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Production operational strategies for high-value-added manufacturing companies. A literature review

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Abstract

High-value-added manufacturing companies deal with a competitive environment where traditional order fulfillment processes, performed through fixed decoupling points systems i.e. ETO, MTO, ATO, MTS, are not a viable possibility. The paper gives a comprehensive overview of the research advances achieved in the field of production operational strategies for high-value-added manufacturing companies, identifying key research issues as well as key research approaches to deal with them. Derived from a structured analysis, relevant uncovered research issues have been identified. Furthermore, the great potential benefit that the adaptation of such special order fulfillment approaches could create on traditional sectors has been highlighted.

Keywords: Floating decoupling points, Make-to-forecast (MTF), Virtual-build-to-order (VBTO)

1. Introduction

High-value-added manufacturing companies (i.e. production of machine tools, mainframe computers, nuclear pressure vessels, earth construction equipment, plastic injection molding machines, etc) deal with a competitive environment where products are large, heavily engineered, and very expensive, the volumes of these products with any particular combination of features are small, and their demand is difficult to predict, the time to purchase components and manufacture the products (production lead time) is much greater than the delivery lead time than customers expect, also customers desire customized features of the product that must be established early in its build cycle, and finally, holding some critical components stock inventories, WIP inventories, or finished goods inventory is many times impossible both financially and even physically (Raturi et al, 1990; McCutcheon et al, 1994; Meredith and Akinc, 2007). In this context, traditional order fulfillment processes performed through fixed decoupling points systems, i.e. ETO, MTO, ATO, MTS (Olhager, 2003; Rudberg and Wikner, 2004) are not a viable possibility.

This paper gives a comprehensive overview of the research advances achieved in the field of production operational strategies for high-value-added manufacturing companies[*]. The paper is structured as follows. Section 2 presents the research method followed in order to develop the literature research. In section 3 three key research issues related to this competitive context are presented. In section 4, the main production operational strategies approaches developed in order to deal with them are shown. A classification of the different approaches

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regards key issues is presented in the form of a matrix in section 5, and finally, in section 6, main conclusions and future research lines are suggested.

2. Research Methodology

The literature research has been conducted using different databases: Blackwell-synergy, EBSCO, Emerald, ISI Proceedings, ScienceDirect, SCOPUS, Web of Science. The databases were searched for a list of keywords as well as for important researchers in the field. Certain articles could not be retrieved from the databases; in these cases SCIRUS and Google Scholar were used in addition. As a result of this search, a preliminary list of 23 references (books, papers, thesis, etc.) was set. After analyzing them in detail, additional keywords considered as significant for this analysis were added. The final search keywords were: Mass Customization, Order fulfilment process (OFP), Order Penetration Point (OPP), Customer Order Decoupling Point (CODP), Fixed decoupling points, Floating decoupling points, Demand Management, Build-to-forecast (BTF), Make-to-forecast (MTF), Virtual-build-to-order (VBTO). Some of the previous references were eliminated and key new ones were added. In total, 10 key references, plus another 9 references considered as complementary, have been employed to develop the present state-of-the-art.

3. Research Problems/Issues

The analysis of the key references, as well as the complementary ones, has allowed the identification of three generic research issues regards production operational strategies for high-value-added manufacturing companies.

3.1. Research issue 1: Conceptualization of production operational strategies for high-value-added manufacturing companies

From a theoretical viewpoint, production operational strategies for high-value-added manufacturing companies conceptualization, and the definition of frameworks and models for identifying the role of these production strategies among the traditional current customization-responsiveness trade-off resolution strategies, i.e. ETO, MTO, ATO, MTS… (Olhager, 2003; Rudberg and Wikner, 2004), has been stated in the literature as important research problem (Raturi, et al, 1990; McCutcheon et al, 1994; Brabazon and MacCarthy, 2005; Meredith and Akinc, 2007).

3.2. Research issue 2: Tactics to alleviate the operational threads related to high-value-added manufacturing companies competitive scenario

When production lead times double desired delivery lead times, firms must have a machine well into the production process before it can be offered to customers with a competitive lead time. Because many of the expensive components cannot be used in other machines or even for alternative models of the same machine type, these firms are heavily committed to forecast. As forecast are not completely accurate, these firms have had to develop tactics for coping with the consequences. The identification and classification of mechanisms and tactics used by these manufacturing firms to alleviate their operational threads has been stated in the literature as a key research problem (Meredith, 1989; Raturi, et al, 1990; McCutcheon et al, 1994; Meredith and Marsh, 1995; Salvador and Forza, 2004; Meredith and Akinc, 2007).

3.3. Research issue 3: Scheduling practices for optimizing the process of matching partially completed units to customer orders

Viewed from the customer order, or marketing, perspective, the relevant problem appears to be finding the "right" in-process unit for each new customer order. This unit should possess the characteristics that it has fixed variants similar to those requested, and is far enough along the production cycle that the delivery lead time requested by the customer can be satisfied. Thus, some concerns are: How should a production item be matched with a new customer order?; What is the basis for choosing the match?; When and according to what criteria should a unit be reconfigured for a different variant?; At what point in the build cycle should manufacturing unfreeze a production work order if no matching order is received?. Therefore, another key research problem identified is the need to find better scheduling practices that would optimize the process of matching partially completed units to customer orders (Raturi et al, 1990; Brabazon and MacCarthy, 2004; Brabazon and MacCarthy, 2006; Meredith and Akinc, 2007; Akinc and Meredith, 2009).

4. Research Approaches

This section presents the main approaches existing in the literature analyzed that try to deal with the research issues identified above.

4.1. Research approaches to issue 1: Conceptualization

The scheduling practice in high-value-added manufacturing companies' competitive environment has been to release the manufacturing order before the customer order is released (forecast based), and subsequently match incoming customer orders to units in progress. As a result, there is the possibility of either getting more orders than can be accommodated causing the rejection of some, or getting too few orders leading to a finished unit without a buyer, which is termed an "orphan" (Akinc and Meredith, 2006). The physical size and financial value of the units make storing of the orphans highly undesirable (Raturi et al, 1990).

This scheduling practice, is an special hybrid of the make-to-order (MTO) and make-to-stock (MTS) production strategies. It is not the typical ATO situation, although in both, a forecast of end-items is made and in both the actual customer orders come in before the end products are completed. In the ATO situation the build process stops at a predetermined point and WIP inventories are held until customer orders arrive. In high-value-added manufacturing companies production operations management, there is no stopping point in the production process and buffer inventories are avoided. Customer orders arrive throughout the production process and are matched to items in any state of production. Therefore it permits both early and/or late customization and thus offers a higher degree of customization than ATO (Figure 1). Also, volumes are much lower than in ATO (Raturi et al, 1990). This scheduling practice was initially labeled in the literature as Build-to-forecast (BTF) (Raturi, et al, 1990; McCutcheon et al, 1994), and later on renamed as Make-to-forecast (MTF) (Akinc and Meredith, 2006; Meredith and Akinc, 2007; Akinc and Meredith, 2009).

This scheduling practice has been adapted by major automotive firms, where it is referred to as Amend-to-order (Holweg, 2000; Holweg and Pil, 2004) and Virtual-build-to-order (VBTO): "*The VBTO system is described as the practice of connecting customer 'either via the internet or in dealer's showrooms, to the vast array of cars already in existence, including vehicles on dealer's lots, in transit, on assembly line, and scheduled for production', with the expectation that customers are likely to find a vehicle with the color and options they most want*" (Agrawal et al, 2001). Therefore, the VBTO system makes available all unsold products that are in the production pipeline to all customers. The basic VBTO system has two segments – a 'finished stock' segment and a 'pipeline' segment that represents the sequence of products to be, or are being manufactured. The upstream part of the pipeline is the virtual segment, typically driven by demand forecasts. Customers can be fulfilled in one of three ways: (1) by a product from stock; (2) by allocating the customer a product in the pipeline; (3)

or by triggering a product to be built-to-order (in which case it enters the start of the pipeline) (Brabazon and MacCarthy, 2004, 2005, 2006).

BTF-MTF and VBTO, treat the customer order decoupling point (CODP), the position in value chain that separates those activities that are forecast-driven from those driven by customer orders (Hoekstra and Romme, 1992; Da Silveira et al., 2001; Yang and Burns, 2003), in a dynamic way. Therefore, these production operational strategies have been referred as floating decoupling points systems (Brabazon and MacCarthy, 2005) in contrast to traditional fixed decoupling points systems i.e. ETO, MTO, ATO, MTS (Olhager, 2003; Rudberg and Wikner, 2004).

4.2. Research approaches to issue 2: Tactics to alleviate the operational threads

Following a multi-case study research, Raturi et al (1990) and McCutcheon et al (1994), designed a framework for reducing the severity of the BTF scenario that consists of three steps: (1) Analyze customer expectations; (2) Assess the firm's capabilities, and; (3) Select and implement appropriate tactics. The first block has to do with market customization and responsiveness issues (i.e. Will customers be willing to pay for it? Will customers be willing to wait for it? How much would they pay for quicker delivery?). The second block has to do with internal firm required capabilities (i.e. amount of excess capacity, cost and feasibility of carrying more inventory, product and process engineering skills, current and potential technologies, cost and feasibility of altering product's differentiation stage, feasibility of improving supply delivery). Finally the third block suggests several approaches regard the mapping between the previous first and second blocks (i.e. flexible process technologies, modular product designs, product family architectures, product-process configuration tools, establishing “time fences” for specifying particular design changes, use "ship set" production, making use of surplus capacity for expediting, retrofiting products that do not match specific customer orders to make them suitable, or expedite partially completed products to make them available within acceptable delivery times…).

Common practices for reducing the severity of the BTF scenario, used by high-value-added manufacturing companies, were also elicited by Raturi et al (1990), McCutcheon et al (1994), and later on contrasted by Salvador and Forza (2004) and Meredith and Akinc (2007):

- One of the more common coping strategies was to cut the production lead time through engineering redesign of the product (DFMA).
- Another approach was to redesign the product in a more modular fashion to allow easier modification to match to customers’ requirements. Unfortunately, in the face of increasing product proliferation, the gains made in easier matching have been largely offset with more variants to match.
- Another approach was to build the products with more expensive variants, and then disable their functionality if the customer was not interested in paying for them. This strategy was also largely ineffective because the cost differential of many of these variants was as much as the cost to modify the cheaper variants.
- Another approach was to rely to some extent on expensive finished goods inventory to meet unexpected customer orders within competitive delivery times. Typically, common-variant models held in the showrooms acted as buffer stocks, using showroom models to bridge the gap between build time and delivery time by offering "loaners" for several weeks. Others used its showrooms to absorb unmatched units. This practice costs a lot of money.
- Another approach was to pressure the sales force to sell units according to the existing production plans. As orders were matched to units in process, the sales people targeted

their efforts at selling the unmatched units, seeking customers that were likely to want the upcoming available models at the appropriate times. This practice may cost the firm customers.

4.3. Research approaches to issue 3: Optimizing the process of matching

Different quantitative approaches (optimization and/or simulation tools) have been identified in the literature regards scheduling practices for optimizing the process of matching partially completed units to customer orders.

Meredith and Akinc (2007) research focus on identifying, through discrete simulation modeling, better matching policies that managers are overlooking. The authors employed 3 heuristic strategies from the managerial world, and one novel strategy that implements a local optimal assignment policy with the following characteristics: (a) Matches made each period are optimal for that period but may not result in strict optimality in the dynamic long run; (b) It considers all current orders (new and already promised) and all units in the assignable window; (c) Orders are assigned to the eligible units by solving a modified assignment problem to maximize the total net contribution for that period. Several industrial scenarios were analyzed: (1) baseline (from actual practice); (2) standard bill of assembly release instead of mixed; (3) increasing rather than decreasing variant costs; (4) shorter lead times; (5) reduced production length; (6-7) expediting/reduced customer lead time; (8) longer customer lead time; (9–11) alternative order arrival patterns; (12) JIT delivery; (13) correlated variants (rather than independence). The simulation determines a ‘‘maximum contribution’’ for each match as the contribution the company would receive if some unit in the assignable window matched perfectly and no modifications were required. If there are incorrect variants, the cost of changing (correcting) them is subtracted from this maximum contribution, which is the net contribution of shipping the unit to the order. The measure reported is the average annual net contribution ratio of all shipped units. The local optimal assignment policy, compared to the best heuristic rule, does over 60% better.

Brabazon and MacCarthy (2004) investigated, through a simulation study, the ability to reconfigure a product in the pipeline in VBTO systems – i.e. change its specification to reduce or remove differences between it and the customer’s preferred specification. In particular their study focused on the impact of reconfiguration costs, customer aversion to waiting and mismatches between the variety envelope produced and that demanded by customers. Reconfiguration in this study is defined as the process of changing a product’s specification as it progresses along the pipeline. Four basic signature reconfiguration cost curves were envisaged in the study: (1) Decoupled - a feature or product starts as generic but then at a point along the process becomes a specific variant, after which the cost of changing the specification is high; (2) Gradual - as a feature or product progresses along the pipeline the cost of changing the specification increases steadily; (3) Ingredient - from an early point along the pipeline the cost of changing the specification is high which can be due to the identity of the product being strongly dependent on its constituents and having low commonality with other variants in the product range; (4) Postponed - not until late in the pipeline does the cost of specification change become significant. In order to quantify the customer aversion to waiting, the authors used the theory of exponential value decay, setting the customer aversion to waiting curve as an inverse function of the former. In their model simulation, as each customer order arrives, a search is performed of the stock and of the pipeline and if a suitable product is found it is allocated to the customer and made unavailable to other customers. The results obtained from the study are the following: (1) If the order fulfillment system allows for products to be reconfigured as they progress along the pipeline and the cost of reconfiguration is not negligible, the more willing the producer is to incur additional costs from reconfiguration, the greater the scope the producer has to segment customers; (2) In another set of experiments, related to customer waiting aversion sensibility proportions and variety mismatch, it is shown that the performance of the VBTO system is sensitive to external conditions. In both situations the strength of the effects on waiting time and fulfillment cost would be different if the customer delay aversion functions were altered.

Brabazon and MacCarthy (2006) studied how search rules alter the likelihood of finding a match for a customer. Simulation was used to compare the VBTO system (with three fulfillment mechanisms – BTO-MTO, open pipeline, MTS) against two conventional mechanisms: MTS, BTO-MTO. For both systems, conventional and VBTO, the ratio of variety to pipeline length was found to be the fundamental determinant of behavior when the feed into the pipeline and customer demand were modeled as sequences from independent uniform random distributions. Compared to the conventional system, in the VBTO system the switchover to BTO-MTO fulfillment was delayed to higher variety/pipeline ratios (Figure 2).

In tune with the previous study, Akinc and Meredith (2006) study focuses on balancing the capacity and demand rate in order to minimize both orphans and order rejections. They state that it is the production process's capacity relative to the average order rate and production and delivery lead times, rather than the managerial matching policies that determine two firm's key performance measures; the number of rejected orders and orphan machines. If the capacity is too large relative to the average order rate, too many units will end up as orphans. Likewise, insufficient capacity will result in too many orders being rejected. Thus, balancing the capacity (or rate of production) with respect to a given order arrival pattern emerges as an important strategic choice for a company. Using a Markov analysis approach these authors identified that strategic changes in relative capacity yields an "efficient frontier" of orphans versus rejections along which firms can operate based on their own costs and preferences concerning orphan and order rejection levels. They also identified that shorter lead times hurt both the orphan and rejection levels. As well as that reducing the variability by half reduced both the orphan and rejection levels at least a 25% for many common industrial scenarios.

5. Analysis

The production operational strategies for high-value-added manufacturing companies, found in the literature, cover a spectrum of models-frameworks, methods-methodologies, and tools (Table 1).

From the analysis of the literature review matrix (Table 1), two uncovered research issues can be stated:

- What kind of methods are needed to successfully implement BTF-MTF-VBTO strategies in real industrial companies?
- How to coordinate BTF-MTF-VBTO strategies with the supply chain configuration domain (geographical locations)? Models-frameworks, methods-methodologies and tools.

6. Conclusions

Build-to-forecast (BTF), or Make-to-forecast (MTF), have been identified as the main strategies that managers have implemented for high-value-added manufacturing industries' competitive environment, where traditional fixed decoupling point systems (ETO, MTO, ATO, MTS…) are not a possibility. The adaptation of BTF-MTF strategy to other sectors (i.e. automotive industry) has been also highlighted: the Virtual-build-to-order (VBTO) strategy.

Some tools identified in the literature research for improving certain aspects of the traditional BTF-MTF production operational strategies, may apply much more broadly than to just those companies that are forced by the competition into a BTF-MTF environment. Therefore, firms currently using MTO may find changing to BTF-MTF-VBTO worthwhile to gain the competitive advantage of faster customer response times without a corresponding reduction in the manufacturing lead time, given the global pressures for increasingly faster delivery of their products.

However, it seems that the theory of production in operations management has lacked attention to the high-value-added manufacturing industries major segment, attending to the published research found. Hence, more research is needed to validate the findings presented with data coming from a variety of BTF-MTF-VBTO industries, and possibly from certain MTO industries. In this sense, some open questions have been identified in the literature reviewed. For instance, and relating the product and processes domains, of special interest for the order matching process would be determining how does commonality, or modular product design, affect the order-matching problem. In fact, generally speaking, more qualitative and quantitative simulation modeling studies regards optimum ways of configuring products to address the customization-responsiveness squeeze would be highly desirable.

Also, managing operations in a BTF-MTF environment is complicated by several factors: market competition based on delivery lead times, complex production-distribution processes, a multiplicity of variants and options, quick technological obsolescence of variants and a high degree of customization in the final product. And any effective mechanism requires coordination across departmental boundaries - such as marketing, manufacturing, and supply chain, or product design, process engineering, and supply chain design - that traditionally have not functioned well together in many firms. Therefore, the linking of product and processes domains should be just the starting point towards an effective alignment of the triad product family architectures-order fulfillment processes-supply network configurations. Thus, another future research line should be also considered specially focused on linking BTF-MTF-VBTO order fulfillment processes with supply network configurations elements, i.e. capacity and inventory geographical locations.

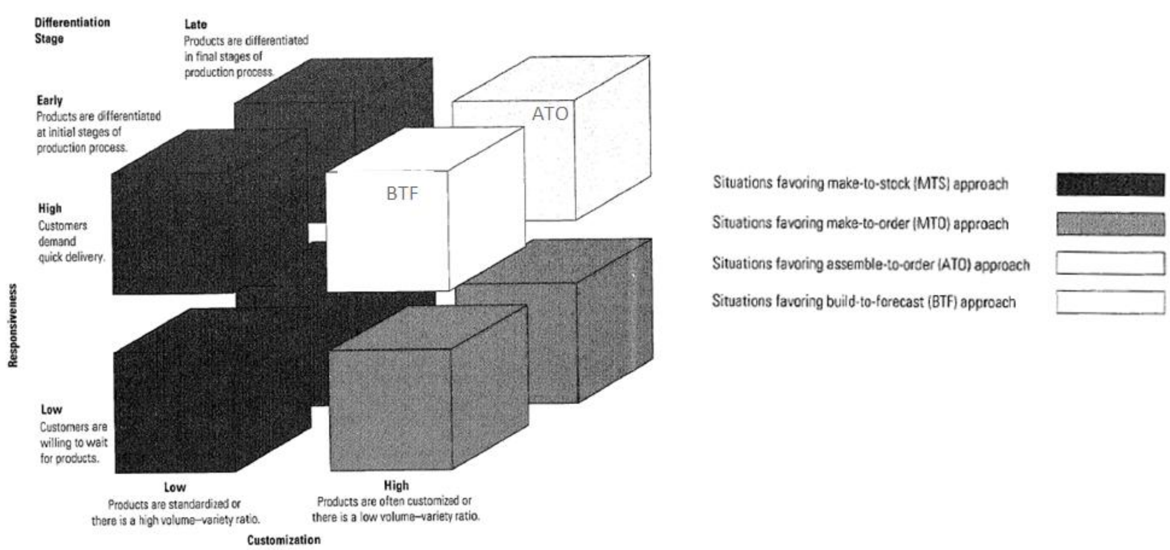

Figure 1. Relative position of BTF strategy with respect to traditional MTO, ATO, and MTS strategies. Source: McCutcheon et al. (1994)

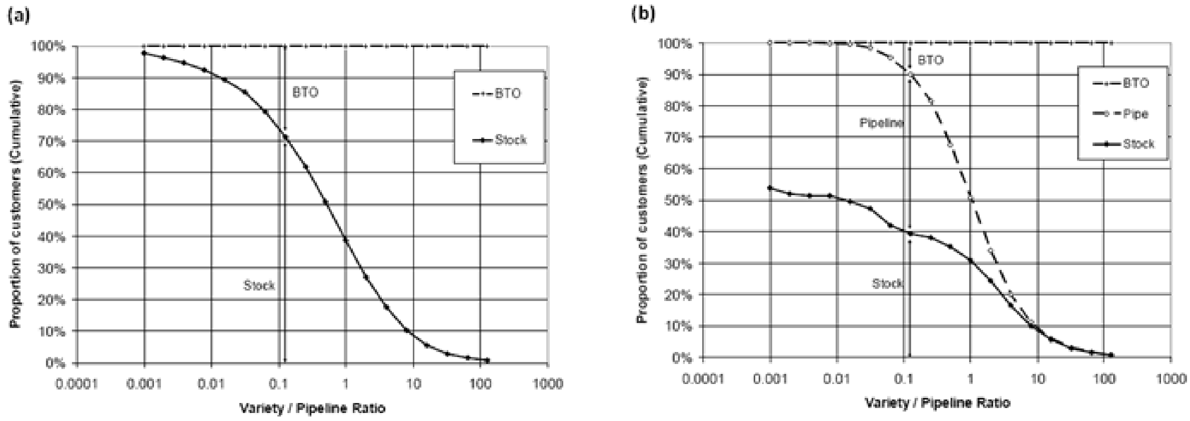

Figure 2. (a) Fulfillment by mechanism for the Conventional system; (b) Fulfillment by mechanism for the VBTO system. Source: Brabazon and MacCarthy (2006)

Table 1. Literature review matrix

Research Issues	Models and Frameworks (RESEARCH APPROACHES)	Methods and Methodologies (RESEARCH APPROACHES)	Tools (RESEARCH APPROACHES)	P (DOMAIN*)	P&O (DOMAIN*)	SN (DOMAIN*)
Research Issue 1 Conceptualization of production operational strategies for high-value-added manufacturing companies	Characterization of the BTF strategy: Raturi et al. (1990); McCutcheon et al. (1994)			✓	✓	
	Characterization of the MTF strategy: Meredith and Akinc (2007)			✓	✓	
	Characterization of the Amend-to-order scenario: Holweg (2000); Holweg and Pil (2004)			✓	✓	
	Characterization of the Virtual-build-to-order (VBTO) strategy: Agrawal et al. (2001); Brabazon and MacCarthy (2004, 2005, 2006)			✓	✓	
Research Issue 2 Tactics to alleviate the operational threads related to high-value-added manufacturing companies competitive scenario	Framework for reducing the severity of the BTF scenario: Raturi et al. (1990); McCutcheon et al. (1994)			✓	✓	
	Practices to configuring products to address the BTF-MTF scenario: Salvador and Forza (2004)			✓	✓	
Research Issue 3 Scheduling practices for optimizing the process of matching partially completed units to customer orders			Scheduling practices to optimize the process of matching partially completed units to customer orders: Meredith and Akinc (2007)	✓	✓	
			Tool for evaluating the impact of reconfiguration costs in VBTO scenarios: Brabazon and MacCarthy (2004)	✓	✓	
			Tool for identifying search rules that alter the likelihood of finding a VBTO match for a customer: Brabazon and MacCarthy (2006)		✓	
			Tool for balancing the capacity and demand rate in order to minimize both orphans and order rejections: Akinc and Meredith (2006)		✓	

*DOMAIN: P-Product; P&O - Processes and Operations; SN - Supply Network

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