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Mix flexibility and volume flexibility in a build-to-order environment

Synergies and trade-offs

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Abstract

Purpose – This paper aims to investigate the factors enabling or hindering the simultaneous pursuit of volume flexibility and mix flexibility within a supply chain through the lens of a manufacturing plant seeking to implement a build-to-order (BTO) strategy.

Design/methodology/approach – To accomplish this empirical investigation, an in-depth case study involving a manufacturing plant and its supply chain was designed. Prior to primary and secondary data collection, this research setting had already decided to implement a BTO strategy and had, moreover, carefully assessed several practices for BTO strategy implementation, as well as their interactions.

Findings – The studied case suggests that a number of approaches typically used to increase volume flexibility, actually negatively affect mix flexibility and vice versa. The existence of such trade-offs may ultimately inhibit the implementation of a BTO strategy and this was the case in the studied company. Nevertheless, empirical evidence also suggests that, to some extent, volume flexibility and mix flexibility may be achieved synergistically, as initiatives such as component standardization or component-process interface standardization would improve both volume flexibility and mix flexibility.

Research limitations/implications – The pursuit of volume flexibility and mix flexibility in implementing a BTO strategy in a specific setting and from primarily an operations management perspective was investigated. As such, the findings can be complemented by viewing the case study results through the lens of other established general management theories or by replicating the study in different research settings.

Originality/value – While past research informs us about how manufacturing firms can successfully achieve mix flexibility or volume flexibility, there are few insights for understanding how volume flexibility and mix flexibility can both be simultaneously achieved within a manufacturing plant and its supply chain. This research fills this gap in the literature and contributes to the development of a theory of BTO strategy implementation, especially in terms of volume flexibility, mix flexibility and their interactions.

Keywords Bespoke production, Mass customization, Response flexibility

Paper type Research paper

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1. Introduction

From consumer electronics (Trommer and Robertson, 1997) to automobile (Howard *et al.*, 2001) to apparel (Aichlmayr, 2001), firms in these and many more industries are striving to adopt what has been dubbed a "build-to-order" (BTO) strategy. A BTO strategy, literally, reflects the idea that value-adding activities – be they distribution, assembly, manufacturing and/or even design – are triggered by customer orders, rather than by forecasts. By performing these value-adding activities to order, a company would accordingly be able to avoid incurring the risks of forecasting uncertain events, which may ultimately lead to excess inventory and poor-service levels (Gunasekaran and Ngai, 2005).

A BTO strategy is evidently more attractive when forecasting is difficult and forecast errors are large, i.e. when the market served by a firm is turbulent (Anderson, 2004). Market turbulence, from an operational perspective, leads to volume variability and mix variability in the output of the firm. Whereas, volume variability refers to the gross fluctuation of orders for a certain class of products across time, mix variability refers to the fluctuation of the mix of ordered items across time.

A BTO strategy, therefore, requires a supply chain that is both:

1. *volume-flexible.*, i.e. It can rapidly change its gross output while maintaining cost-effectiveness (Sethi and Sethi, 1990; Khouja, 1997; Jack and Raturi, 2002); and
2. *mix-flexible.*, i.e. It can rapidly change the mix of items being delivered to the market while maintaining cost-effectiveness (Berry and Cooper, 1999; Zhang *et al.*, 2003).

Mix flexibility, in turn, requires both process flexibility and product flexibility. Process flexibility "refers to the speed at which the company can make decisions, alter schedules or amend existing orders to meet customer needs" (Holweg and Pil, 2001, p. 76). Product flexibility, on the other hand, "relates to how well a company adapts the product to the customer's specifications and how much it is able to delay or reduce the degree of product tailoring" (Holweg and Pil, 2001, p. 79).

But what does it take to implement a BTO strategy? Undoubtedly, insights into the implementation of a BTO strategy can be found in past research on how manufacturing firms can successfully achieve mix flexibility (Ho and Tang, 1998) or volume flexibility (Khouja, 1997; Jack and Raturi, 2002). Yet, understanding how mix flexibility or volume flexibility can be increased may not be sufficient, since the pursuit of a BTO strategy fundamentally forces a firm to strive to simultaneously achieve both volume flexibility and mix flexibility. From both a theoretical and a pragmatic standpoint, it becomes important, therefore, to address the following research questions:

RQ1. Are there any interactions between principles and/or practices supporting volume flexibility and those supporting mix flexibility?

RQ2. If so, when are these principles and/or practices in trade-off and when do they work synergistically?

By seeking answers to these two research questions, we should be able to pinpoint more specifically the extent to which, and the conditions under which, volume flexibility and mix flexibility can be simultaneously pursued within a manufacturing plant and its supply chain. These answers should, in turn, lead to identification of theoretically and pragmatically relevant insights that ultimately would support the implementation of a BTO strategy, especially in terms of volume flexibility, mix flexibility and their interactions.

To provide insights into our research questions, we engaged in an in-depth case study to investigate the factors enabling and hindering the simultaneous pursuit of volume flexibility and mix flexibility within a manufacturing plant and its supply chain. The manufacturing plant under scrutiny manufactures equipment for the Lawn & Garden market. In Section 2, we outline the research methodology applied in this study. Then, in Section 3, we describe the research setting, emphasizing the requirements of the research setting as to the volume variability and the mix variability facing this particular manufacturing plant and its supply chain. In Section 4, we report and discuss speculative insights provided by various informants within the manufacturing plant – speculative insights as to actions and initiatives that may be undertaken as part of implementing a BTO strategy. We propose a synthesis of the findings of the study and sketch future research directions in Section 5.

2. Method

From the outset, a qualitative research approach appeared to be most appropriate in order to address the research questions focusing on the implementation of a BTO strategy. Such an approach would unveil not only what interactions might possibly take place between the principles enabling volume flexibility and those supporting mix flexibility but also "how" such interactions might come about (Creswell, 2002).

The manufacturing plant selected for this exploratory empirical inquiry offered an ideal research setting, given the corporate decision to pursue a BTO strategy. We timed the collection of interview and archival data to occur after the decision had been made to pursue implementation of a BTO strategy. The decision itself was made after key informants within the manufacturing plant had had sufficient time to review issues and opportunities presented by a BTO strategy. By doing so, we were able to jointly explore with the key informants all the hypothetical options supporting volume flexibility and/or mix flexibility, as well as their interactions, regardless of eventual constraints to the feasibility of each option.

In selecting the key informants, we deliberately tried to allow for multiple and divergent perspectives with respect to issues related to implementing a BTO strategy within the manufacturing plant. We identified and targeted the plant manager, the accounting manager, relevant product design engineers, relevant manufacturing process engineers and relevant supply management specialists for interview data collection. Interviews were conducted onsite by two or more members of the research team and were tape-recorded to avoid loss of information or distortion of meaning and to allow for an assessment and verification of content validity after transcription (Rubin and Rubin, 1998; Kvale, 1996). We developed an interview protocol consisting of a set of open-ended questions, exploring what solutions the key informants considered in order to implement a BTO strategy, as well as what obstacles they foresaw in the pursuit of such solutions. We asked, to the extent possible, the same questions of multiple informants in order to increase the reliability of the collected interview data (Jick, 1979). Moreover, we also collected data from a second-fundamental source of information, namely archival documents, internal presentations, internal and official reports, etc. We triangulated the interview data from key informants with the data from the secondary information sources, so as to further strengthen the reliability of the collected data (Scandura and Williams, 2000).

When data collection had concluded, we performed intra-case analyses adopting the coding techniques recommended by Strauss (1987). We first clustered interview data into large conceptual categories (open coding) and subsequently identified sub-categories (axial coding), according to an indented coding scheme (Rubin and Rubin, 1998). The coding scheme included a description of the current architecture of the product, as well as of the current configuration of the supply chain. An additional part of the codes covered the reasons why the company had chosen to pursue a BTO strategy, the possible options for implementing a BTO strategy, and the obstacles to the implementations of these options, all according to the key informants.

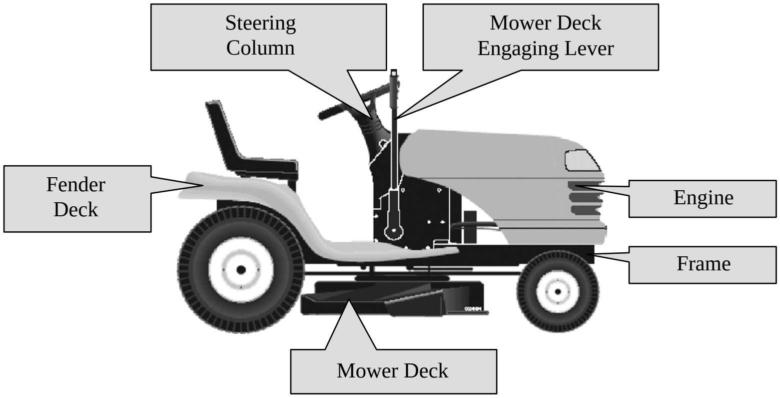
3. The research setting

3.1 Market trends

The manufacturing plant selected for the case study, which we henceforth refer to as "LawnWorks," manufactures lawn tractors, a piece of equipment for the Lawn & Garden Market (see Figure 1 for a schematic drawing of a lawn tractor manufactured by a competitor). The Lawn & Garden Market, particularly in the USA, is a highly-competitive industry characterized by large competitors, relatively mature products, and slowing growth. Up until the 2000-2001 fiscal year, sales of equipment for the Lawn & Garden Market has been growing, on average, 2.7-4.7 percent year-to-year. However, in 2001, a number of events led to a reversal of this trend in sales growth, including the stock-market implosion and economic recession at the beginning of the first quarter, the extreme and unpredictable weather patterns leading to extended drought and flooding conditions during the typical sales season, and the unfortunate terrorist-related event on September 11, 2001. In fact, for 2000-2001, the decline in sales for the entire equipment segment of the Lawn & Garden Market was estimated to be 5.5 percent.

3.2 Seasonality

Equipment sales in this market segment have been, and continue to be, structurally and inherently affected by severe seasonality, with consumers typically buying



Source: www.Husqvarna.com

Figure 1.
Example of schematic representation of a lawn tractor

equipment "in season" when needed or postponing their purchase decisions until the next season. Approximately, 67 percent of total equipment sales are generally transacted during the spring and early summer months. For equipment sales, manufacturers such as LawnWorks, a 1:7 ratio, on average, is therefore, not atypical when comparing the month with the lowest demand level to that with peak demand level (Figure 2). This ratio may well fluctuate between 1:4 and 1:10, depending on the specific product family considered. For LawnWorks, the seasonality challenge has historically translated into finding ways to increase capacity without incurring fixed costs.

3.3 Product families and product variants

Besides the seasonality challenge, LawnWorks faces additional uncertainty and complexity in serving the Lawn & Garden Market, some of which stems from the heterogeneity of customer needs. An essential distinction needs to be made between heavy-duty and regular equipment. Heavy-duty equipment is more robust and more durable, with greater versatility and operational capabilities. In contrast, regular equipment is neither as robust nor as durable and has less versatility and operational capabilities. While all equipment is designed for a ten-year replacement cycle, heavy-duty equipment is designed to work for more than 1,200 hours, roughly four times more than regular equipment (Figure 3). Therefore, the price would vary accordingly (from approximately $2,000 up to more than 10,000).

The ten product families that LawnWorks offe tos on the market span the continuum from heavy-duty equipment to regular domestic versions conceived for the most price sensitive segments of this market. Blanketing the price spectrum with so many product families has been historically a great concern for the marketing function, which has influenced, and continues to influence, new model designs to meet all possible price points observed in the marketplace.

For each product family offered by LawnWorks, a set of product models can be selected by the customer. Typically, product variants would differ across a product family in terms of engine power and brand, size, servo mechanisms, tyre size and other

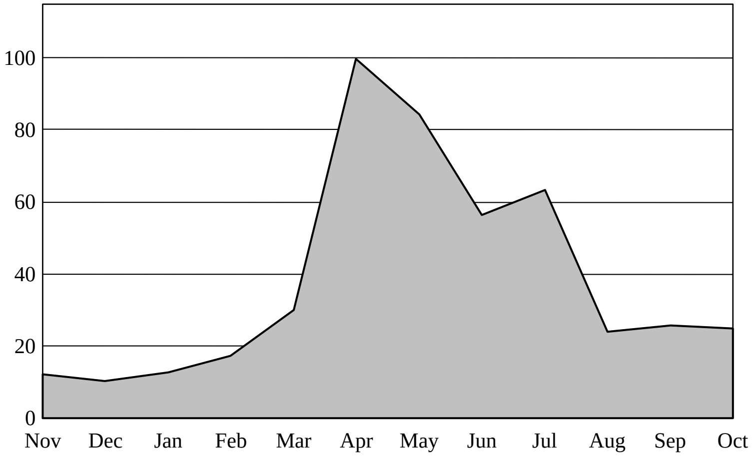


Figure 2.
Production volume per month (100 = peak month)

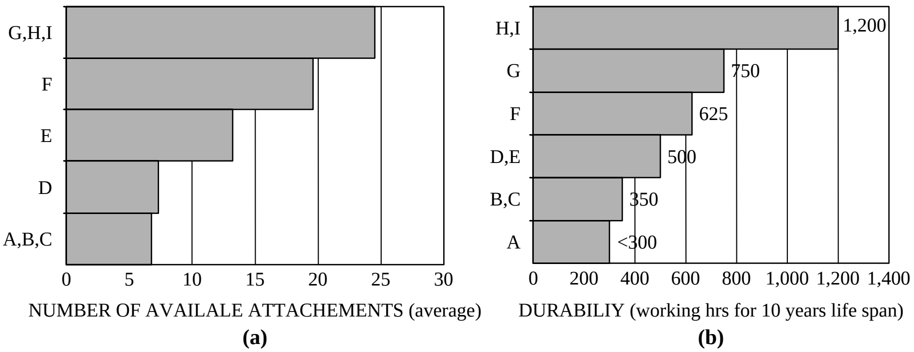


Figure 3.
Durability and number of attachments per product family

accessories, etc. Finally, once a customer has chosen a product model within a certain product family, the customer can customize the equipment with appropriate attachments, based on the specific work that the equipment is expected to perform. The assortment of attachments is generally greater for more powerful and expensive equipment models (i.e. 24 attachments), while it is more limited for simpler, cheaper and less-powerful models (i.e. seven attachments). Over time, with greater segmentation to meet possible price points, LawnWorks has had to become more mix flexible, so that its output could be more rapidly adjusted to the demand for the different product variants.

3.4 Evolution of products and product families

Over time, the product families have undergone frequent changes. Since, the products offered are relatively mature in terms of their product life cycles, these changes are driven not so much by the incorporation of new technology, as by the market, which is the fundamental driver of product change. In understanding how market dynamics affect product offerings across time-three different factors – i.e. customers' needs, retailers' requirements, and competitors' actions – deserve attention.

Customers' needs have evolved and matured over time as well. As customers gain experience with using the equipment, they have become more and more aware of what they like and dislike (Salvador *et al.*, 2002). Unfortunately, customers do not all like and dislike the same things about a particular equipment model. Some customers may just be interested in "getting the job done" as fast and as cheaply as possible, looking for stripped down versions of the product with very competitive prices. Other customers, instead, may be willing to pay more and are interested in getting more functionalities from the equipment they purchase. The progressive segmentation of the customer base, over time, is mirrored in the number of product families, which jumped from three in the early 1980s up to ten in the early 2000s.

The evolution of distribution channels, with the establishment of powerful retail chains and of speciality stores alongside the existing dealership network, has further magnified the effect of greater customer heterogeneity. The emergence of home centers and discounters as potential sales and distribution points for equipment has led to the development of mass-market versions of the equipment. Since, the mass market is extremely price sensitive, it prompted the development of *ad hoc* low cost, bare bones versions, which added to the pre-existing product lines. At the same time, speciality outlets and dealers began to focus on more up-scale models and more demanding customers. The price premium that these customers are willing to pay, as well as their ability to engage in competitive comparisons, forced LawnWorks to provide an adequate assortment of product models.

Finally, the very dynamics of competition across different manufacturers of equipment for the Lawn & Garden Market have led the marketing function within LawnWorks, as well as their counterparts in other competing firms, to further proliferate product variety in order to keep pace with competition and to create sharper differentiation in product offerings. For example, in order to match competition, equipment models that accommodate a 20, a 21, and a 22 hp gasoline engine have had to be manufactured and made available to customers. In fact, across product families, a total of 16 different engines supplied by four different engine suppliers are available for 37 different equipment models. Sometimes differentiation in technical features goes hand-in-hand with differentiation as to aesthetical features. For example, in order to emphasize the uniqueness and identity of a new easy-to-handle piece of equipment, LawnWorks had to design, source and assemble a steering wheel in two colors, instead of using the one-color component that was available for use in other product families.

3.5 Production

LawnWorks operations have been designed to achieve the objective of productivity rather than flexibility. The plant layout is product oriented, with each product family being assigned to its own separate assembly line and each separate assembly line including its own welding stations for stamped metal parts with various components for the product family. Assembly line yields vary according to the specifications of individual product families, ranging between 50 and 200 units of output per shift. Each assembly line has been designed to allow for some flexibility, meaning that it can build, on a daily basis, all the equipment variants of the product family assigned to it. However, across-family assembly flexibility is severely limited by the long set-up times – around 2-3 days – needed to re-tool an assembly line from one product family to another. Evidently, such a long set-up would represent an unacceptable waste, especially during the seasonal peak.

Automation is relatively intense in the operations preceding the final assembly line. Frames, stamped metal parts, etc. are put together by welding robots in a series of welding booths. Welded parts are then hooked to a roll bar and automatically driven to the paint shop, from which they return painted into the same assembly line from which they departed. Necessary parts – subsystems and components – are moved to the assembly line via forklifts or automatically guided vehicles (AGVs).

3.6 Component sourcing

With the exception of the drop-forged sheet metal parts, all essential components needed to build each piece of equipment are sourced from external suppliers. The major components include the engine, the cooling system, the transmission, axles, wheels, steering system, hydraulics, servo systems, wire harness, instruments and console, and other body parts such as hood and fender deck.

The housing itself is made from stamped sheet metal parts provided by the stamping plant owned by the same business group that LawnWorks belongs to. This stamping facility is located relatively near to LawnWorks and was originally conceived as a way to reduce the costs of metal parts made in high volumes by means of stamping instead of welding. Because of the high-fixed cost investment in equipment, tools, and fixtures, set-up costs are high, encouraging the stamping facility to produce in large batches. Consequently, when unexpected demand for a particular housing occurs, it would take a few weeks for the stamping plant to react.

Of all components, the most challenging component to source is the engine, since engine suppliers are unable to react quickly to unpredictable demand fluctuations because of technological rigidities (castings) and operational complexity (building an engine entails making and assembling a great number or parts). Moreover, because high-end engines are being imported from an overseas supplier, the order-to-receipt lead time of several months for these engines is extremely long, relative to other components.

The situation for many non-major component suppliers is not very dissimilar from that faced by the stamping plant. These suppliers tend to structure their operations to be efficient using highly repetitive operations, making it difficult for them to react nimbly to demand variations that significantly deviate from original forecasts. On the plus side, these suppliers are located relatively near to LawnWorks, with component delivery times generally oscillating within the 3-5 weeks range. However, when deviations from plans require second-tier suppliers to react, delivery times become more unpredictable, with these times increasing to as much as a few months.

3.7 Distribution

LawnWorks maintains a national warehouse for the US market and another one for the European market. The original function of the warehouses was to pile up inventory in the low season so that there would be a sufficient quantity of end items to meet market demand during high season. This mismatch between factory output and seasonal market demand, in fact, requires keeping a large amount of decoupling inventories. Such inventories are depleted from March through July and accumulated for the remaining part of the year (Figure 4). Recently, the warehouses also serve a second

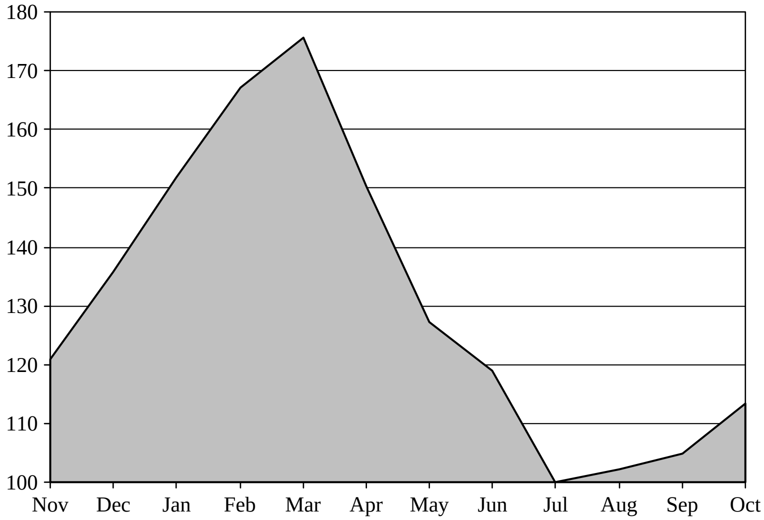


Figure 4.
Distribution channel inventories for 2001-2002 season (100 = lowest level)

function for LawnWorks, essentially buffering LawnWorks from the demand variations imposed by speciality shops and dealers. These two functions, coupled with the trend towards product proliferation, pose serious financial and market liabilities for LawnWorks. The severity of this problem has recently forced LawnWorks to shutdown production for several weeks, since the US National Warehouse was at full capacity. Worse still was the fact that what was in inventory at the warehouse was not what the market was asking for, causing order fill rates to plummet down to approximately 60 percent.

4. Implementing a BTO strategy: insights from LawnWorks for flexing volume and/or flexing mix

During the interviews with the various plant informants, the interviewees were prompted to discuss potential solutions – i.e. principles and/or practices – that they thought should be adopted in order to implement a BTO strategy. As part of this discussion, the plant informants also offered up their perspectives on factors that would hinder efforts at implementing a BTO strategy. Subsequent analyses of both the interview data and the various secondary data sources not only identified common solutions discussed by plant informants but also highlighted a number of interactions, both positive and negative, between solutions for increasing volume flexibility and those for increasing mix flexibility.

4.1 Product flexibility

By far, the most frequently invoked principle for implementing a BTO strategy discussed during the interviews and highlighted in the archival records was for LawnWorks to pursue greater component commonality across product families. Component commonality, itself, is a specific instance of product flexibility (Holweg and Pil, 2001). All informants, in fact, regardless of their functional area of responsibility and expertise, consistently pointed to increasing across-product family component commonality as a pivotal principle to efficiently flex both production mix and production volume. Of course, when coming to specific recommendations, different informants centered their attention on aspects of their jobs about which they were most knowledgeable. As a result engines, transmissions, frames, wire harnesses, body parts, etc. have all been mentioned by different plant informants as possible candidates for becoming a common component across product families.

Initiatives geared towards increasing component commonality qualify as an important lever to enable a manufacturing plant to enhance mix flexibility so as to better match the actual variability of customers' orders that it experiences. Almost all plant informants interviewed suggested ways to keep offering to customers the same assortment while reducing the required number of components. For example, one suggestion was to standardize the mower deck attachment (Figure 1) so as to allow a single version of the mower deck to be used across multiple product families. This would allow customers to have greater flexibility in choosing the grass cut width of their equipment. The obvious rationale for suggesting such actions is that reducing component proliferation would mean less inventory to keep, less-complex operations to manage, and, in general, less resources to build a given set of end products, or in other words, greater mix flexibility.

From the description of LawnWorks that was provided in the previous section, it would appear that the requirements for volume flexibility are far more severe than the requirements for mix flexibility. As such, the plant informants' emphases on initiatives that increase component commonality may look a little bit surprising. In fact, one may expect more focus on solutions aimed at increasing volume flexibility (Jack and Raturi, 2002).

A fundamental explanation as to why component commonality may be of interest among the plant informants may be due to the fact that its benefits extend beyond enhancing mix flexibility, as it indirectly exerts a positive effect on volume flexibility as well. To understand this, we have to first recall that volume flexibility, as previously defined, means that a company can vary its production volume while remaining cost effective, i.e. keeping the full cost of one product volume-invariant. Such a condition is fulfilled only if fixed costs are zero. Intuitively, when production volume is, for example, reduced, the total unit cost of the product is unaltered only if total fixed costs are zero. If total fixed costs are not zero, in fact, they would be spread over a lower amount of products, thus increasing the total unit cost of the product. More formally, when the full cost of one product is volume-invariant, the sum of "variable unit product cost" (CUVAR) and "fixed unit product cost" (CUFIX) is volume-invariant. In mathematical terms $\partial(\mathrm{CUVAR}+\mathrm{CUFIX})/\partial V = \partial(\mathrm{CUVAR})/\partial V + \partial(\mathrm{CUFIX})/\partial V = 0$. Since, $\partial(\mathrm{CUVAR})/\partial V = 0$ by definition, then the condition is $\partial(\mathrm{CUFIX})/\partial V = 0$, which, since $\mathrm{CUFIX} = \mathrm{CFIX}/V$ being $\mathrm{CFIX} =$ fixed costs, implies $-\ \mathrm{CFIX}/V^2 = 0 \longrightarrow \mathrm{CFIX} = 0$. Therefore, the volume flexibility requirement implies, ideally, zero fixed costs.

Given this premise, any approach that increases the theoretical output of a process without adding any fixed cost actually also increases the volume flexibility of the process (under the assumption that variable costs are not influenced). This is what happens for most initiatives aimed at increasing component commonality. By reducing the number of different components, a production system has to process, less resources – people, time, tools, etc. – are devoted to switching from manufacturing a component to manufacturing another. Automatically, such resources become available for productive tasks so that the overall theoretical capacity for a given mix gets increased, assuming that average lot size remains unaltered. Increasing component commonality, therefore, can simultaneously increase both mix flexibility and volume flexibility.

Moreover, the positive impact of greater component commonality on volume flexibility can also arise from the reduction of fixed costs. For example, if a common stamped metal component can be used instead of two or more such components, all the tools, dies, and fixtures needed are reduced by at least 50, 66 percent, etc. Since, tools, dies, and fixtures constitute fixed product costs, then achieving greater component commonality would increase volume flexibility by cutting non-productive set-up times and reducing fixed costs.

4.2 Assembly flexibility

Another frequently mentioned principle in order to implement a BTO strategy was for LawnWorks to increase the flexibility of the final assembly process. Recall from the description of LawnWorks that it fundamentally follows a "focused factory" approach, with different product families being assigned to dedicated final assembly lines. Such an approach rests on the implicit assumption that operational complexity can be reduced by partitioning operations into semi-autonomous units, or focused factories. Since, operational complexity is a major driver of operational overheads (fixed costs), the focused factory approach would make LawnWorks' operations more volume-flexible. Yet, as numerous informants pointed out, the focused factory approach severely penalized the capacity of LawnWorks to be mix-flexible. In fact, design and product engineering teams were focused factory-oriented too, i.e. they had been paying little attention to the pursuit of part commonality across products built in different focused factories. Likewise, process engineering teams centered on the optimization of tools and equipment within each focused factory. As a consequence, it was impossible to accommodate different product families on any single assembly line, in reasonable time and at reasonable cost. Last but not least, multiple respondents reported that numerous attempts to increase component commonality were frustrated by the accounting system, which was built around the focused factory concept as well. More precisely, the accounting system lacked the appropriate cost drivers to quantify overhead reductions due to across-family component commonality. Consequently, standardization projects seldom got approved, as the accounting system could not quantify whether the increased costs of component commonality (Ulrich, 1995) were counter-balanced by sufficient cost reduction in overheads. In synthesis, by applying the focused factory approach LawnWorks benefited from some improvement in terms of volume flexibility, at the cost of a lower mix flexibility, at least when the mix of products across product families is considered.

LawnWorks' management has been considering other methods to increase volume flexibility, such as Design For Manufacturing and Design For Assembly (Boothroyd *et al.*, 2002). A peculiar feature of these methods is that they seek to cut assembly time by reducing the part count of a product. If the assembly time is reduced, it follows that the theoretical capacity of the assembly line gets increased, and so it would become more volume-flexible. However, when the part count gets reduced it means that different parts, originally separated, are now being integrated into larger but fewer parts. Unfortunately, doing so violates the aforementioned principle of greater across-family component commonality and may result in decreased levels of mix flexibility. To elaborate, consider, for example, two components A and B, each with three variants. Theoretically, the variants of A (A1, A2, and A3) and B (B1, B2, and B3) can be combined to build nine configurations. This combination would entail one assembly operation of connecting A to B. Consider what would happen if we were to consolidate A and B into a single component. Clearly, the assembly operation that existed to connect A to B is no longer required – hence, a reduction in assembly time. However, we would now need 9 A + B component variants to get the same original nine configurations of A1B1, A2B1, A3B1, A1B2, A2B2, A3B2, A1B3, A2B3, and A3B3. Of course, if we have sufficiently high volumes for each of the nine consolidated A + B component variants, the benefit of a simplified and quicker assembly may outweigh the cost of parts proliferation. Therefore, in the opinion of our informants, Design For Assembly and Manufacturing techniques offered limited opportunities for LawnWorks and, most importantly, their application should be carefully validated when it involves reducing part counts.

Overall, our information suggests LawnWorks was experiencing a serious trade-off between volume and mix flexibility in its assembly operations, as the two approaches considered to increase volume flexibility – the major issue for LawnWorks – ended up compromising its mix flexibility. Yet, it is interesting to observe how component commonality could substantially reduce this trade-off. In the case of the focused factory, in fact, by designing common or partially common frames across different product families, it would be much simpler to mix across the same assembly line products currently made in different assembly lines. On the other hand, in the case of Design For Assembly, as long as part count is reduced by merging common components across two product families, then the risk of part proliferation would be avoided.

4.3 Workforce flexibility

Enhancing worker flexibility is another fundamental consideration in implementing a BTO strategy, particularly in terms of developing the capability of final assembly to quasi-effortlessly switch from building one equipment variant to another. Plant informants point to workforce policies as potentially affecting both volume flexibility and mix flexibility.

With respect to volume flexibility, a straightforward decision would be to run a third shift in-season, thus increasing LawnWork's production output by 50 percent. Indeed, such an option is easier said than done. Flexing up production output by 50 percent requires that suppliers are able to also flex up their output in a similar fashion. Moreover, third shifts in relatively labor-intensive assembly operations are often plagued by high-defect rates, so that their economic viability is uncertain. On top of this and specific to LawnWorks, it was almost impossible to recruit highly skilled maintenance technicians to work on the night shift, making third-shift productivity even lower than expected due to the reduced availability rate of machinery during such shifts.

As for mix flexibility, it was clear that component proliferation had made the assembly workers' task more complex, as component proliferation directly translates into assembly operations variability. Workers, therefore, had to be trained so that they could rapidly understand what task they had to perform depending on the product variant they were assembling. This training requirement became particularly demanding for "floaters," cross-trained workers who could work at multiple stations during production periods in attempts to balance workflow.

Workforce policies geared towards enhancing worker flexibility, in light of the constraints to volume flexibility and mix flexibility, were therefore major concerns for LawnWorks. Since, adding a third shift was not practical, the alternative to increase volume flexibility would have to be to engage a "chase" approach to capacity addition (Mangiameli and Krajewski, 1983) by hiring-and-firing according to the seasonal demand pattern. This assumed, however, that there would be a sufficient supply of seasonal workers. Moreover, to increase mix flexibility, this "chase" approach would require annual training of newly hired workers – a significant and, perhaps, too high, an investment for LawnWorks. Hence, while the workforce appears to be essential both to achieve volume flexibility and mix flexibility, it is hard to envisage workforce policies capable of simultaneously pursuing these two objectives for implementing a BTO strategy. In other words, the objectives of mix flexibility and volume flexibility may prove to be conflicting from a workforce management standpoint.

Note that the trade-off between workforce policies supporting volume flexibility and those supporting mix flexibility may, once again, be alleviated by means of increased component commonality and interface standardization across components belonging to the same component family. In fact, if the products were designed in such a way that a given component has always to be mounted in a certain way, regardless of the specific component variant considered, then the need to train workers to achieve a certain degree of mix flexibility may be drastically reduced. In other words, by standardizing the interface needed to connect pairs of components, it may be possible to increase worker capacity so as to allow handling of different product variants without additional training – the result being an increase in mix flexibility without the negative effects on other aspects of performance. The same outcome may be achieved by standardizing the interface between a component and the manufacturing process. For example, by standardizing certain geometric features of the frames of different product families, it may be possible to use a common fixture to hold the frame, so that the same assembly line can handle the different frames with ease.

4.4 Supplier flexibility

Plant informants were cognisant that the requirement for increased levels of volume flexibility and mix flexibility would unavoidably affect LawnWork's supply chain. From a purely technical perspective, increasing both volume and mix flexibility at the suppliers' facilities is as difficult as it is at LawnWork's plant. Specifically, to achieve these goals, suppliers should engage in the same product, assembly and workers' flexibilization initiatives previously discussed for LawnWorks. However, this assumes that suppliers, who are independent companies, other than the stamping facility, would be willing to change their cost structure, reducing the relative weight of fixed costs over variable costs. Clearly, this kind of change cannot be enforced by an external entity such as a customer, which, at best, can only exert some influence on this issue.

As previously discussed, a key lever to simultaneously improve volume and mix flexibility for the supplier, as for LawnWorks, would be to increase part commonality. Clearly, as the supplier is delivering parts that are designed by LawnWorks, it has to first rationalize its product designs in order to enable the supplier to become more volume and mix flexible. In other words, improvements in the suppliers' mix and volume flexibility are frozen until LawnWorks has increased component commonality within the sourced parts. Furthermore, in the specific case of LawnWorks, suppliers' volume and mix flexibility improvements would take place at a much slower pace than in the final assembly plant. In fact, while final assembly gets an immediate benefit when a pre-existing product is phased-out, the same does not happen to suppliers, who are required to keep building the phased-out parts for another ten years, for maintenance and repair reasons. In synthesis, achieving better mix and volume flexibility in supply by means of developing the capabilities of existing suppliers appeared, to the interviewed managers at LawnWorks to be a difficult path towards BTO – because of the difficulty of forcing change upon a supplier, because of the dependence of suppliers' mix and volume flexibility upon LawnWorks designs, and because of the expected slow pace of improvement due to service part obligations.

From LawnWorks' perspective, a different and promising avenue towards increasing supplier flexibility may require redesigning the first tier of the supply chain, as opposed to developing the capabilities of the existing suppliers. Such redesign may include engaging in multiple sourcing, or replacing an existing supplier with a more capable supplier. In the first case, LawnWorks can engage in the subsequent allocation of different part variants to different suppliers. Hence, compared to the current situation, each supplier would be required to provide a lower level of mix flexibility and to focus instead on meeting the requirement for volume flexibility. In the latter case, LawnWorks' would presumably select another supplier that would already yield the desired levels of mix and volume flexibility.

In the case that multiple sourcing and suppliers with improved levels of mix and volume flexibility relative to the current ones are not available options, there is still an opportunity to increase supplier flexibility by reducing the order-to-delivery time by switching to suppliers located closer to LawnWorks' plant. Since, flexibility is, by definition, related to the amount of time needed to change either volume or mix, any reduction in order-to-delivery time does increase mix flexibility, volume flexibility, or both.

In conclusion, mix and volume flexibility in supply can be improved by working on extant suppliers and on the product design, as well as by changing suppliers and by altering the structure of the first tier of the supply chain. When volume and mix flexibility in supply are pursued by means of developing the capabilities of existing suppliers, the same synergies and trade-offs previously discussed apply. In addition, it becomes harder to achieve these flexibilities for the simple fact that it is not easy to enforce change into an external organization, like a supplier's operations. On the contrary, when volume and mix flexibility in supply are pursued by means of supply chain re-configuration, the compatibility of these two performance goals can be ensured through such actions as: replacement with a more flexible supplier, replacement with a more proximal supplier, and reduction of suppliers' mix flexibility requirements via multiple sourcing.

4.5 Reducing the need for volume flexibility and mix flexibility

A number of LawnWork informants questioned the need to implement a BTO strategy and instead asked whether forecasting could be improved. From probing this issue, it appears that the logic for this discussion point rests on the belief that a true BTO approach is not really feasible given the huge seasonal variations facing LawnWorks. The bottom line was that some equipment would have to be built to forecast and stored for seasonal peaks.

When requirements for product, volume and mix flexibility appear realistically impossible to meet in a certain context, a fundamental step to be taken consists of selectively meeting some of these requirements. In other words, it may be possible to purposefully leave part of the "ideal" flexibility unmatched by the supply chain. Needless to say, the reduced supply chain flexibility should be sufficient to generate a profitable business.

A potential solution to reduce the inventory risk may be to rank forecasts based on their reliability, so that only the most reliable forecasts drive actual inventory build-up. Items characterized by more uncertain market demand may be suited to BTO. Commitment from marketing here becomes crucial. In fact, forecast reliability is not only a matter of different historical variances for demand of different items. Forecast reliability can be selectively increased for certain items if marketing commits to support, with appropriate promotion, such items. Therefore, appropriate coordination between marketing and production planning may indeed smooth some of the uncertainty.

A more advanced approach to implementing BTO may be to alter demand, or to change the time when final demand materializes. For example, customers may get incentives to order off-season, or pre-season promotions may be offered. Alternatively, the company may try to trade customization, or some sort of discount, for fast delivery. In this way, product availability may become less important for customers, as they may be less interested in getting the product immediately, if they can get it really as they like. The important assumption behind this kind of approach is that customers really care about product customization, which, as we saw, is not true for all customers.

A final area of potential improvement toward BTO is to perform product change in a time-phased manner, so that it does not interfere with seasonal peak. Most product changes, in fact, may be concentrated in periods where the supply chain is not strained by the spring production peak, with the exception of safety-related product changes. Many of these changes, indeed are commanded by either marketing or engineering because of technical or competitive issues, thus locking precious resources. Of course, imposing such kind of "disciplined product change" is not easy as it goes against the unwritten "power hierarchy" of the company: marketing first, than engineering and then supply chain.

5. Managerial implications

Our findings indicate that meeting the joint requirements for mix and volume flexibility is a demanding objective, as multiple trade-offs do exist between practices aimed at improving mix flexibility *vis-à-vis* those aimed at improving volume flexibility. In our specific research site, "focused factories," "Design-For-Assembly/Manufacturing," "three-shift production," "chase approaches to capacity addition," and "workers training programs" appeared to improve volume flexibility at the expense of mix flexibility. The awareness of these trade-offs prompted many managers to stress the risk of "blindly pursuing" a BTO strategy. Accordingly, multiple informants proposed to reduce the requests for flexibility by leaving part of the ideal flexibility unmatched by the supply chain. This would entail such approaches as "rank forecasts based on their reliability, and then build to order only those items whose forecasts are more uncertain," "increase forecast reliability for certain items though demand management initiatives," and "time-phase product changes outside seasonal peak."

Nevertheless, our study highlights potentially important synergies between volume and mix flexibility as well. Practices supporting mix flexibility, in fact, may support volume flexibility too, thus offering to manufacturing companies the attractive possibility of "killing two birds with one stone." This is because mix flexibility implies less time is wasted in switching production from an item to a different one. The reduction of set-up times would automatically free up time for production, so that increased mix flexibility would also imply increased maximum theoretical output and – potentially – increased volume flexibility. Of course, such potential increase of volume flexibility would materialize to the extent that significant fixed costs are not incurred to improve mix flexibility. "Component standardization" and "components-process interface standardization" have been consistently stressed by our informants as approaches to simultaneously increase not only mix flexibility – as everybody knows – but also volume flexibility.

The insights provided by our informants suggest that a contingency approach should be taken towards the formulation of BTO strategic plans. Such a contingency approach postulates that different practices would differently support volume and mix flexibility improvements. Likewise, different companies face different volume flexibility and mix flexibility strategic requirements. Therefore, different mixes of BTO practices are needed by different companies to implement a BTO strategy appropriate to prosper in their environment. Unfortunately, the trade-offs existing between mix flexibility and volume flexibility constrain the capacity of a company to implement the BTO strategy perfectly fitting its environment. Consequently, a company may have to decide whether:

- it should prioritise volume flexibility or mix flexibility;
- it can alter the requirements for volume and mix flexibility in its environment; and
- it can move to a new environment where the requests for mix and volume flexibility can be more easily met.

6. Conclusions, limitations, and future research

The present research explores and formalizes some of the operational challenges and opportunities a firm may face when implementing a BTO strategy. Taking a strictly operational perspective, we framed BTO strategy implementation as the simultaneous achievement of volume flexibility and mix flexibility. This framing allowed us not only to theoretically and empirically juxtapose BTO within the well established Operations management concepts of mix flexibility and volume flexibility but, more importantly, to take advantage of the concepts of performance trade-off and performance compatibility (Skinner, 1974; Mapes *et al.*, 1997; Filippini *et al.*, 1998) in understanding possible synergies and constraints in the implementation of BTO.

According to Yin (1984), the legitimacy of case studies stems from the opportunity to pursue analytical generalization as opposed to statistical generalization. Therefore, rather than trying to select a "representative" case or set of cases, we strived to generalize our study's results by explaining the logic that justifies the discovered insights. Nonetheless, we are cognisant of the fact that the validity of these insights is not set a priori but must be further strengthened through subsequent scientific inquiry (Whetten, 1989).

Clearly, the same phenomenon should be studied in other research settings as well, so that other significant independent or contextual variables can be unearthed and included in subsequent theorizing efforts. Moreover, any eventual theory of BTO strategy implementation in terms of the joint pursuit of volume flexibility and mix flexibility within a supply chain would necessarily have to undergo a large-scale empirical test. Research focusing on the organizational factors that drive firms' decisions with respect to how to implement a BTO strategy would be highly relevant. Finally, organizational theories, such as trade-off theory (Campbell and Kelly, 1994), may complement a pure operations management perspective and lead to enriched descriptions, explanations, and predictions about the implementation of a BTO strategy within a manufacturing plant and its supply chain.

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