at the production site, they give the corresponding feedback for their selection as pre-assembled items. Once the restrictions are clarified, the items are selected for pre-assembly by the merchandising team, which are then validated by the production site planners. At that point, the pre-assembled items are ready for order placement by the supply planners.

Pre-assembly decision impact - Pre-assembling results in making investments on a SKU level, making the selection of the right items for the segment extremely important. If an item that overperforms is not selected for pre-assembly, an amount of stockouts could have been avoided. If, on the contrary, an item that underperforms drastically is selected for pre-assembly, the manufacturing cost cannot be avoided, as the parts are already semi-assembled at that point. When the order from the market of a pre-assembled item does not meet the committed volume, it is then consumed by standard replenishment orders. In case a pre-assembled item has not received any more orders in the past two months, any left-over semi parts are remelted. Thus, it is crucial to avoid underperformers among pre-assembled items and having a forecast estimate higher than the actual order placed.

Pre-assembly success – To evaluate the pre-assembly strategy benefits, it should be investigated if the correct items were selected for pre-assembly, and then, if these items had a better performance based on relevant metrics. For the item selection success, sales figures and performance against forecast should be evaluated within the initial weeks after launch, as pre-assembled items should be high seller overperformers. A simple way to measure the overperformance of an item is by looking at the portion of the launch pack (volume allocated in stores ready for the launch campaign date) that was consumed within the initial weeks after launch. If the launch pack is consumed fast, it points that the item has overperformed, while if the consumed portion is low, it has underperformed. For the strategy's success, as its goal is to enhance responsiveness, availability rates and fill-rate metrics within the initial weeks after launch could be compared between pre-assembled and standard items. Furthermore, if the inventory health is part of the analysis, overstock built within the initial weeks could be included.

3.2. Quantitative analysis

Once the most relevant points of the pre-assembly were understood from the interviews, the quantitative analysis was performed as described in **Section 2.1.2**. This section focuses entirely on the findings of step A (Analyze) of the DMAIC methodology.

When checking the normality of the data, a highly skewed distribution was identified, having the majority of the values clustered at the lower end, with a long tail of very high performers. The non-normality of the data could be clearly spotted by plotting it, and it was confirmed by conducting both the Shapiro–Wilk and the Anderson-Darling Normality Tests. As applying a Logarithmic transformation was not found to be convenient, the Mann-Whitney U test was conducted for every hypothesis.

Results from the test are outlined in **Table 3**, following the structure of the hypothesis described in **Table 2**. The test was conducted for each semester of 2022 and 2023.

Table 3. *P-values derived from statistical test*

Hypothesis		*Semester 1*	*Semester 2*
1. Turnover	*2022*	⊕ 9,53E-03	⊕ 1,24E-07
	2023	⊕ 5,12E-05	⊕ 4,18E-03
	Total		⊕ **9,04E-11**
2. Sales units	*2022*	⊕ 9,48E-03	⊕ 4,60E-08
	2023	⊕ 4,36E-05	⊕ 3,88E-03
	Total		⊕ **1,04E-10**
3A. Pack consum. (Week 1)	*2022*	8,09E-02	⊖ 3,10E-02
	2023	⊕ 2,79E-03	8,93E-01
	Total		**6,49E-01**
3B. Pack consum. (Week 6)	*2022*	⊕ 3,58E-02	⊖ 1,13E-02
	2023	⊕ 6,40E-03	6,04E-01
	Total		**9,87E-01**
4. Availability	*2022*	6,30E-02	⊕ 4,32E-03
	2023	7,11E-01	⊕ 1,88E-03
	Total		⊕ **1,51E-04**
5. FROT	*2022*	⊕ 2,04E-02	⊕ 2,13E-03
	2023	4,83E-01	⊕ 4,11E-03
	Total		⊕ **1,39E-04**
6. FH	*2022*	2,17E-01	⊕ 5,00E-02
	2023	5,36E-01	2,20E-01
	Total		**1,32E-01**
7. Excess	*2022*	7,23E-02	2,71E-01
	2023	⊖ 2,49E-02	4,99E-01
	Total		**5,92E-02**

By establishing a 95% confidence interval, we rejected the null hypothesis (and thus accept the alternative hypothesis) for p-values below 0,05. These values are marked with "plus" and "minus" signs in **Table 3**. "Plus" signs in black denote that the average value of the given measure is significantly higher for pre-assembled items, while "minus" signs denote that they are significantly lower. **Table 4** summarizes the interpretation of the outcomes of the test.

Table 4. *Interpretation of statistical test outcomes*

Hypothesis	**Test result**
1. Turnover ⊕	Pre-assembled items drive significantly more revenue than standard items within the initial weeks of launch
2. Sales units ⊕	Pre-assembled items trigger significantly more demand than standard items within the initial weeks of launch
3. Pack consumption	There is not a significant difference between pre-assembled and standard items in the portion the launch pack that is consumed within the initial weeks
4. Availability ⊕	Pre-assembled items offer significantly a higher availability than standard items within the initial weeks of launch, mainly with the items launched in the second half of the year
5. FROT ⊕	Pre-assembled items offer significantly a higher FROT than standard items within the initial weeks of launch
6. FH	There is not a significant difference between pre-assembled and standard items in the FH they offer within the initial weeks
7. Excess	There is not a significant difference between pre-assembled and standard items in the Excess rates they experience within the initial weeks

4. DISCUSSION

As described in **Section 1**, the aim of the study was to evaluate the implementation of a pre-assembly strategy within a fashion firm, measuring its benefits when responding to market orders. In this section, we will interpret the results obtained in **Section 3** in relation to the aim of the study. Moreover, we will suggest some improvements and control measures, as well as emphasize the study limitations and potential research directions.

4.1. Interpretation of results

The qualitative assessment allowed understanding the rationale behind the conducted pre-assembly strategy: deal with the challenges posed by the company's extensive product variety and the high probability of stockouts due to the dynamic nature of demand, with a focus on new product introductions. Then, the quantitative analysis allowed to evaluate the strategy´s success.

As listed in **Table 4**, pre-assembled items sell on average significantly more than standard ones, both in turnover and units. This supports the main intention of the strategy, which tackles items that drive high sales and where experiencing lost sales would be critical. The study assumes that pre-assembled volumes cover uplift in sales of overperforming products, meaning the strategy is avoiding stockouts whenever an overperformance is identified. As described in **Section 2.1.2**., we measured the pack consumption within the initial weeks of launch to evaluate this outperformance. However, results show what the launch pack consumption behavior of pre-assembled and standard items is similar. This means that the item selection is not optimal and should be improved. On the one hand, there are standard items that overperform and consume their launch pack very quickly, for which a notable portion of their stockouts could be avoided if they were pre-assembled. On the other hand, there are underperforming pre-assembled items not consuming their pack after week 6 after launch, meaning that the pre-assembly strategy should not have been applied for them. However, the high uncertainty makes this selection very challenging.

Focusing on the hypothesis related to the pre-assembly success, results show that the selected items have a significantly higher availability than the standard ones, supporting the use of the strategy. Similarly, FROT is proved to be significantly higher, suggesting that pre-assembled items are more likely to arrive on time. When looking at the full data, FH values are also higher for pre-assembled items, but findings show that this difference is not significant. This implies that, even though standard orders do not arrive on time as frequently, they are still consolidated in the first order. Furthermore, the created excess within the initial weeks does not seem to be higher for pre-assembled items, and it is even significantly smaller in the second half of 2022. This suggests that, even though pre-assembling optimally enhances availability and reduces stockouts, it maintains healthy inventory levels.

4.2. Improvement

Once gathered the relevant qualitative and quantitative data and interpreted the findings, we identified areas where the pre-assembly strategy could be improved or expanded. This corresponds to step I (Improve) of the DMAIC methodology.

A. Critical time periods – As noted in **Section 4.1**, the findings indicate that there is potential for improvement in the selection process. Also, as products were analyzed according to their launch campaign, the investigation sheds light on the time periods for which the pre-assembly selection is more accurate or where the strategy is having a higher positive impact. The company should conduct a more thorough exploration into this area to conclude if there are some specific time periods for which there is a higher or lower need for the strategy´s implementation. The analysis could show discrepancies for low or high-selling peak seasons of a given item. Other factors impacting the selection process, such as manufacturing constraints, are discussed in the following points.

B. Rewards with pre-assembled high-sellers – As previously described, the use of the pre-assembly strategy supports overperforming items in reducing their amount of stockouts during the initial weeks. However, there are some cases for which the pre-assembled volume is not sufficient, and the amount of experienced stockouts is still very high. It would be interesting for the company to simulate the amount of stockouts they would have experienced without the use of the pre-assembly strategy. This would give a good overview of the benefits of the strategy in comparison to the standard approach.

C. Cost of pre-assembled underperformers – From the answers gathered at the qualitative analysis, it was detected that the staff had insufficient knowledge of the actual costs of the pre-assembly strategy. As described in **Section 3.1**., the current process results in remelting when the pre-assembled items underperform and their semi-parts experience overstock. The company should thoroughly examine the costs of underperforming pre-assembled items to accurately assess the strategy's true value.

D. Pre-assembled items discarded by manufacturing constraints - Production constraints for pre-assembling were not included in the data analysis but could bring relevant insights for the item selection process. It would be interesting for the company to map the products that would have been selected for pre-assembly but discarded due to manufacturing restrictions. These would fall most likely into the standard overperformers discussed in section 4.1. If big potential is identified on certain items, the company could consider addressing the correspondent challenge to lift the restriction. If, for instance, a given product is not selected for pre-assembly due to the high sourcing lead time of one if its components, the company could explore other alternatives to source this critical material quicker, such as a substitute vendor, a premium trade agreement, etc.

E. Pre-assembly strategy for established assortment - So far, as described in **Section 3.1**, the company has aimed the pre-assembly strategy at new items, as these are the ones presenting the highest level of uncertainty. However, if the aim of the strategy is to enhance responsiveness to avoid lost sales, it could be applied in old items that experience critical stockouts. For that purpose, the company needs to make a thorough investigation on the behavior of their stockouts, including their frequency, their length, the time periods with the lowest availability rates, etc. Not only it would be important to understand the as-is of the stockouts, but also the characteristics of the products experiencing them in terms of forecast accuracy, sales figures, seasonal behavior, etc. An appropriate product segmentation would be required for the success of the strategy on old assortment.

F. Various advantages of mass customization – As of now, the pre-assembly strategy has been useful to reduce the lead time when delivering campaign items to the market. However, many additional benefits and opportunities could be explored. Maximum benefits can be achieved when the postponement strategy does not only address physical transportation but also product customization (Battezzati & Magnani, 2000). As described in **Section 1**, the pre-assembly strategy presumably helps in managing costs effectively by standardizing the initial stages of production and only customizing the final stages as needed. By preassembling, the company could offer additional features, such as customer personalization. This way, the pre-assembly strategy would cover not just the time factor, but also differentiation, as it helps in keeping the products affordable while offering a high degree of customization.

G. Various methods to achieve shorter lead times – The way the company is enhancing responsiveness with the pre-assembly strategy is by reducing the lead time once the order is placed. However, this lead time reduction can be achieved in other different ways, such as shortening cycle times of specific manufacturing tasks, reducing waiting times, offering faster delivery methods, etc. This opens up a wide range of possibilities with which the company's supply chain could be more responsive.

4.3. Control

The last step of the DMAIC methodology is C (Control), where the importance of ensuring the maintenance of the strategy and the suggested improvements is highlighted.

Overall, it is imporant that the company maintains and promotes a culture of continuous improvement to constantly seek ways to refine and enhance processes such as this pre-assembly one. Also, regular performance reviews and audits are required to ensure that all the obtained improvements are maintained and deliver the expected benefits. On top of that, engaging relevant stakeholders from different departments is required to maintain these improvements. The company should ensure a robust reporting system that provides real-time data and insights to all these stakeholders, ensuring transparency and timely decision-making.

For the actual opportunities listed in **Section 4.2**, specific control measures are outlined.

A. Dynamic selection based on time period – The company should make sure to continuously improve the use of the strategy in relation to the campaign and time period where is applied. Thus, item selection should be closely coordinated with the positive impact of the strategy on the given campaign.

B. Continuous estimation of lost sales – There should be a higher awareness on the impact of pre-assembling on stockout mitigation and the value it creates. To that extent, it would be relevant to regularly track overperforming items, and within the pre-assembled ones, quantify the number of orders that could be delivered thanks to the lead time reduction.

C. Periodic cost review – A periodic review of the costs associated with pre-assembled items and cost-benefit analyses would be required to ensure positive earnings from the strategy, which should be adjusted and refined over time. For that, they should monitor KPIs such as defect rates, remelting occurrences, and inventory turnover rates for semi-parts of pre-assembled items.

D. Document manufacturing constraints removals – The company should develop a process to map and thoroughly document manufacturing constraints affecting pre-assembly decisions. Then, they could periodically analyze items discarded for pre-assembly due to these constraints to identify high-potential items that could be reconsidered with adjustments to the sourcing process. On that note, a robust supplier evaluation system would be required to identify and secure alternative vendors or premium agreements that could potentially reduce sourcing lead times or mitigate other supply constraints.

E. Dynamic identification of items requiring higher responsiveness – To dynamically identify critical items experiencing stockouts among the whole assortment, which could also benefit from the pre-assembly strategy, the company should implement a continuous monitoring system for stockouts. This could capture data on frequency, duration, and affected items. This would give the information to the company to achieve a product segmentation based on stockout behavior, ensuring the pre-assembly strategy is applied effectively to high-impact items. A critical point would be to create a feedback mechanism where sales, inventory, and customer service teams can report stockout issues, which can then be analyzed for potential pre-assembly applications. While it is beneficial to postpone the material de-coupling point as far downstream as possible in the supply chain and close to the final marketplace, the information de-coupling point (the furthest point to which information on real final demand penetrates) should lie as far upstream as possible (Christopher, 2000). This communication at store level would be crucial to address critical issues.

F. Customer voice on customization – The success of standardization and pre-assembly depends on how quickly and effectively the reaction is to an urgent need, and the ability to predict future needs (Gibb, 2001). Thus, the company should regularly gather and analyze market trends and customer feedback on personalized products and customization requests to assess the impact of pre-assembly on customer satisfaction.

G. Best practices to reduce lead times – As for the alternatives to achieve shorter lead times, the company should continuously review and optimize manufacturing and delivery processes to minimize waiting times and enhance overall efficiency. The use of best practices and lean manufacturing techniques, and leveraging technology solutions such as ERP systems, automation, and advanced analytics would be critical to streamline operations and reduce lead times.

4.4. Limitations and future research

Some limitations, which can be addressed in future research, are worth noting.

First, as it was a single case study, the study reports the findings of a very specific company in a narrow sector. Expanding the study to include other companies within the fashion industry would enable more robust comparisons and a better interpretation of the implementation and benefits of pre-assembling. Furthermore, it should be noted that external factors, such as marketing promotions, supply chain disruptions, competitor actions, and others, could influence the results of the comparison between pre-assembled and standard items. Thus, the study could benefit from further contextualization of external factors influencing strategy effectiveness and broader industry comparisons to strengthen its generalizability and applicability to other industries

Moreover, as the strategy is a recent implementation of the case-company, the timeline of the study was limited to two years. It would be relevant to conduct a similar analysis in the future with more data available and a higher number of items to be compared.

The study was conducted under the assumption that DC availability is correlated with store availability. Thus, Availability, fill-rate metrics, and excess rates were measured on a DC level, but it would be relevant to measure them at store level to assess the actual impact of the strategy on the end customer. On this note, assessing the impact of pre-assembly on actual lost sales, and not just at a stockout level, would be of great relevance.

The suggested improvements and control initiatives would need to be evaluated by internal stakeholders to assess their validity.

It is important to note that the conducted hypothesis testing determines whether there is a statistically significant difference in any of the selected measures between the two types of products. However, finding a significant discrepancy does not imply causation, meaning that a difference in a given metric does not automatically indicate that the product being pre-assembled or standard is the reason.

5. CONCLUSION

This study examines the effectiveness of a pre-assembly strategy in a fashion company with high product variety and demand volatility. The findings evidence the advantages of pre-assembling in improving availability and on-time fill rates. They also highlight some potential weaknesses in the current strategy implemented by the case company, such as the low pack consumption of the selected pre-assembled items compared to the standard ones.

This paper contributes to the field by offering empirical evidence of how pre-assembly enhances responsiveness and reduces lead times in a volatile market environment. Findings of the study suggest that fashion companies can benefit from mass customization principles and additionally shows room for achieving higher benefits. Mass customization principles continuously prove to be highly beneficial across various industries, with considerable potential for further application.

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