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December 2002

Working Paper DT-2002-BM-1

(to appear in IJPPC)

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Keywords: demand and supply network design, strategy, customisation, order-to-delivery time

Abstract:

This paper first presents personalising and personalised manufacturing as means for firms to meet the rising challenge, faced by a large variety of manufacturers, to offer innovative highly personalised products with short and reliable delivery delays in a digital and global economy that is highly turbulent and competitive. It positions personalising versus the current trend of mass customising. It characterizes complementary types of personalising and highlights the key elements for their successful implementation from a demand and supply network perspective. Finally, it illustrates the scope and addresses how personalising affects the design of the demand and supply network, emphasising the scope of this design influence, the variety of options for each element of the network, and the interrelationships between the design decisions.

1. Introduction

The demand and supply network of a firm usually starts with customers who consider purchasing a product either through independent stores or dealers, or directly from the enterprise, either shopping physically or virtually through an e-commerce site. Each customer has needs, expectations and elasticity relative to the product, its price and its delivery time. At one extreme, there are customers who want standard products immediately off the shelf. At the other extreme, there are customers requiring highly customised products, ready to pay some extra price and to wait some extra time before delivery. Between these extremes, there is a large spectrum of alternatives that defines the domain of what we describe as personalised manufacturing. In the personalised manufacturing philosophy, in each of its targeted market segments, an enterprise has to specify its value proposition in terms of product personalisation, delivery personalisation and pricing personalisation. This strategic decision making about the firm's offering influences and is influenced by the design of the enterprise's entire demand and supply network, which includes its distribution, assembly, manufacturing, supply, engineering, design, technology, marketing and sales networks and processes. The paper first positions personalising versus the current trend of mass customising. It then characterizes complementary types of personalising

which the firm may combine to define its offer. Emphasis is put on the key elements for their successful implementation from a demand and supply network perspective. Finally the paper illustrates the scope and addresses how personalising affects the design of the demand and supply network, emphasising the scope of this design influence, the variety of options for each element of the network, and the interrelationships between the design decisions.

2. From mass customising to personalising

There has been considerable literature on mass customising in the past decade as customers became more demanding within the context of global competition in manufacturing industries. The literature movement has begun in the mid 1980s with Davis' (1987) discussion of mass customisation (MC) in his book titled *Future Perfect*. Essentially, MC refers to a firm's ability to offer customised products for individual customers at mass production prices and delivery delays (Pine 1993). Prior to the mid 1980s, manufacturers could be characterised as being anywhere within the range of custom producers with long lead times to mass producers of low cost products with short lead times (Duray 2002). Due to advancements in several sectors such as computer technologies, information systems, managerial practices and machinery, manufacturers in the 1990s were able to offer more customization with limited cost increases and delivery delays.

During the 1990s many components that are deemed essential to achieve mass customising have been proposed in the literature. Pine (1993) suggests the following five fundamental methods for a mass producer to achieve mass customising: customise services around standard products, create customisable products, offer point of delivery customisation, reduce lead times, and modularize components. Mintzberg (1996) upholds that customisation capability is function of customer involvement in the value chain. For different reasons, several authors (Goldhar and Jelinek 1983, Pine 1993, Baldwin and Clark 1994, Salvador et al. 2004) support a second factor important to mass customisation, which is modularity in production. The essence of modularity is to produce standard components at mass production costs so that these components can easily be combined to offer a wide variety of customised products. Lastly, Mikkola and Sklott-Larsen (2004) argue the importance of postponement as a key strategy in offering mass customization. Postponement strategies attempt to delay product differentiation as late as possible where final operations are done only in response to customer orders. What rises strongly from the literature is that manufacturers adopting mass customisation need to have a blend of customer involvement, modularity and postponement.

Research in recent years has also suggested that other factors play a key role in the success of mass customizers. For instance, customer interaction and product fitting has gotten considerable attention. Piller (2003) discusses how

electronic business and the internet is a recent enabler of mass customization by better providing choices to customers. MacCarthy et al. (2003) present key value attributes that affect customer perception of mass customization. Logically, the fitting process can be complex and necessitate advanced web-based information technology (Khalid 2003). Customer interfaces should be personalized and provide tools to fit the customer with the best product (Riemer 2003). Duray (2004) has also shown how several successful mass customizers adopt certain tactical planning strategies such as production planning, inventory management and distribution channels in function of their type of modularity and customer involvement in their production system.

The transition from traditional manufacturing to mass customising can be described by two paths. For one, mass producers have involved customer towards the end of the fabrication process such as modifying finishing or distribution. The other path has been with custom producers who have kept customers involved during the early stages of production but have adapted methods such as modularity to reduce lead times closer to those of mass producers (Pine 1993). This point of view is reflected by Duray *et al.* (2000) who proposed four mass customising types: fabricators, involvers, modularizers and assemblers. Based on a survey of 126 firms, they developed their framework by determining the degree of customer involvement and modularity at the design, fabrication, assembly and customer stages within each firm. Fabricators involve customers and modularization in the early manufacturing stages and they resemble the most to traditional customizers. Contrarily to fabricators, assemblers involve customers and modularity late in the production stages, which positions them closer to traditional mass producers. Involvers do implicate customers early in the production stages but they only adopt modularity in late stages. Lastly, modularizers do implement modularity early in the production stages, but customers are only involved in the late stages. Duray *et al.* (2002) claim that each of these four types of mass customizers has preferred manufacturing systems or capabilities to enable fulfilment of offers. They also suggest that certain implementation approaches exist to attain these different types of mass customisation.

Similarly, Alwis *et al.* (2001) propose that firms should pick between five mass customising strategies in function of where the consumer effects production (decoupling point), these strategies being pure standardisation, segmented standardisation, customised standard, tailored customisation and pure customisation. However, not all firms have completely switched to mass customising. Kotha (1995) and recently Duray (2002) have shown that both mass production and mass customising can co-exist in the same facility.

Our stand is that the black-and-white decision whether a firm should be a mass producer or a mass customiser is a wrong question, and that the key decision is relative to which combinations of levels of customising to offer to customers in

each market segment. This implies the potential concurrent multiplicity of offering options. Lempel and Mintzberg (1996) also emphasized that mass customization should be viewed as a wide range of unique offers while they focus on the point of customer involvement as the main indicator of customization and uniqueness of the product. In order to differentiate our perspective from the well studied mass customising perspective, we thereafter refer to personalising and personalised manufacturing. The goal with personalising is to ever develop the competitiveness of the firm by having an offer that closely matches the evolving personalised expectations of customers in the targeted segments and by having the capability to profitably deliver the offer on a reliable basis.

Taking a customer perspective, in the next section we describe illustrative types of personalised offers, which provide complementary options available to manufacturers. This classification scheme is in line with the one from Alwis *et al.* (2001) while being adapted to the personalising perspective allowing concurrent distinctive personalised offers.

3. Product personalisation

Key to this paper is the strategic decision by an enterprise to personalise its offer to its customers. Basically, this implies that the enterprise attempts to develop offers that respond to the personalised requirements of its customers in targeted segments. In this paper, our focus for the personalisation of an offer involves concurrently, the personalisation of products, the personalisation of delivery and the personalisation of pricing. These three aspects are addressed briefly in this section. From a product perspective, there exist several types of product personalisation that a firm can concurrently offer, as is summarised through our introduction of a five-type categorisation of offer personalising, which synthesizes our findings from in-depth case studies of personalization potential in a variety of industries.

3.1 Popularising

The first personalising type, which can be termed popularising, offers off-the-shelf to clients a limited set of standard products. Each popular product may be focused on a specific spectrum of customers and their needs. It may be adjustable by the customer himself according to his needs, through software, electronic or mechanical means. There is extensive investment in understanding customer needs, in designing a limited number of standard products which jointly permit to highly satisfy a wide variety of customers, and in insuring their fast and reliable availability at adequate price to customers, mostly off-the-shelf.

Let us use snowmobile manufacturing as an example. A typical mass producer offers roughly between one hundred and two hundred standard vehicles. Prior to the selling season, all its dealers have to commit themselves to buying a selection

of these standard products. Most of its retailers purchase only a limited subset of these products and do push selling during the selling season, attempting to sell their set of snowmobiles to customers, often having to offer them compromising substitutes for their unavailable preferred choices. Using the personalizing philosophy, a manufacturer could develop a popularizing offer by focusing on a reduced number of vehicles to be made available all season long in the dealerships, and rapidly replenished by the manufacturer as needed. These snowmobiles would be selected to maximize the probability that an impulsive customer wanting a vehicle right now would find a fit in the dealer stock.

The main process capabilities enabling efficient popularising are:

1. Capitalising on the built strengths of mass marketing, production and distribution, coupled with information technology; the customer perceives standard offers as satisfying most of his needs right now at affordable prices.
2. Close-to-customers, innovative marketing research aims at deeply understanding customers, their needs and expectations, always looking for the next frontier, the next degree of potential needs satisfaction, the next functionality fusion level achievable.
3. Exploiting faster product life cycles, the enterprise is continually tabling on innovation for the next product generations to ever better serve the evolving needs of customers.

In contrast to literature on mass customisation, we do not require customers to be involved in the manufacturing process. The essence of popularising lies in the closeness that the firm has with its targeted customers, both from a product design perspective and product availability perspective. It concentrates on best satisfying their immediate needs all the time. On one hand, it thus involves making sure that popular products are nearly always available for purchase immediately. On the other hand, it involves making sure that popular products do remain popular, which implies the modification and evolution of the popular product set in function of evolving needs of targeted customers. This contrasts with mass producers that exploit the traditional life cycles of a product. Optimising popular product cost can readily involve the exploitation of modularity at different stages to reduce product costs and delivery times.

3.2 Varietising

With the second personalising type, which can be termed varietising, a firm offers an extensive mix of products, passing for example from 100 to 10,000 standard products, making it easy for a customer to find a product in the offered variety that closely matches his personal requirements. Swatch illustrates nicely the concept of varietising. It offers to retailers a

huge and evolving variety of fashion watches, from which each retailer picks his offering to his clients. This wide variety is profitably offered by clever modular design of the watches and by their production through a highly flexible production system.

Through a varietising offer, the illustrative snowmobile manufacturer would design and engineer its product line and production system so as to be able to offer a wide variety of snowmobiles, far exceeding the typical few-hundred vehicle mix to an offer of many hundreds or thousands of vehicles. For example, he can offer ten colours instead of two, five types of seats instead of two, and three types of windshields instead of one. These simple changes grow the product mix by a factor of 37,5 to one. Yet these three features are only but a few of the potential for product differentiation, others include hard core items such as the engine and detail items such as the handle grips. The manufacturer would have to decide which features would be offered in wider variety, and would have to manage the constitution of its product mix. Dealers would constitute their own off-the-shelf offering by selecting a subset of the product mix and would rely on the manufacturer to let them deliver fast and reliably the other vehicles in the mix.

The main concern with accessorising is to carefully match a customer's needs with an appropriate offered product. This matching is enhanced through four main business processes.

1. Product design focuses on creating an attractive variety, giving the impression that the product mix completely covers the potential spectrum of potential customer needs, while minimising varietising costs by maximising non-differentiating parts commonality and by easing the quick creation of variety.
2. Customer purchasing is guided so as to best match the offered products to customer needs. E-technologies such as interactive websites can also be adopted to help each client identify his needs and narrow down his selection from a myriad to a few preferred products.
3. Locate-to-order distribution capability enables customers to have network-wide visibility and access to in-stock products at all participating dealers.
4. Mixed-model manufacturing and modularity of parts allows fast production and delivery of ordered products.

As with popularising, the customer is not involved in the manufacturing stages. It is again important to stress that personalised offers focus on the client's perception of the personalisation facet in the product. When varietising, the firm designs its business processes to portray an extremely large variety of products to customers while offering relatively short delivery time or off-the-shelf, and at competitive prices.

3.3 Accessorising

With the third type of personalising, termed accessorising, the customer selects a basic product and then adds accessories at will to personalise it to his requirements. With a limited number of core products, each client can create a personalised product. Globally, a multitude of final products can be customised through the combination of accessories.

Through a varietising offer, the illustrative snowmobile manufacturer would produce a limited number of semi-finished vehicle types, which would be finalized according to consumer specifications. Accessories for which choices could be made by the client could include items such as chain cases, clutch covers, front shocks and suspension, gauges, grills, headlight mouldings, idler wheels, mirrors, rewind handles, seats, skis, snow guards and windshields. This creates a huge number of product combinations. Ready-to-accessorize vehicles could be produced and shipped to distributed fulfilment centres equipped to efficiently finish the vehicles according to one-of-a-kind accessorising specifications, allowing fast and reliable delivery of accessorized vehicles to dealerships, either to fulfil a client order or to showcase the vehicle in the dealer's showroom.

The accessorising offer is enhanced by a combination of product and accessory design, customer purchase guidance, and clever core product and accessory manufacturing and distribution.

1. Products are designed for accessorising, and accessories are designed to jointly satisfy a variety of specific customer needs.
2. The customer is guided through his purchasing process, selecting the right product and then the right set of accessories for that product.
3. Manufacturing and supply are geared to efficiently and rapidly produce and/or source the limited number of standard core products and the high variety of standard accessories.
4. Core products and accessories are deployed through the distribution network, with accessorising of the product being done by the customer himself, the dealer or a fulfilment centre, either at product sales time or at a later time following the sale.

This is the first type of personalisation offer that involves the customer during the manufacturing process depending on the accessories selected and the design options for the realization of the final product. There is a definite focus on modularity between core products and accessories to maximise the number of matches and thus increase customer choice.

3.4 Parametering

In parametering, the customer specifies his product by selecting values for design parameters and by selecting specific options, including accessories. Indeed the product is defined through specification of its product code, similar to a genetic code, set by the combination of functional and/or technical parameters and options. Each manufactured product is thus potentially different from all others.

Through a parametering offer, the snowmobile manufacturer would permit the client to specify a wide number of features by letting him pick among alternatives components and options. Beyond the flexibility offered by the accessorizing offer, the manufacturer could let the user pick alternatives for core modules such as platforms, engines, tracks and rear shocks and suspensions, as well as for items such as bumpers, colours, decals, heaters, ski stances, slider shoes and starters. Clients taking advantage of a parametering offer would specify the complete set of parameters defining the unique vehicle they want to purchase. Once ordered, the manufacturer would guarantee fast and reliable delivery to the clients. The manufacturer would assemble the vehicles to specifications, picking the right set of modules and components to realize the ordered vehicles. These would then be fast shipped to dealers for customer delivery.

To make parametering pay off for customers involves process capability building in three key areas.

1. Design emphasis is directed toward platforms and modules as an interlaced easy-to-connect set which globally permits to satisfy a large spectrum of individual needs. Design specifies the customer-oriented set of product codes by defining parameters and options. It also specifies the manufacturing-oriented set of production codes by translating product codes in required sets of platforms, modules, parts and accessories, and related manufacturing activities.
2. Customers must be guided through the creation of their products, helping them develop the product codes best satisfying their specific needs while maintaining product integrity in terms of safety, compatibility, performance, maintenance and aesthetic perspectives.

3. Delivery, manufacturing and supply are geared to rapidly and efficiently produce and deliver parametered products ordered by customers.

3.5 Tailoring

The fifth personalising type is tailoring. Within a defined design spectrum, the customer provides the manufacturer with product specifications and drawings, according to which the manufacturer produces the personalised product. When the specifications are functional, this involves engineering-to-order from the manufacturer.

For the snowmobile manufacturer, a tailoring offer could permit simpler specifications such as one-of-a-kind hood painting as done in luxury motor coaches, or much more complex engineering specifications such as would be required by speed and raid racers.

To be successful, tailoring requires three key process capabilities.

1. Through the selling process, the enterprise makes sure that customers understand its design and engineering capabilities, as well as its manufacturing and delivery capabilities. It guides the customers toward a fruitful exploitation of these capabilities so as to fulfil their needs.
2. The enterprise has strong interactive design and engineering capabilities, best helping the customer bridge the gap from needs to satisfaction by coming up with highly adequate product specifications.
3. Delivery, manufacturing and supply are geared to rapidly and efficiently produce and deliver one-of-a-kind tailored products.

3.6 Selecting the appropriate product personalising offer set

Globally and for each targeted market segment, the enterprise needs to position its offer in terms of personalised products. The positioning may vary from segment to segment. Also, within a segment, the offer may involve combinations of personalising types one to five. Selecting the appropriate personalising offer set needs to be finely tuned to customer demand and expectations. Figure 1 illustrates the output of a revealing, in-depth customer survey performed by a manufacturer about personalising. It shows that its client pool would opt for popularising at 30%, varietising at

20%, accessorising at 35%, parametering at 15%, and almost none for tailoring. For this manufacturer a personalising strategy focusing solely on a specific type of offering could be disastrous to its future market shares.

It is important to emphasise that the five-product-personalisation-type classification presented in the previous sections should not be perceived as being comprehensive and final in intent, it is rather a broad illustration of the potential for diverse types of personalised offers. Innovative enterprises may well develop new attractive personalising offers that do not fit within the five types described here.

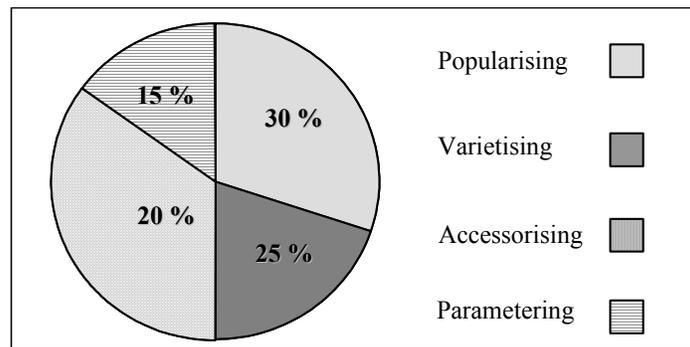


Figure 1: Sample of customer demand and expectations for personalising

4. Delivery personalisation

Firms must realize that product personalisation decisions are tightly coupled to decisions related to product delivery in terms of mode, location, time and reliability. Indeed it would appear ideal to deliver the product to each client in the mode he prefers, at the location he selects, at the exact time he wishes, and this with 100% reliability. However, like with product personalisation, there is a cost associated with delivering such an offer, and not every client may be willing to pay the extra price tag associated with covering this cost. Therefore, enterprises have to decide what they are to offer in terms of delivery personalisation, in tight relationship with personalised products and pricing.

For the past decade, many firms have invested in reduction of order-to-delivery time (OTD) and have used it as a competitive advantage. However, high levels of personalisation involve make-to-order production that may make it tough to guarantee fast delivery. For example, it is still highly common in 2003 for clients wanting parametered cars from world leader manufacturers to have to wait for several months before receiving their car. Yet there is worldwide pressure to reduce such long lead times for personalised vehicles, with a global race toward a ten to fifteen day delivery. In a global society where speed is the norm, the question to be asked by every enterprise in each of its target markets is:

what is the delivery time elasticity of customers relative to personalisation? How long are customers willing to wait for a personalised product? In the car industry, it is still counted in months or weeks. In the microcomputer industry, it is counted in terms of days. In the fast food industry, it is counted in minutes. Contrasting with the above emphasis on speed, it is important to emphasise that for some clients, the right delivery time may not be now, but rather at a specific time best fitting his needs, which may be weeks away in the future. Also, for many clients, delivery time reliability may be more important than speed. Being able to count on their supplier to deliver on time may be essential for them, so that they may be ready to accept longer lead time promises if they are sure at 99,9% that these promised delivery times will be respected.

As shown in figure 2, the pressure for fast delivery may also differ highly depending on both the type of personalising and the time of the year. For example, the client may expect a popular product in the catalogue to be either available right now on the shelf or at worst within three days at the peak of the selling season. The client may be willing to wait up to fifteen days for the same product in the off season. In the peak season, delivery speed expectations for accessorised products may be up to five days while the client may be willing to wait ten days for a parametered product. Matching client expectations and providing reliable delivery within these expectations is central to achieving competitive success.

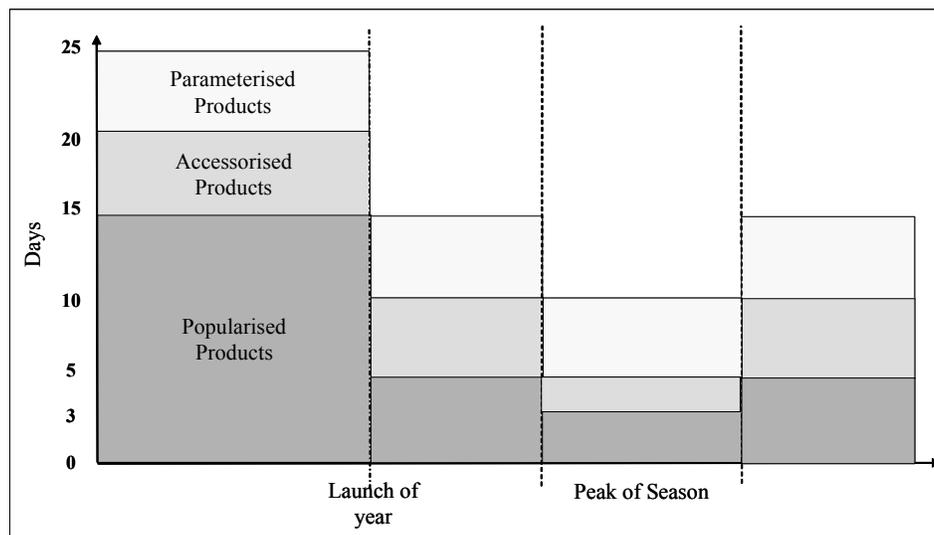


Figure 2: Example of client delivery time expectations depending on type of personalising and on time of the year

By knowing the delays acceptable by clients depending on the type of personalisation and the time of the year, the firm could adjust its capacity and production planning during the year to better fit demand and thus reduce its production costs. For instance, once a firm is aware of delivery expectations such as those expressed in figure 2, it may be far from

optimal to gear its manufacturing network to produce its products within three days of their order, in a just-in-time production-to-order mode, as this would require high capacity peaks. A potential alternative would be to dynamically build and adjust an inventory of popular products, varietised products, ready-to-accessorise products, accessories, sub-assemblies, modules and parts, and to have flexible resources to complete orders within their particular delivery time expectations. Hence, goals for reliability and speed of delivery could be attained, for the various offered types of personalising while offering adequate prices and maintaining excellent profitability. It is therefore important to develop a delivery time offer that exploits as best as possible customer expectations and elasticity in terms of delivery time and reliability.

There are many key business processes that firms can adopt for insuring fast and reliable order-to-delivery speed matching the personalised customer requirements. Their applicability is case based and highly dependent on the product personalising strategy. Below are summarised generally recognised success factors.

1. Develop manufacturing flexibility and agility to reduce lot sizes, vary production paces, and increase variety capability, which in turn allows firms to reduce throughput time.
2. Postpone product differentiation as much as possible. This permits firms to make to stock similar components in the early stages of production and to rapidly customise products on a make-to-order strategy.
3. Invest in product modularity to take advantage of economies of scale and offer fast personalisation.
4. Move final product realisation physically closer to the customers. Have retailers or even customers do some simple finishing or assembly operations.
5. Minimise transportation time between suppliers and retailers for make-to-order products that are not stocked near retailers. Select transportation options that allow frequent, smaller deliveries; or outsource transportation to specialised logistic providers. Adopt optimisation software to minimise routing time and costs.
6. Capitalise on digitized, web enabled communication and planning systems throughout the demand and supply network for quick and intelligent information and decision flow.
7. Adopt appropriate performance measurements and objectives to promote increases in delivery speed and reliability.

5. Personalised pricing

Combined with its product and delivery personalisation strategy, a firm must determine its personalised pricing strategy based on what it perceives the customer is ready to pay for the added product personalising and faster, reliable delivery.

Over its product mix and all market segments, a firm must make sure that the costs of personalisation at the required speed are covered by the offered prices in order to provide margins insuring the firm's profitability and development.

The price structure may charge the cost of product and delivery personalising to each client given his specific order. In such a setting the client is informed of the price tag depending on his selections relative to both product and delivery. He may be provided with options and aids to help him best select his preferred compromise. For example, the firm may depict a price vs. delivery time graph for the personalised product to be offered. He may be shown alternative products near to his preference that may have smaller price tags or may be available faster.

Firms may decide to embed the personalising cost in the core pricing instead of charging it explicitly to the customer. For example, in the golf equipment industry, firms do not tend to increase consumer prices for personalisation requiring only alterations in the operations, while they will explicitly charge for customisation requiring different components. Some firms may also use personalising to attract new customers, subsidising its cost and accepting lower margins for these sales to new customers in the expectation of future profits from repeat sales. Firms must be careful of the impact of their total pricing structure on demand for products from each of their personalisation offers. A highly personalised product that is priced too closely to less personalised products may shift demand towards the former type, hence changing forecasts and indirectly, resource planning strategies.

The pricing structure may be made dynamic, strategically used as a demand management mechanism. Dynamic personalised pricing can be used to deliberately channel clients towards targeted products, product parameters, accessories, and delivery options, so as to repair situations created by decisions taken based on non-realized forecasts. It can also be used to respond proactively to local attacks from competitors.

6. Demand and supply network design

Designing the personalised offering of an enterprise in terms of product, delivery and pricing requires concurrently designing its demand and supply network so that it will be capable of profitably realizing the designed offer. Indeed, the enterprise's entire demand and supply network is affected by personalising. This includes the firm's marketing, sales, distribution, assembly, manufacturing, supply, engineering and design networks and processes. This section first describes the scope of demand and supply network design for personalised manufacturing, emphasising the extent of the design influence of personalising, and then follows in greater depth on design options for five of these elements. The descriptions and recommendations derive from our synthesis of our findings from in-depth field case studies, which have

been later been put to challenge through extensive discussions with a pool of executives from over twenty manufacturing companies.

Innovative product design and engineering is a springboard permitting personalised offers. Product design and engineering must be tightly attuned to targeted clients, understanding their needs and expectations. It must be reoriented and reorganised so as to innovate not only in function of families and products, but in terms of platforms, modules and accessories that exploit standardisation and compatibility between parts.

Sales and marketing should put to value the capabilities of engineering by portraying to customers the immense possibilities of personalisation, via innovative interactive internet tools or through direct contact with clients, so as to best fit customer needs. Retailers need to be organised to focus on customer service. They need more flexible purchasing contracts with the manufacturer, allowing them to stock popular products and accessories ready to be delivered immediately, while permitting them to order highly personalised products frequently with quick, reliable delivery.

The final product could be realized at several locations in the demand and supply network depending on the level of personalisation and quoted lead times, from the location of the customer all the way back to the factory. Key decisions must also be taken relative to modules, accessories, parts and materials. Internal production or external sourcing, on site manufacturing vs delivery from farther (foreign) sites, and so on, are all key decisions which must be aligned with the realities of personalisation. Manufacturing and supply must become fast and reliable personalisation enablers instead of constraints.

On the manufacturing side, production centres need to be designed and organised to provide the appropriate level of flexibility and agility to support the personalisation offer of the firm. Designs can vary immensely between single level, single pace, single product production lines, to multi-level, multi-product, multi-pace networks. The configuration of resource levels to respect customer response times at minimal cost must be determined. The resource requirements for supporting next-day assembly are very different from those for supporting longer assembly lead times such as three or ten days. The random demand peaks must be dealt with reliably up to the targeted service levels. These peaks are much smoother for longer lead times as they are for shorter lead times. For example, a product with a normally distributed daily demand with a 100-unit average and a 10-unit standard deviation requires a daily capacity of 130 units to offer

reliable 3-sigma next-day service level. This required daily capacity respectively drops to 118 and 110 for 3-day and 10-day assembly lead times.

On the supply side, the firm should strive to have cooperative suppliers with ample capacity, short delivery times and high reliability. To stress the importance of reliable supply, take a product composed of 100 components. If the supply of each component is 99,9% reliable, then the reliability of supply availability for the product is 90,4%, which means that roughly 10 out of 100 ordered personalised products could not be assembled on time due to lack of components. If the supply of each component merely drops to 99%, then the reliability of product supply availability drops to 36,6%. For those suppliers falling short of the supply ideals, procurement policy options should be chosen accordingly. Performing suppliers can be synchronised with production centres while for others, the firm should require buffers to protect themselves against supplier delivery uncertainty.

Production and inventory planning and control policies should be more adaptive and carefully controlled to deal with demand seasonality and demand uncertainty associated with personalised offers that imply a wide variety of final products. Some popular products and components may be forecasted with tight confidence intervals, but most products are difficult to forecast, which implies much larger forecasting confidence intervals. In turn, these imply higher requirements for product stocking whenever possible, and higher requirements for keeping short term fast product realization capacity for personalised-to-order products.

Personalised manufacturing has strong implications for information and communication technology selection and deployment. From web-based customer interfaces guiding each client toward the most appropriate combination of product, delivery and pricing, to intelligent software agents supporting demand, distribution, production, and supply orchestration, passing by life-cycle serial-number product and component tracking through the network, the pressures are important. Most functionally oriented statements in this paper have implications on information and communication technology requirements.

The following sections describe in more detail selected demand and supply network design facets that affect and are affected by personalised manufacturing. The selected facets are: retailer-manufacturer contractual relationship design, final product realization network design, product and accessory distribution network design, manufacturing and fulfilment centre design, and dynamic supply network design. These facets have been selected as a sample of the various

types to be considered, with the intent of allowing deeper understanding of the depth of design implications, and to illustrate the interrelationships among multiple facets throughout the network.

6.1 Retailer-manufacturer contractual relationship design

When products are sold in the retail market through networks of retailers, both brick and click types, the contractual relationships between retailers and manufacturers have to be aligned with the personalising strategy. Their specification is part of the overall design scope for the demand and supply network. Table 1 provides typical available options to be decided upon for each retailer the manufacturer deals with. It presents seven retailer-manufacturer contractual relation options, and states if each is generally recommended, satisfactory, poor or infeasible for each type of personalised offer.

Table 1: Typical available options for retailer-manufacturer contractual relations

Options	Principal agreement conditions			Personalisation types					
	Stock Purchase	Finance	Manufacturing delivery	Popularising	Varietising	Accessorising	Parametering	Tailoring	
1	buy pre-season	without aid	prior to season	○	○	○	●	●	
2	buy pre-season	without aid	prior to season	○	○	○	●	●	
3	base pre-season with replenish	without aid	base before season, rest is order time and mix dependent	●	●	●	●	●	
4	volume commitment in pre-season	without aid	order time and mix dependent	●	●	●	●	○	
5	buys when desires	without aid	order time and mix dependent	●	●	●	●	○	
6	buys showroom only	stock in consignment	order time and mix dependent	●	●	●	●	○	
7	does not buy, commission	not applicable	order time and mix dependent	●	●	●	●	○	
				● = Recommended option	○ = Satisfactory option	● = Poor or infeasible option			

Within the first few options, the retailer takes higher risks by relying on forecasts while he reduces this risk in the latter options. The inverse holds for the manufacturer. Options 6 and 7 appear particularly risky for the manufacturer, as he owns the stock and the retailer has no inventory push for motivating him to sell. However the manufacturer gains dynamic control on stock creation and deployment through its global distribution network.

Even though options 1 and 2 are viable for popularising and varietising since there is no absolute need for product realization to order, options 3 to 7 are more adapted to a personalising offer. With options 1 and 2, the manufacturer gains the solidity of firm orders long prior the market selling season, however the overall network gets committed to

decisions based on seasonal demand forecasts taken long in advance, with no way to adjust the network inventory in season according to ongoing sales and stock positions. If it happens that the season proves to be a low selling season, the retailers will get stuck with unsold end-of-season inventory to pass to the next selling season, which may dramatically affect the sales and profitability of the manufacturer in the following year. If the selling season results in a great one, retailers will rapidly find themselves in shortages for the most popular products with no replenishment possibilities, and thus have to offer substitute products either from the manufacturer or competitors, often at discounted prices, implying losses in potential sales and profitability for the manufacturer.

For parametering and tailoring, the first three options do not make sense, except for some display items, so opening the floor for options 4 to 7 only. For tailoring, these options are shown to be only satisfactory, as dealing with independent retailers not owned by the manufacturer is much tougher when offering tailored products than dealing with company-owned retail outlets.

6.2 Final product realization network design

A personalised product could be realized by several entities in the demand and supply network. Six possible options are contrasted in table 2: a factory, a subcontractor, a fulfilment centre, a distribution centre, a retailer, and the customer. For each product personalisation offer type, the natural tendency is to finalise products nearer to the factory as the personalised product requires customer involvement earlier in the manufacturing process. When final product realization is easy and safe to perform, retailers or final customers can readily perform this process given they are provided with assembly kits and instructions. Popular products are either realized at the factory or at subcontractor and put on retailer shelves to be readily available for customers. With accessorising, the number of potential options of where to accessorise and thus complete the products is much wider. Clearly, accessorising can be achieved in a factory, especially when late processes require complex operations or if they are crucial to the value of the product. It can also be done by the customer himself in cases where accessorising is easy and safe. For slightly more complex operations, accessorising can also be achieved by retailers if they are willing to do so, and thus be trained, equipped and monitored adequately for insuring high quality standards. It can also be achieved as an extra activity in distribution centres or can be performed in specially designed fulfilment centres. Ready-to-accessorise core products are typically realized in factories. The preferred options for a given enterprise also depend heavily on the accessories chosen by the customer – whether they are necessary or extra parts to the final product.

[Table 2: Typical options for final product realization location at various personalising types

Option	Description of location	Personalisation types				
		Popularising	Varietising	Accessorising	Parametering	Tailoring
1	Factory	●	●	○	●	●
2	Subcontractor	●	○	○	○	●
3	Fulfillment centre	●	●	●	●	●
4	Distribution centre	●	○	●	●	●
5	Retailer	●	●	○	●	●
6	Customer	●	●	○	●	●
		● = Recommended option	○ = Satisfactory option	● = Poor or infeasible option		

Typically, full fledged parametering has the options of product realization being done either in the factory or in a fulfilment centre. The latter is amenable when product design permits fast and easy assembly from modules. Clearly, when some parameters are equivalent to accessories, then the options for accessorising are also possible for parametering.

From a realization standpoint, varietising lies between popularising and parametering. Its option set is thus the union of theirs. The economies of scale pull it toward the factory or a subcontractor. Yet, often in order to allow varietising, the products have been designed in a modular fashion, making them nicely amenable to be assembled in a fulfilment centre. In some cases such as when final operations are relatively simple and there is very large number potential final products, it may be satisfactory to assemble them in distribution centres as when accessorising.

6.3 Product and accessory distribution network design

Stock in the network compensates for transportation, production and supply constraints in terms of speed and capacity. Though not possible for tailoring, parametering and for some accessorising, stocking finished products in the network allows the other personalising types to provide some immediate availability for customers at retailers, to accelerate delivery speed, and to increase capability to deliver within a given time frame. Where in the network are products and accessories to be stored is a key decision. Table 3 expresses some typical options available for deployment, visibility and sharing of product and accessory stock through the distribution network. With option 1, each retailer has only access to his own stock. With options 2 and 3, retailers gain the potential for sharing their stock with other retailers. With options 4 to 7, through diverse means, the manufacturer deploys a global stock visible and available to the retailers.

Table 3: Typical available options for visibility and sharing of product and accessory stock through the network

Option	Product and accessory stock deployment, visibility and sharing through the network
1	Each retailer has only access to his own stock.
2	Retailers can contact other retailers within close proximity for availability checking and for verifying the advantages of transferring products and accessories.
3	Stock of all participating retailers is made visible network wide, permitting locate-to-order, with transfer of products and accessories between retailers made easy through predetermined protocols.
4	The manufacturer maintains a centralised stock at a retailer in each region, visible to all dealers.
5	The manufacturer maintains a factory-located stock, visible to all dealers.
6	The manufacturer maintains stock through a third-party logistic partner that assures quick availability on the territory.
7	The manufacturer deploys distribution centres throughout the territory, each with their own stock.

With popularising and varietising, finished products manufactured for stock should be near retail sites to maximise off-the-shelf availability, yet at the same time close to centralised locations in order to maximise overall coverage with fast replenishment to retail sites. With a popularising offer, one is mostly dealing with fast moving items. With a varietising offer, the overall flow of products is fast moving, but each individual product moves much slower. Therefore, inventory policies must be well adapted to each offer. The economics of storage and transportation, and the relationships with retailers, dictate the best options for each case. With accessorised products, the storable items are accessories and ready-to-be-accessorised products. Ready-to-be-accessorised core products could be managed as popular products if they are in small enough quantity, whereas accessories could be managed similar to varietised products when there is large variety of accessories.

There are strong relationships between the stock related options and the retailer-manufacturer relationship options. The most vivid example is when the manufacturer selects option 1 for its relationship with retailers, forcing them to buy and receive all their stock prior to the selling season, with no financial support from the manufacturer. This requires retailers to make harsh decisions relative to what and how much they are to buy. Stocking options 4 to 7 become irrelevant, since all stock is retailer owned. They can still share among themselves, and be supported to do so, as in options 2 and 3, yet the hard competitive relational setting put in place tends to favour stocking option 1, with limited cases of option 2. Simply illustrated, consider a retailer who has speculatively invested to store a product that happens to be a winner, will he be willing to transfer stock of this winning product to other retailers who selected not to store enough of the product? As a contrasting example, when the retailer-manufacturer relation is according to option 7 where the retailer does not buy products but rather gets a commission on each sale, the manufacturer has complete freedom as to how stock is dynamically deployed through the network.

6.4 Manufacturing and fulfilment centre design

From a manufacturing network perspective, firms need to decide how many factories and fulfilment centres they are to have, where they should be located, what they are to produce, and how they are to be organised and managed (Spring and Dalrymple 2000). There are many important compromises to analyse such as deciding between having fewer factories profiting from economies of scale, or having more smaller-sized factories minimising delivery times due to their overall proximity to markets. There are also compromises between factory costs and transportation, and warehousing and service costs. Beyond these cost issues lie strict manufacturing capability issues related to harnessing the scope complexity.

In order to illustrate the types of options available and their implications, figure 3 depicts conceptual designs options for each factory, also applicable to each assembly line and manufacturing centre or cell. Designs symbolically schematized as arrows in figure 3, increase in complexity from (1) to (9). The first of three factors used to describe the designs is the shape of the objects inside the arrows which corresponds to the product type produced by the factory or line. The shade of each object corresponds to the model type and the height reflects its production pace. Each factor is stated as being either single, switchable or mixed where the latter two indicates the ability to deal with multiple instances, respectively involving significant setups or not.

Design (1) deals with a single product, a single model of this product and a single fixed pace. This corresponds to the ultimate mass production line. Design (2) is capable of dealing with various models of a single product at a single pace, requiring setups when changing from a model to another. Design (3) is similar to design (2), except that its pace can be altered when changing from one model to the next. Design (4) is capable of producing at a single pace the various models of a single product in mix mode, in lots or in units, in continuous mode without setup when changing models. Design (5) is the first to allow multiple products to be produced; it does so at a single pace and requires setups when switching from a product to the next. Design (6) further allows multiple models for each product, with inter-model setups, and allows pace alteration when performing a changeover. Design (7) allows switching between models without setups for each of multiple products. Design (8) is highly flexible, allowing at a fixed pace, to produce whatever mix of allowed products and their models without any significant setups. Finally design (9) offers extreme flexibility allowing to smoothly change products, models and pace without setups. It should be clear that the lower numbered designs are generally easier and cheaper to realize and manage than the more flexible higher numbered designs.

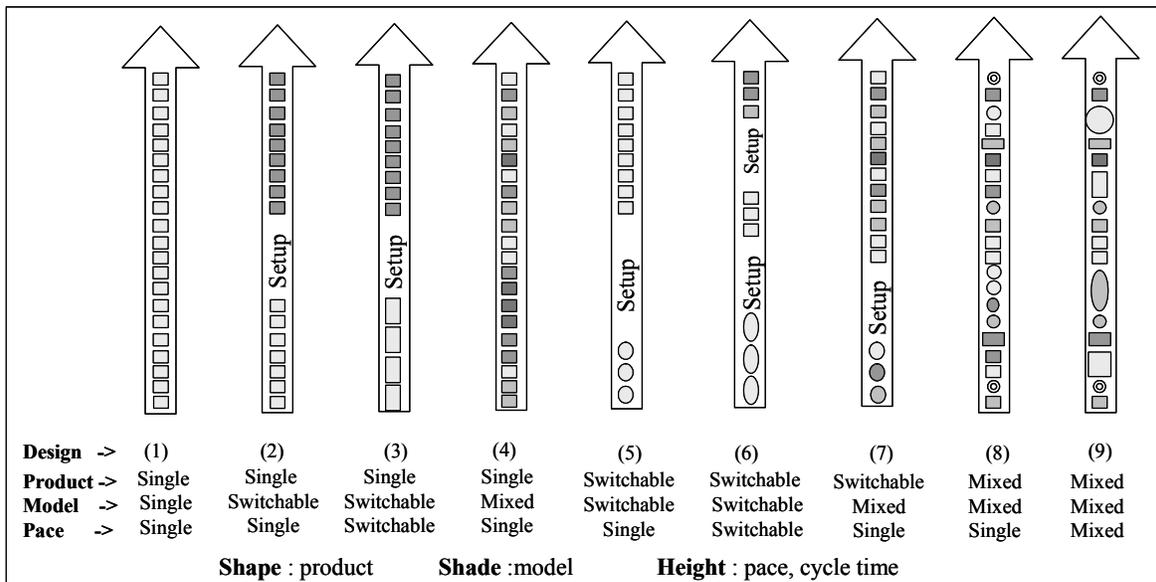


Figure 3: Manufacturing centre design scope

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With popularising, a manufacturer can opt to have factories devoted to a single product as in design (1) or to have more flexible factories as in the higher-numbered designs. This added flexibility is bounded by the limited number of products. When switching to varietising, design (1) becomes almost impossible but for a few of the top selling products. Varietising necessitates having flexible centres to offer the wide variety of products within acceptable delays. A key design decision becomes to evaluate whether each factory is to produce all products or some families within the wide mix, or only very few products - a typical compromise between fractal factories and group factories (Montreuil *et al.* 1998). For certain volatile market conditions, fractal factories are privileged since each production centre can make any product.

When accessorising, the ready-to-be-accessorised core products have the same manufacturing requirements as the popular standard products in a popularising offer, being high volume low variety. Accessorising products from the core products at a fulfilment centre or at a factory requires a design approaching the most flexible designs (7) and (8), yet this is quite achievable due to the nature of accessorising, especially when products and accessories are designed accordingly.

Parameterizing and tailoring both require the most flexible designs. With parameterizing, each ordered product can be different from any other ordered product, and this product differentiation occurs in early production stages. Tailoring requires extreme flexibility since each product is personalised so much as to become unique, from design to delivery.

Another key issue to consider is how to integrate the conceptual designs chosen for each production centre, from the workstation to the entire factory. Figure 4 illustrates multilevel design options open to manufacturers, each being more appropriate for certain personalisation levels. The larger, vertical arrows refer to a line that assembles the final product for which the centre is responsible. Components and sub assembly lines could supply this line at different parts of the line.

Manufacturing design options presented in figures 3 and 4 are highly interconnected. For instance, accessorising could benefit from options 3 in figure 4 where core products could be produced separately in sub lines and then combined in secondary lines where accessories are added to finalise the product. Popular core products could be produced by dedicated sub assembly lines such as options 1-3 in figure 3, mixed with more flexible sub assembly lines to produce the remaining core products. The key is to consider both types of design options concurrently. Even though in figure 4 all lines have been depicted in the same plant, the same logic holds for multi-plant settings.

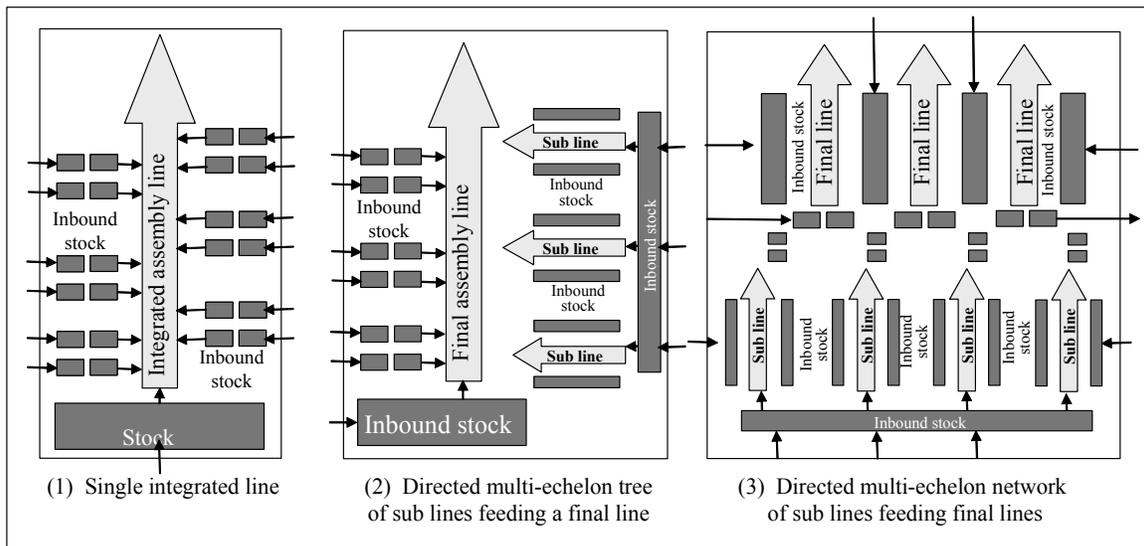


Figure 4: Multi-level assembly design options

An important element to consider when evaluating design options in figures 3 and 4, are the resource requirements to support variable delivery delays in function of the personalisation offer. Firms must verify that offers quoting short delivery delays will have sufficient capacity either through inventory or production resources. Due to the large number of products in a personalised offer, capacity will tend to take the form of extra resources rather than final product inventory.

From a capacity perspective, fast-delivery final product realization may be eased by reducing the time required to finish each product, through the earlier production and inventory of semi-finished products and finishing modules and accessories. As stated earlier, next-day assembly of a product with an average daily demand of 100 units and a standard deviation of 10 units requires a capacity to produce daily up to 130 units in order to insure a 3-sigma service level. If 10 person-hours are required to realize each product, then this implies 300 person-hours required daily above the average requirement of 1000 person-hours. This involves 38 persons at eight-hour-a-day above the average 125 requirements. In the case where finishing the product requires only one hour instead of ten, then in average roughly 13 persons are required for finishing, with an extra requirement of 4 persons to deal with daily peaks.

To minimise resource costs of the global demand and supply network, firms need to be careful where they decide to invest resources in the network to adjust response times at each node in the network so as to reliably sustain the personalised offer mix. Compromises between resource utilisation, work-in-process and response time have long been shown to be important. For example, Hopp and Spearman (1996) indicate that for standard products, resource utilisation around 75% minimises response times rather than higher utilisation rates causing high WIP and lead times. The importance of these issues are enhanced and made more complex with personalisation.

6.5 Dynamic supply network design

Defining the supply network of the manufacturer, stating which supplier is to provide which materials, components, modules or accessories, according to which relationship is of utmost importance for reliable and fast personalised manufacturing. Also important are the decisions concerning supply policies to be applied for each item and the collaboration to be established with each supplier. Ideally, all suppliers would be capable of operating according to a sequenced supply policy with minimal lead time, and every effort should be made to economically reach that level. Overseas suppliers, commodity suppliers, as well as critical suppliers for which the firm is a minor client, may all require to use less synchronised policies such as kanbans or reorder points with lot sizes, and may require major buffer stocks.

As an example of important design elements in cases where the enterprise actually exists and has a current supplier network, figure 5 proposes options for supplier development when pursuing personalised manufacturing. Development options depend on the current supplier capacity, its delivery lead time and its delivery reliability. The following options exist for each supplier: changing suppliers, seeking ways with the supplier to increase its capacity, complementing the supplier by another, helping the supplier to improve its operational control or to increase its delivery speed, and exploiting further its value by seeking ways to give it more business.

Supplier capacity	Normal delivery delay	Delivery reliability	Privileged action
Limitative	Long	Low	Change
Limitative	Long	High	Increase / complement
Limitative	Short	Low	Increase / control / complement
Limitative	Short	High	Increase / complement
High	Long	Low	Control / accelerate / change
High	Long	High	Accelerate
High	Short	Low	Control
High	Short	High	Value

Figure 5: Development options for the supplier network

Figure 5 shows that when a supplier has high capacity, short delivery delay, and high delivery reliability, then it should be valued, nurtured, better integrated into the product realization process, and awarded more business. When a supplier is found to have limitative capacity but fast and reliable delivery, then the key development options are to work collaboratively with the supplier to find ways to increase its capacity, or to look for other suppliers to complement the capacity-limited supplier.

Figure 6 proposes preferred procurement policies in function of the guaranteed delay of the supplier and the type of item supplied. For both standard and optional items, very short delays could arrive in sequence with the customer orders. As delays lengthen, the firm should keep stock buffers and should order based on forecasts.

		Item type	
		Standard	Optional
Guaranteed delay of the supplier	Very short	Sequenced to order	Sequenced to order
	Short	Pulled by order, with buffer	On forecasts of options, with buffer
	Long	On forecasts and product plans, with buffer	On forecasts of options, with buffer

Figure 6: Procurement policy options

5. Conclusion

This paper aimed to present the concept of personalised manufacturing, show the complementary options for developing a personalised offer, and then provide an overview of the interrelated enterprise wide impacts of reliably and profitably delivering such a personalised offer. A strong emphasis has been put on presenting demand and supply network design

options, as there is no unique recipe to become competitive in personalised manufacturing. The dynamic nature of the design has also been emphasised as it is an ever ongoing process.

Slightly more complex to grasp than its extreme mass production and mass customising counterparts, we perceive personalising as a robust and flexible framework to adopt when developing a strategic vision and plan for manufacturing enterprises. In this article we have only touched the tip on how to equip firms to develop complete competitive personalised offers. It opens a wealth of potential further conceptual, instrumental and empirical research.

From a conceptual research perspective, our efforts to provide for characterizing personalizing offers, for defining design options and their relationships, and so on, have been exploratory in nature. There is a huge need for a comprehensive conceptual framework which would help to represent and understand demand and supply network design in a personalizing context, and help to harness the complexities so as to enable designers to conceive innovative networks enabling the enterprises to thrive through their mastering of personalized manufacturing.

From an instrumental research perspective, methodologies and tools are needed to design each element in the demand and supply network, as well the overall network itself, so that it can support the desired personalising offers. There is a significant void of highly adapted analytical methods, optimization models and heuristics, and simulation modelling frameworks to support the design, planning and management of personalizing-enabled demand and supply networks. Within the personalising context, interactive software tools should be develop to enable designers to model, propose and evaluate designs options in a holistic way, and to operationally manage the designed network in face of dynamic challenges.

From an empirical research perspective on personalized manufacturing, there remains much to be learned about the challenges, stakes, options and relationships. Case studies of leading manufacturers, action research involved with strategic and innovative business initiatives in personalized manufacturing, and questionnaire based investigations may allow to uncover important insights and practices. Simulation based empirical studies may also allow to explore the intricacies of the complex stochastic dynamic interrelationships between design options and network configurations. This would require high fidelity simulations which adequately model consumer behaviour when faced with personalized offers, as well as the inner working of all actors in the demand and supply network.

Acknowledgments

This research has been supported by the Natural Science and Engineering Research Council of Canada under Grant No. 44138, by *Le Fonds Québécois de Recherche sur la Nature et les Technologies* under grant No. 98ER2094 and by the Canada Research Chair Program under grant No. 95-01-173.

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