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Mass Customisation: issues of application for the food industry

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Abstract

The strategy of mass customisation is being increasingly adopted as companies seek to exploit market trends for greater product variety and individualisation. The implications of changing to mass customisation practice are considerable, where traditional contradictions of high volume and extensive product variety have to be reconciled. The literature discusses the need for an integrated approach to mass customisation across all business functions if micro-segmentation of markets is to be profitably pursued, and the current paper investigates extending the paradigm of mass customisation into the hitherto poorly represented sector of food processing. Product design and manufacturing system design for mass customisation are reviewed and contrasted with good practice in more traditional mass customisation industries. Via a case study based on yoghurt production this paper particularly assesses manufacturing activity, describing issues specific to a typical food business which is considering reconfiguring itself into a mass customisation operation.

Keywords: Food industry; mass customisation; product design and manufacturing system design

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1 Introduction

Much has been written on mass customisation (MC) since the term was first coined (Davis, 1987). Before this the need for change had become increasingly evident as the limitations of traditional high volume manufacturing practice became exposed. The primary problem was neither product pricing nor product quality, for long considered the two bedrocks of then current production models, but instead an inability to react to other competitive criteria additionally contributing to market success. As these other criteria began to gain prominence – as customers began to appreciate that they too could be satisfied – manufacturers faced an entirely new competitive landscape.

With new manufacturing and wider operational practices being identified, there was a stark awakening to the inadequacies of the traditional mass-manufacturing paradigm (Schonberger, 1986). Over a comparatively short period the previously limited criteria on which competition was based became simultaneously joined in important additional areas (Williams, 1996). In an era of global competition issues of product differentiation and responsive delivery quickly rose in importance. At the same time product quality standards continued to rise, sometimes dramatically, and required product costs fell. Development lead times for new products were slashed. The length of time that a given product was available for sale typically diminished (Franza and Gaimon, 1998). Expanded product choice was introduced and customer expectations were significantly and permanently altered. Jones and Kouyoumdjiam (1993) showed that there had arisen a ‘fundamental shift’ in consumer behaviour. Traditional product development methods and highly inflexible process-led volume manufacturing systems were unable to deliver adequate performance in these new competitive terms (Shimokawa, 1994).

An array of new manufacturing techniques and operational practice issues were gradually embraced, initially under the labels of *just-in-time manufacturing* (Taiichi 1988) and, later, variously, *agile manufacturing* (Dugary *et al*., 1997), *lean manufacture* (Womack *et al*., 1990) and MC (Jiao and Tseng, 1999). Improvement was sought in areas as diverse as worker participation and the changed assignment of roles and responsibilities (Murakami, 1995). From a more direct production standpoint waste in areas such as inventory, manpower and rejected products or material was attacked. Far superior cross-functional communication was sought; (Factory Logic white paper) and the use of *kaizen* improvement teams propagated (Imai, 1985). Many other options for revised practices were expounded (Bicheno, 2003). Similarly, and perhaps inevitably, the categorisation of these opportunities as *lean* or *agile* or *mass customisation* techniques has been debated (Ansari and Mela 2003).

MC represents the adoption of selected refined work practices within revised business structures, leading to a highly adaptable, customer-centric, value creating enterprise (Tseng and Piller, 2003). Techniques identified above may be variously adopted, alongside other new techniques which are generally regarded as being specific to the MC model (Pine, 1993). Indeed, some further techniques might yet be identified. The need is for their matched and integrated selection and implementation, where emphasis is on profitable response to an array of customer demands, most notably in terms of the manufacture of differentiated products. Contrast can be made to the previously widely exploited MC paradigms, for example those developed by Henry Ford, to whom the famous alleged comment 'any colour so long as its black' is widely attributed (Abernathy, 1978). That MC might be a key instrument for business competitiveness in many of today's highly personalised markets does not mean that implementation is straightforward. Two issues stand out:

- There is no 'good-for-all' approach recognised to build new structures that prioritise equally the diverse product demands of every single customer (Greenwood and Hinings, 1996). Implementation has to be tailored dependent on the specific market and business circumstances of the company seeking a MC capability.
- For MC to be successful changed working practices are required across all a business's operations, from supply chain logistics through to up-to-the-minute market understanding and feedback (Corranado *et al.,* 2004).

This paper assesses potential changes to a food organisation's manufacturing function. Emphasising once again a previous point that implementation is dependent on market circumstances and the products under manufacture. For the food industry these market and product situations can be notably different from what has been experienced to date within more traditional industries such as fashion-ware (Christopher *et al.*, 2004), into which MC implementation has been much more comprehensively attempted. Some major differences are detailed.

2 Mass customisation: reviewing a new rationale for product and manufacturing system design in non-food industries

For manufacturing systems in the past there has frequently been an ideal, as far as has been deemed realistic, of a limited range of products (Pine, 1993). For example at an extreme level one can cite Ford's single-specification Model T, to which whole factories were exclusively dedicated. Reasons for this can be readily identified. Product cost and product quality were both perceived to benefit, not least through rigid task demarcation and precision-made components which could be incorporated into larger assemblies without the need for any skilled adaptation (Womack *et al.*, 1990). Excepting breakdown and maintenance downtime, stable uninterrupted line output was possible, where there was no significant losses due to changeover (McIntosh *et al.*, 2001). When changeovers were necessary the goal of low product cost was also apparently assisted by minimising the frequency at which changeovers did occur (Coates, 1974). At the same time that line uptime was being maximised, likely post-changeover problems of unstable product quality and deficient output rate (Garvin, 1988) were simultaneously avoided. Other potentially highly significant production advantages of a limited product range could also be achieved. Significantly, potential difficulties of entirely new product innovation and development, or at least significant differentiation, could also be substantially averted.

2.1 *Pursuing a highly adaptive manufacturing organisation*

Significant refinements to historic mind-sets and practices are required before a successful MC enterprise can emerge from a more traditionally structured manufacturing set up and before the paradigm of mass manufacture can be broken.

The key driver for manufacturing system revision is the acknowledgement of a far wider and deeper customer influence on internal factory operations (Tseng and Piller, 2003) that is, instigating responsiveness throughout to highly individualised customer demands. These demands have to be able to be met without significant penalty to the manufacturer. They impact upon each of: supply chain relationships and activity; internal manufacturing system design and operation; product design and assembly.

2.2 *Cross-domain interaction*

How relationships both within an organisation and with external partners are conducted differs depending upon the manufacturing paradigm the organisation adopts (Pine, 1993; Womack *et al*., 1990). The driving influence on the organisation also differs depending on paradigm, being for example either manufacturing process-led or highly customer-focussed. Thus, exactly how a MC company is able to benefit from a primary focus on its customers is dependent on how customer demand information is permitted to propagate through the company. Optimally, this needs to occur both swiftly and in good detail. Moreover, customer demand information should be used to positively influence product and manufacturing system design, understanding the response, cost, differentiation and other criteria that are required.

2.3 *Customer relationship management*

The topic of customer information, including how it is sourced and managed, is important in that it is what drives and inspires manufacturing MC; it is what ‘pulls’ manufacturing activity and, motivates the design of MC-compatible products and process hardware. The point is a simple one: that correct market information has to be available to manufacturing operations (and the design thereof) and has to be correctly used. This step of gaining correct market information, often coupled with seeking to gain lasting supplier-customer relationships, has received considerable attention in the literature (Gentle, 2002; Dyché, 2001). Customer relationship management (CRM) aims to build customer loyalty through relationship-building strategies such as partnerships, branding, and good customer service, and shows how companies can reinvent the way they market to customers and translate customer data into customer interactions. Further, CRM provides mechanisms to define the right products for the customer – the ones which the company then has to make (Mello, 2003). Information technology (IT) can be a prevalent enabling tool (Lakhnech and

Yovine, 2004), but its use alone is not sufficient, as in itself IT is nothing more than technical infrastructure, aspiring to assist a company to effectively manage customer data and build lasting relationships with customers. Like all technical infrastructure it is a tool available for misuse – including, as damagingly, misinformed use.

2.4 ***MC primary focus on customers - not products and not manufacturing***

As noted, CRM is seen an essential building block for the customer centric enterprise, conducting information to the business wherein the customer inspires product (and response) requirements. The customer, in doing so, defines where value lies; where competitive criteria lie. Customers define what is required (what product features; what cost; what delivery) and it is incumbent on the manufacturing organisation to structure appropriate responses. The better the response capability, assuming there is no penalty to the organisation, the greater the likely competitive strength of the organisation.

2.5 ***Mechanical product and manufacturing system design***

The MC organisation's goal is clear: to provide goods and services that are customised and assembled on demand for each individual customer. Its ultimate goal is to meet individual customer's requirements exactly without a significant increase in production or distribution cost (MacCarthy *et al.*, 2003). These goals are necessarily integrated within CRM strategies. Equally they require to be integrated within manufacturing system design and operation and, similarly, product design and development. An MC company's actions may be enabled by technology – be this IT systems or highly responsive, flexible manufacturing hardware – but equally it is wholly dependent on appropriate and matched business practices.

Except for being touched upon here in review, best business practices that are wholly separate to technology (that is, separate to hardware that enables MC) are not within the scope of this paper. Thus for example managers can use selected techniques to determine customer needs and their value-based requirements, and then choose which requirements to satisfy in order to distinguish their products from the competition. This is not assessed further. Of interest here however, as part of CRM, is a company understanding of market-driven product definition and, more particularly, the techniques which allow these products to be realised – all in a MC context of rapid development and responsive delivery. It is hardware, products and directly associated practices which this paper will now address. This is here considered to be the physical nuts and bolts of MC; that is, technical issues associated with manufacturing systems and product design.

For *lean manufacturing*, appropriate engineering and operational literature in respect of product and/or manufacturing system design certainly does exist, as for example presented by Hobbs (2003). In contrast it is interesting to note that even for more conventional MC industries (footwear perhaps) such considerations were until even fairly recently incompletely resolved, where Tseng *et al*. (1996) state that:

"*… the engineering approach to produce an increasing variety of customers' requirements without a corresponding increase in cost has not been well developed*."

Tseng and Piller (2003) subsequently revise their stand slightly, observing that MC is still evolving and still gaining prominence. They add that practical implementation has only recently started to come about, grounded on much more extensive preceding conceptual work. Recently more substantial work on MC product design and in particular development (Roach *et al*., 2005) is starting to be published. The extent to which manufacturing capability has indeed evolved might be seen for example by an in-depth study of the manufacture of automotive components by the Japanese firm Denso Co. Ltd. – to highly specified demand criteria by a major customer Toyota (Whitney, 2004). The study in which no fewer than 288 different kinds of meters can be made with almost no changeover time, delay or cost penalty amply identifies many of the techniques of MC.

3 Some key tools and techniques of mass customisation

Comments by Tseng (1996), McCarthy (2004) and others that MC's manufacturing system and product design rules have not yet fully matured are probably true. Indeed, if they were not there would be little need to characterise desirable practice in food industry implementation. Nevertheless, as is now presented, some of the specific tools and techniques of MC can be readily identified.

3.1 Modularity

One well understood technique is *modularity* in product design (Kratochvil and Carson, 2005). This has been adopted for example by Densai, being described by Whitney (2004) as the “combinatoric method of achieving model-mix production”.

Secondly, the literature often cites a *decoupling point* in MC. Winkner and Rudberg (2005) write that “a customer order decoupling point separates decisions made under uncertainty concerning customer demand”. It represents the point at which a company’s activities switch from speculation to commitment. The better the understanding of customer demands – the more customer-centric the organisation is, and the better its customer relationship management – the lower the degree of speculation it has to endure. Modularity can not only increase the variety of the products but also delivery time can be reduced and economy of scope can be achieved (Duray, 2002). Modularity refers to division of products into sub-assemblies and components and this facilitate the increase of components thus more variety of products can be offered. Modularity allows the calibration of the level of customisation of the entire product with respect to each product feature/ function (Kumar, 2004).

3.2 Delayed differentiation

A very similar technique which can be employed is *delayed differentiation* (Aviv and Federgruen, 2000). Delayed differentiation refers to preparedness for customer orders and their switching from being speculative to commitment. It means leaving product differentiating activity as late in the manufacturing process as possible. It is a tactic which enables pseudo-responsiveness of the manufacturing system in the eyes of the customer by relying on responsiveness only of later manufacturing operations. In truly responsive organisations, that is an organisation whose response capability is present throughout delayed differentiation is unnecessary. Delayed differentiation is another term for the much more usually applied term of *postponement* (Burns and Backhouse, 2004), meaning postponement of product differentiating activity.

The concept of postponement can be divided into three generic types, (Bowersox and Closs 1996)

- *Form postponement:* involves delaying some certain activities of the manufacturing process until the customer places their order. It is not suitable for products which require short lead time because extra time is necessary for the final processing. Form postponement which can be divided into four main streams (Zinn and Bowercox, 1988): labelling postponement, packaging postponement, assembly postponement and manufacturing postponement

- *Time postponement:* refers to delaying the movement of products till the customer's order is received
- *Place postponement:* means that positioning of inventories upstream in centralized manufacturing or distribution operation, to postpone the forward or downstream movement of products

In addition to the above, *logistic postponement* (Bowersox and Closs, 1996) refers to a combination of time and place postponement and can be applied to the structure in which goods are stored at a limited number of centralized locations and products are dispatched after the customer orders are received.

4 So, what is different about the food industry ?

Although some research has been published about manufacturing system design and product design to cope with MC (Matthews *et al.,* 2006; Fisher *et al.,* 2005), little has been published to date on MC implementation for the food industry (Boland, 2006). More exactly, little has been written in respect to significant guidance, or even identification of both design opportunities and constraints. Although some wider discussion of food industry supply chain, marketing and customer relationships has been published (Dole, 1999). The lack of food industry uptake may be a reflection that the MC paradigm is still maturing. More critically, however, poor levels of MC uptake may be because of important differences in either food manufacturing processes or the industry's products when contrasted with more usual mechanical product industries (automobiles; vacuum cleaners; footwear). One major factor in a general lack of pursuit of MC might be in the differences to be faced between food products and more usual mechanical products. These differences are now considered.

In the following section contrast is drawn between food industry and conventional "mechanical" industry MC, in which the product comprises mechanical assemblies and/or the use of mechanical assembly techniques. The information presented here has been drawn from collaborations between 16 UK food processing companies and the authors over the last four years.

The research process took the form of multiple visits to each company's site where informal interviews were performed with the company's production related staff and audits of the products and their related process were conducted. The emphasis of the research was from three perspectives:

- operational characteristic of supply chain management (distribution, consumption of materials etc).
- product characteristic (constituents, manufacture process etc).
- process characteristic (construction, flow of product etc).

The research generated in these collaborations has identified 13 key distinguishing factors:

1. *Chemical change:* For many food processes the products under manufacture experience chemical change as a result of their being mixed or otherwise combined. Chemical change always occurs during cooking and fermentation (Wedzicha and Roberts, 2007)

2. *Food product decay:* Many, if not all, food products additionally experience chemical change through decay. Decay can also include textural change to the food product, where even though there may be no toxins present the product becomes unpleasant to eat. Packaging and controlled processing/storage conditions in the factory can slow the decay process. For other food products, drying or other decay prevention strategies may be adopted.

3. *Maturing cycles/delay:* Some food products need to undergo a maturing cycle. This is the case with cheese; stilton might be expected to be stored (in carefully controlled conditions) for between three to six months prior to sale

from the factory. For a few selected products, for example whisky, the storage period may be considerably longer.

4. *Mixing products and assembling products:* In its simplest form, purely mixing ingredients can be seen as different to assembling products. An implication is that mixable ingredients are either in finely divided or liquid form.(Mullinuex and Simmons, 2008). Equally, there are no assembly precedent relationships in thorough, pure mixing, unless chemical change considerations apply. Potentially, therefore, mixing is a much easier automated activity than conventional assembly. The mixing of ingredients potentially confers many advantages in terms of applying postponement strategies for MC.

5. *Recycling/recovery:* Once the food production process has been set underway, taking into account the previous points, the original ingredients cannot usually be recovered (although, occasionally, valuable alternative by-products may be obtained).

6. *Cleaning/purging:* More than for most other industries, and especially considering cross contamination (food allergies) and hygiene, food processes are liable to be subject to stringent cleaning requirements. There is no doubt that cleaning in any case represents a major problem, even in many conventional product changeovers (McIntosh *et al*., 2001). Although specialist food process cleaning techniques can be of assistance (Quarini, 2002), experience in different factories which manufacturing or packaging food products indicates the extent of the general cleaning problem. In previous research at a frozen vegetable packing company, effort devoted to clean down process equipment varied considerably dependent on which vegetables were being switched between. Major periodic equipment cleans were also undertaken. During product changeover at this factory clean down could represent up to 53% of per-changeover man-hour losses. (McIntosh *et al*., 2001).

7. *Packaging:* For some food products the product itself has to be packaged within special environments, for example some bacon and potato snacks. Packing very frequently has to occur in microbiologically clean environments. Murakami (1995). In almost every case packaging can be distinguished from the food product that it encloses in the sense that the packaging operation is normally entirely mechanical.

8. *Simplifying product design for MC:* The previously highlighted Densai case study (Whitney, 2004) demonstrates the potential of simplifying the design of the product for the very specific purpose of facilitating MC. That the same may be possible for a food product is debatable. For many products the list of ingredients is extensive and cannot easily be diminished. Largely inflexible assembly precedents (the combining of the separate ingredients and other production processes such as cooking) may apply. Also, taste and texture are always highly important and even small changes are likely to be discerned by the final consumer.

9. *Access:* Access to the place at which value is being added to a product (where physical change is occurring) may be restricted. For example, when heat is an agent of change it is unlikely that access will be available. Moreover, many other food industry’s process events occur in vessels or pipes within in flow lines, it may often be indeterminate when such events actually occur.

10. *Delicate foodstuffs (handling):* Food products are generally more delicate than many ‘mechanical’ products. Special handling considerations may in themselves limit MC implementation. Special handling can apply both during processing and distribution (Matthews *et al.,* 2008).

11. *Legal provisions (sell by date and other):* The complexity of specific legal provisions in relation to food may inhibit MC implementation, such as identified in the food safety act. (Food safety act, 1990)

12. *Economies of scale:* For some industries, for example steel and some chemical processing industries, economies of scale are disproportionately influential on final product cost. In these particular circumstances selected MC tactics which are reliant upon disrupting true uninterrupted high volume production may be much more difficult to apply. The same inhibitions may also apply to specific food processes – where, by virtue of an economically constrained manufacturing process, late-postponement options are difficult to enact.

13. *Distribution:* Many foodstuffs have special distribution requirements. For example fruit and vegetables need to be processed as quickly as possible once harvested or, later in the overall manufacture and distribution chain, require to be at their retail destination as quickly as possible.

With these 13 factors in mind, the following sections identify the approaches firstly for adoption of MC to existing manufacturing setups and secondly for manufacturers design new production setups.

5. Existing production setups

The emphasis of this section is to present the suitability of MC to today's food industry. Section 4 of this paper discussed that food products bear potentially highly significant differences to what the current author's term as mechanical products. Thus cooked pasties are demonstrably different to, say, shopping trolleys. In consequence they are significantly different in terms of applicable MC techniques that their manufacture, and even distribution, might employ. Equally, condiment sauces and yoghurt readily fall into such a classification as a non-mechanical product. When investigating the capability of existing equipment to handle a variant product invoked by the company's policy of mass customisation, the engineers need to look at ways to develop the flexibility of the existing design, as figure 1 depicts. Here the inherent capability of the system is expanded to encompass the variant product. Approaches to support this are discussed in section 5.

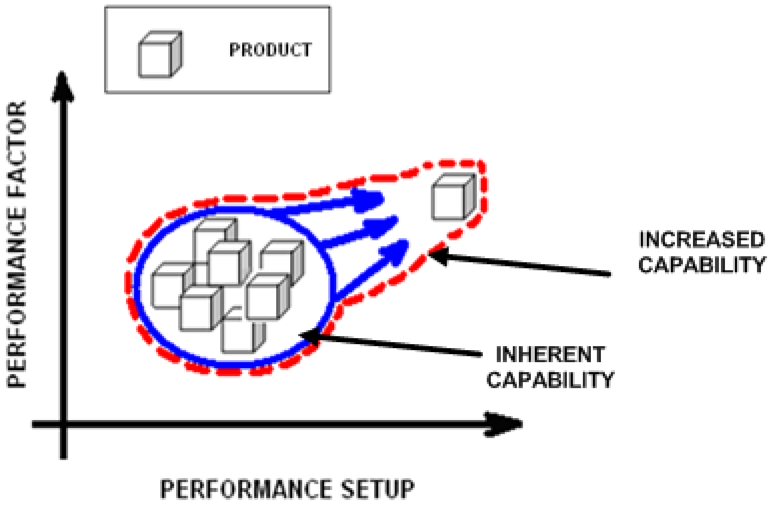

Figure 1 Process flexibility

5.1 MC techniques applied to existing setups

The authors particularly assess the scope for modularity and postponement tactics, considering as well that both product and manufacturing system redesign might beneficially be employed. The food processes the authors have researched leave much more restricted scope for modularity to be introduced than is apparent in many mechanical product manufacturing environments. Similarly, scope for product or process redesign to enhance modularisation would appear more limited. In mechanical product MC implementation, as has been illustrated previously in this paper for panel meters, fully integrated product and process redesign can yield highly significant results. Certainly different factors potentially need to be taken into account for food and once again, for the food products and processes the authors have studied, significant impact redesign opportunities appear more difficult to conceive. A summary of these approaches when applied to existing setups of two yoghurt productions sites and a potato crisp manufacturer can be seen in table 1.

Strategy	YOGHURT PRODUCTION Reason		POTATO CRISP PRODUCTION Reason	
Modularisation	**P**	It is possible to make the standard yoghurt for all yoghurt products including yoghurt with and without fruits, yoghurt drinks and other products.	**Y**	Discussing with a broad view, it can be said that it has been applied already because uniform crisp are made and then flavoured, if it can be defined as modularisation. However it is only possible to differentiate the flavour but not the thickness or texture.
Manufacturing postponement	**N**	Because the yoghurt production is a flow from the arrival of the milk, it is not sensible to stop the flow in the middle of production stage	**P**	If it is possible to store the sliced potato by freezing or somehow, normal and lighter (lower fat) crisp can be offered, however, considering shorter life of slices compared to deep fried crisp, it is very unlikely.
Assembly postponement	**P**	Linking with modularisation, it is possible to delay the addition or altering of yoghurt, however there is very little time available to do this (maximum few days). Consequently the shelf life of the yoghurt reduces.	**P**	The customisation of the flavouring and additives can be customised according to the customer order; it may have been applied already. However, this is provided that flavour is not necessary to be added right after deep fried and also not required to be packed as soon as possible. If those two criteria is must factor, then it is unlikely.
Packaging postponement	**Y**	Packaging can be postponed till the customer orders are received, to a big carton, small carton or multiple packs. Again the time is limited and shelf life can be reduced.	**P**	It also may have been applied already, to a bigger pack and smaller pack as well as multiple packs. However same discussion as assembly postponement, if the crisp is required to be packed immediately after it's cooled then, it can be difficult.
Labelling postponement	**P**	This option is dependant on the location of the factory, if it is UK, probably not. Because it is not sensible to ship the yoghurt over the sea to export. On the other hand, it is possible in Europe, as they can be distributed to each country by rail easily. However the regulation on each county need to be considered.	**P**	The packaging has been already printed before crisp is packed and it may be hard to label on the already packed crisp. Some packing films offer the potential for printing in the packaging process.
Time postponement	**N**	The yoghurt have been manufactured already and there is limited shelf life, it is not sensible to store the finished yoghurt until the customer order.	**Y**	With the products relatively long shelf life, it is possible.
Place postponement	**N**	As with time postponement, it is not sensible to store the finished yoghurt until the customer order.	**Y**	As with time postponement, because of its relatively long shelf life, it is possible.

P= Possibility of application, Y= Definite potential for application, N= No potential for application

As well as restricted scope to employ modularity, there is also an indication that postponement opportunities for foodstuffs might generally be more limited. A consequence is that food organisations have to err much more towards speculation (Pagh and Cooper, 1998) rather than allow themselves to be driven by precise customer demand information – which they cannot easily respond to. The flexibility of the manufacturing process as a whole, reflected as a ready ability to customise products without penalty, is restricted. Yang (2003) discusses that postponement can be related to different descriptors or components of the overall product provision process (above) yet separate food research into all such potential opportunities is limited.

As has been described, postponement can occur at any stage of the overall manufacturing and supply process. Thus final product differentiation can even be undertaken by the customer upon purchase. An example might be the mixing of house paint to a customer's instruction at a retail home improvement warehouse, which typically will occur with the customer being present. Relating to food, and with some similarity, the combining of previously separated flavour and base yoghurt components immediately prior to consumption is done by the customer in products for example offered by the Muller yoghurt company (fruit and plain yoghurt components are supplied in separate sections of a single sealed tray). In one sense this represents an ultimate manifestation of postponement – but only in terms of these very specific and pre-determined modular elements. As with the example of paint, the final product results from mixing rather than assembly, and arises as well from the customers' ability to mix at home. The Muller yoghurt example of postponement also needs to be analysed in terms of what it is not. It is not conferring upon the customer any real choice as to the composition of separate and distinct yoghurt products – for example those which are of a more creamy texture, comprise alternative flavours, or have differing fat contents. Instead it only presents a significantly constrained postponement option, providing to the customer only marginal real benefit (excluding perceived benefit) arising from the possibility to vary mix concentrations. It does however offer potentially significant manufacturing advantages to the brand owner.

5.2 Supporting approaches

In order to determine the requirements for the equipment and/or altered processes it is necessary to first understand the limitations of the existing equipment, the rules necessary for successful processing, and the variation in materials and/or product that need to be accommodated. These three elements are central to realising redesigned or new equipment that overcomes the limitations of existing equipment and ultimately improve performance (quality, efficiency and/or flexibility and capability). To address the need to analysis existing equipment capability a number of supportive approaches are available. Matthews *et al* (2006; 2007) employed a constraint-based technique to assess the ability of production equipment to manufacture variants products. In Tolio and Valente (2007) a stochastic approach is considered for machining operation systems for the manufacture of part families, this research was directed at the manufacturing systems and operation level. Fisher *et al. (*2005) presents the concept of modelling the food products with the consideration for late customization. Other research has concentrated on *planning of product families* and *platform development* (Haung *et al.*, 2005). These are aimed at producing the variety in products efficiently and effectively, with the main emphasis being on financial benefits (Seepersad *et al*, 2005). And to address any short term redesigns and modifications there are a number of redesign methodologies: Machine system focused Hicks *et al.*, (2001; 2004) function based Hashim et al (1994), and one Specific for small to medium sized enterprises (Bradford and Childe, 2002). As noted by Yang and Burns (2003) and in the technology briefing (Matthews *et al.*, 2008) it is the product factors that constrain the ability of any system to be able to successfully produce. When considering the equipment it has been identified in section 2, that two constraining factors potentially restrict the adoption of MC techniques. Namely, *assess* and *cleaning/ purging*. It is highly unlikely that retrospective application of MC and the employing of the supportive techniques identified above will be sufficient to totally aid the approach, this would have to be addressed in the design of new equipment.

6. New production setup

The emphasis of this section is to present what new developments (requirements specification) should be made for the food industry to apply MC. The core of existing knowledge (academic and industrial) is biased towards the design of product and variants to suit customer demands.

6.1 Product considerations

As previously noted in section 4.2, food product distinguishing factors are the constraints on successful implementation of MC. Factors such as: chemical change, food legal requirements and maturing cycles are factors that cannot be changed; they are intrinsic of the product. But mixing/ assembly and simplification of product can be addressed for new designs. This section considers some previous work that can aid this approach. Product variety is often described using so called product parameters or product characteristics. Erens (1996) defines a product parameter as a “variable quantity or quality that makes a product family specific. Parameters are used to derive a product variant from a product family, but also to make a product feature specific for its application.” Research into product platform design is seeking to address issues of shorter time-to market and ever decreasing product life-cycles Hermann *et al.*, (2004). Such platforms are architectural concepts, comprising interface definitions and key components, addressing a market and being a base for deriving different product families. Research has been developing platforms of stable elements which are shared between products or even product families (Meyer and Utterback,1993).

Design for Variety (DFV) aims to reduce time-to market by addressing generational product variation. Martin *et al. (2002)* developed indices for generational variance to help designers reduce development time and cost of future evolutionary product design. Gu *et al.* (2001) propose a methodology called Adaptable Design which seeks to increase product functionality by increasing the product’s adaptability. Product architecture is critical for a product’s adaptability. Adaptable Design is seeking improvement by segregating the product architecture using platforms, modules and adaptable interfaces. The above approaches all seek to reduce or isolate the impact of product variety caused by the ever increasing demands for customisation. Tseng and Jiao (1996) made this the core of their Design for Mass Customisation (DFMC) approach. It is not incompressible that the above approaches could not be extended to manufacturing equipment.

6.2 Process considerations

If the product leans itself to MC, then when designing new equipment you are not bounded by existing design and manufacturing constrains. It was identified in section 4 that the following issues were constraining factors for MC implementation: *assess* and *cleaning/ purging*. These can be addressed in the design specification; also greater consideration can be given to the *handling of delicate food stuffs.* Also, when discussing MC techniques it can be easy to lose sight of one of the most fundamental of all, which should be available throughout MC activity, namely *responsiveness* (Aviv and Federgruen, 2000). *Changeover improvement* is a key tool to enact responsiveness in time-based manufacturing (Reik *et al.,* 2006). Other potentially important techniques include *jigless manufacture* (Whitney, 2004) and *in-house development of manufacturing technology* (Hirotec, 2008). So for new production setups, it allows the equipment manufacturers to employ different strategies to the production process. Not only can the systems have increased flexibility as in figure 1, but design strategies can be employed where the performance envelope can be shifted to encompass the variant product, changing its configuration. Although, this will not give the flexibility to produce the existing products, as the inherent capability will be moved from x on figure 2b to y, or the system can be designed so that change parts may be employed to reconfigure the design, and hence allows the design envelope encompass the new product. This moves from x on figure 2 to y, but leaving the option to move back to x. (Matthews *et al.,* 2006). In assessing the potential for such designs to process the MC product, the techniques identified in section 5.2 are also applicable.

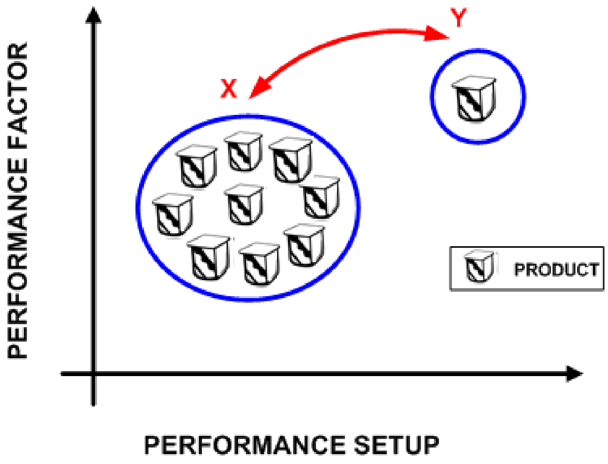

Figure 2 Addition process flexibility

A prominent process improvement objective when considering MC therefore becomes a reduction in changeover times, with application of Shingo's SMED (Single Minute exchange of Die) methodology (Shingo, 1985) having now become so well established that it can almost be regarded as the only applicable route to changeover improvement. Crucially SMED is intended to be retrospectively applied, a notable gap however is apparent in the OEM (Original Equipment manufacturer) design of changeover-proficient machinery, and in tools that OEM personnel might employ to serve this aim. But it offers the designer of new food equipment to consider changeover at the design configuration stage. Approaches by Reik *et al.,* (2006) and McIntosh *et al.,* 2001, fill this gap, and offer greater potential for the designer.

The 9-step design for changeover (DFC) approach by Riek *et al.,* 2006 provides guidance for designers from the modelling and evaluation of a changeover process through to identifying improvement possibilities and developing improvement concepts. The basic approach is seen in the flowchart figure 3.

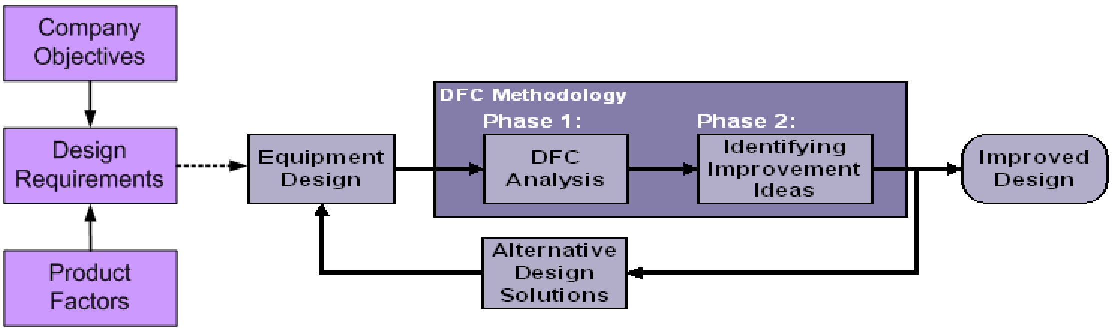

Figure 3 DFC flowchart

Here the objectives of the design have to be decided by the manufacturing company (common to design activity Pahl and Bietz, 1996), the product factors will be those identified in section 4.2. The process is iterative and potential solutions to aid MC are investigated.

7 Conclusions

This review has contrasted the theory and practice of what has been termed conventional mechanical product MC with a theoretical appraisal of MC implementation in the food industry, for which much more limited research is available. Aspiring to MC, and with a wide range of manufacturing process improvement techniques already being known, a decision has to be taken as to which techniques should be adopted; and whether indeed they can be adopted in food manufacturing circumstances. The purpose of this paper has been to seek to determine whether these techniques are of restricted applicability in a typical food industry situation: which techniques to adopt? Which together brings about system reconfiguration for MC, also has to be decided with full understanding of the system’s target capability. Of these potential techniques this paper has assessed particularly for modularisation and postponement.

7.1 MC techniques

The literature already notes that the application of modularisation and postponement techniques is dependent on specific product and process situations and that no ‘good-for-all’ prescriptive implementation solution exists. In order to determine the requirements for the equipment and/or altered processes it is necessary to first understand the limitations of the existing equipment, the rules necessary for successful processing, and the variation in materials and/or product that need to be accommodated. These three elements are central to realising redesigned or new equipment that overcomes the limitations of existing equipment and ultimately improve performance (quality, efficiency and/or flexibility and capability)

7.2 Product and MC take-up

Limited food industry research to date confirms the papers this papers findings that, techniques can often be more readily adopted for food packaging (rather than the foodstuff itself) which, as a mechanical product, is more amenable to MC. This paper identifies the 13 key factors which differentiate food stuffs from conventional mechanical products. These are the factors which effect the successful implementation of MC techniques to existing and potential equipment/ setups, namely: access and cleaning/ purging. The paper has also identified potential techniques to analysis existing and potential equipment for variant products and has identified design for changeover (DFC) as a dominate approach that should be employed in the design of new equipment that will have to cope with MC. This paper concludes that:

- The differences between food and mechanical products are that mixing rather than product assembly takes place and that chemical reactions very frequently occur, which are time dependant and irreversible. These along with other significant factors like product decay, cleaning and legal requirements, limit the extent of potential MC implementation.

- And that directed design for modularity, which has demonstrably significantly assisted MC implementation elsewhere, is likely to be of limited value in a food context. Not least of the reasons for this finding is that a majority of possible structural and ingredient changes to a food product are likely to be unacceptable by the customer and especially so if food product simplification is contemplated. For mechanical products functionality has to be maintained under modular redesign. For food products the far more sensitive criteria of taste and texture require to remain substantially unchanged.

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References

1. Abernathy, W. J. The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry. Johns Hopkins University Press. 1978, ISBN: 0801820812.
2. Anon (1990) Food Safety Act1990, Chapter 16, HMSO, London.

3. Ansari, A and Mela, C. F. (2003) E-Customization. Journal of Marketing Research **40**(2), 131–45.
4. Aviv, Y and Federgruen, A. (2001) Design for Postponement: A Comprehensive Characterization of its Benefits under Unknown Demand Distributions. Operations Research **49** (4), 578-598.
5. Bicheno, J. (2003) The New Lean Toolbox - Towards Fast, Flexible Flow, PICSIE Books, Buckingham.
6. Bille G.P. and Keya, L.E (2002) Comparison of some properties of vat heated and dry skin milk powder fortified set yoghurts. The J. of Food Technology in Africa. **7**, 21-23
7. Boland M, 2006, Perspective: mass customisation of food, Journal of the Science of Food and Agriculture, **86**, 7-9.
8. Bradford J., Childe S.J (2002) A non-linear redesign methodology for manufacturing systems in SMEs Computers in Industry, **49** (1), pp. 9-23.
9. Christopher, M., Lowson, C. M., and Peck, H. Creating agile supply chains in the fashion industry. International Journal of Retail and Distribution Management. 2004 **32**(8), 367-376.
10. Coates J.B (1974) Economics of multiple tool setting in presswork, Sheet Metal Industries, , **51**(2), 73-76.
11. Coronado A.E., Lyons A.C., Kehoe D.F and Coleman J(2004) Enabling mass customisation: extending build-to-order concepts to supply chains. Production Planning and Control, **15**(4), 398-411.
12. Davis, S (1987) Future Perfect, Reading: Addison-Wesley, 1987.
13. Dyche, J (2001) The CRM Handbook: A Business Guide to Customer Relationship Management. Boston, M.A : Addison-Wesley Pub Co.
14. Dole, C (1999) Towards a supply-chain community? Insights from governance processes in the food industry" Environment and Planning. **31**(1) 69 – 85.
15. Duguay, C., Landry, S and Pasin, F (1997) From mass production to flexible agile production, International Journal of Operations and Production Management, **17**(12), 1183-1197.
16. Franza, R. M Gaimon, C (1998) Flexibility and pricing decisions for high-volume products with short life cycles, International Journal of Flexible Manufacturing Systems, 98 **10**(1), 43–71.
17. Garvin, D. The Process of Organization and Management. Sloan Management Review, 1998, **39**, 33-51.
18. Gentle, M . (2002) The CRM Project Management Handbook: Building Realistic Expectations and Managing Risk. London : Kogan Page Ltd.
19. Greenwood, R. and C.R. Hinings(1996) Understanding radical organizational change: Bringing together the old and the new institutionalism. Academy of Management Review, 21: 1022-1054.
20. Gu, P., Hashemian, M. and Nee, A. Y. C. (2004) Adaptable design. Annals of the CIRP, 5, **53**(2). 539-557
21. Factory Logic, The bullwhip effect, Factory Logic Whitepaper, 2003. Available online at: www.factorylogic.com (accessed November 2006).
22. Fischer, C., Mullineux, G., Medland, A. J and Hicks, B. J. The design of food processing systems for improved responsiveness and late customisation. In Advances in Integrated design and Manufacturing in mechanical engineering, A Bramley, D Brissaud., D Coutellier and C McMahon (eds). 2005, 377-388.
23. Fisher, C. and Scott, T.R (1997). Food Flavours, Biology and Chemistry. The Royal Society of Chemistry, Cambridge, UK.

24. Hashim, F. M., Juster, N. P and de Pennington, A. A functional approach to redesign 1994, Engineering with Computers. **10** (3), 125-139.
25. Herrmann, J. W., Cooper, J., Gupta, S. K., Hayes, C. C., Ishii, K., Kazmer, D., Sandborn, P. A. and Wood, W. H. (2004) New Directions in Design for Manufacturing. Proceedings of the ASME 2004 Design Engineering Technical Conferences DETC'04, USA, 1-9.
26. HIROTEC.http://www.hirotec.co.jp/hirotec/renew/eng/02product/equipment.html. (accessed January 2008).
27. Hobbs, D. P. Lean Manufacturing Implementation: A Complete Execution Manual for Any Size Manufacturer. 2003, J. Ross Publishing, Inc. ISBN-13: 978-1932159141
28. Imai, M (1986), Kaizen: The Key to Japan's Competitive Success, McGraw-Hill/ Irwin, ISBN 0-07-554332-X
29. Jiao, J. and Tseng, M.M. An Information Modeling Framework for Product Families to Support Mass Customization Manufacturing , CIRP Annals, 1999, **48**(1): 93-98.
30. Jones, V and Kouyoumdjiam, V, Meeting the Challenge: Japanese Kaisha in the 1990s. Tokyo, Japan: JETRO, 1993.
31. Kratochvíl, M and Carson, C. Growing Modular: Mass Customization of Complex Products, Services and Software. 2005 Springer, UK. ISBN -3:978-3540239598
32. Lakhnech, L and Yovine, S. Formal Techniques, Modelling and Analysis of Timed and Fault-Tolerant Systems: Joint International Conferences on Formal Modeling and Analysis of Timed and fault tolerant systems, 2004, Springer ISBN-13: 978-3540231677.
33. Matthews, J., Singh, B., Mullineux, G., Medland, (2006). A constraint-based approach to investigate the 'process flexibility' of food processing equipment. Computers and Industrial Engineering. **51**(4), 809-820.
34. Matthews, J., Singh, B., Mullineux, G., Medland, A constraint-based limits modelling approach to investigate manufacturing machine design capability. *Strojniski Vestnik*-Journal of Mechanical Engineering, 2007, **53**(7-8) 462- 477.
35. Matthews, J., Singh, B., Mullineux, G., Ding, L and Medland, A.J. Food product variation: an approach to investigate manufacturing equipment capabilities. Food manufacturing efficiency. 2008, 1(3), 38-45.
36. Martin, M. V. and Ishii, K. (2002) Design for Variety: Developing standardized and modularized product platform architectures. Research in Engineering Design, 13, 213-235.
37. Murakami, T (1995) Introducing team working-a motor industry case study from Germany Industrial Relations Journal **26** (4), 293–305.
38. Mullineux, G and Simmons, M. J. H. Influence of rheological model on the processing of yoghurt. Journal of Food Engineering, 2008, 84(2), 250-257
39. Mathlouthi,M (1999) Food Packaging and Preservation. Springer, UK ISBN-10: 0834213494.
40. MacCarthy, B., Brabazon, P.G., Bramham, J., 2003. Fundamental modes of operation for mass customization: International Journal of Production Economics 85(2003) .289-304.
41. McCarthy, I (2004) Special issue on 'Mass customization', Production Planning and Control, **15**(4).
42. McIntosh, R. I., Culley, S. J., Mileham, A. R. and Owen, G. W. 2001, Improving Changeover Performance. Butterworth-Heinemann, Oxford, UK.

43. Mello, S. Customer-Centric Product Definition: The Key to Great Product Development, 2002, PDC Publishing, Boston , USA. ISBN: 0-9745604-0-5
44. Taiichi, O (1988), Just-In-Time for Today and Tomorrow, Productivity Press, ISBN 0-915299-20-8.
45. Meyer, M.H. and Utterback, J.M (1993). The Product Family and the Dynamics of Core Capability. Sloan Management Review (Spring) Cambridge, Mass. USA.
46. Muller Company - http://www.muller.co.uk/ accessed (17/07/08)
47. Pagh, J.D., Cooper, M.C. (1998), Supply chain postponement and speculation strategies: how to choose the right strategy, Journal of Business Logistics, **19**(2).13-33.
48. Pahl, G. and Beltz, W., Engineering Design A Systematic Approach, Second edition, Ken Wallace (Ed.), Springer-Verlag (London), 1996.
49. Pine, B.J. (1993), Mass Customization, Boston: Harvard Business School Press, 1993.
50. Quarini, G. L. Send in the ice pig! Food Science and Technology.2002, **16**(2), 46–50.
51. Reik, M. P., McIntosh, R. I., Owen, G. W., Culley, S. J., and Mileham, A. R. A formal design for changeover (DFC) methodology. Part 1: theory and background. Proc. IMechE, Part B: J. Engineering Manufacture, 2006, **220**(B8), 1225-1235.
52. Roach, G. M., Cox, J. J and Sorensen, C. D. (2005) Optimal supply configuration for platform products: impacts of commonality, demand varaiblility and quality discount. International Journal of mass generation, **1**(1) 83-106.
53. Schonberger, R.J. World Class Manufacturing: The Lessons of Simplicity Applied, The Free Press, New York (1986).
54. Shimokawa, K. 1994, The Japanese automotive industry: a business history, Athlone Press, London.
55. Shingo S., 1985, A revolution in manufacturing, the SMED system, Productivity Press.
56. Taiichi, O. Just-In-Time for Today and Tomorrow, Productivity Press, 1998, ISBN 0-915299-20-8
57. Tseng, M.M. and Jiao, J Design for mass customization. CIRP Annals, 1996, **45**(1): 153-156.
58. Tseng, M. M and Jiao J A variant approach to product definition by recognizing functional requirement patterns Computers and Industrial Engineering, 1997, **33** (3-4) 629-633.
59. Tseng, M.M., Piller, F.T. (2003), The Customer Centric Enterprise, Springer, Berlin.
60. van Hoek, R.I. (1999), Postponement and the reconfiguration challenge for food supply chains, Supply Chain Management, **4** (1), 18-34.
61. van Hoek, R.I. (1997), Postponed manufacturing: a case study in the food supply chain, Supply Chain Management, **2** (2), 63-75.
62. van Hoek, R.I. (2001), The discovery of postponement: a literature review and directions for research, Journal of Operations Management, **19**(2),61-84.
63. Wedzicha, B and Roberts, C (2007) Modelling: a new solution to old problems in the food industry. Food manufacturing efficiency. **1**(1) 1-7.
64. Whitney, D. E**.** 2004, Mechanical Assemblies - Their Design, Manufacture, and Role in Product Development. Oxford University Press, New York.

65. Wikner, J and Rudbery., M. Integrating production and engineering perspectives on the customer order decoupling point. International Journal of Operation and Production Management, 2005, **25**(7):623-641.
66. Williams, D.J., 1994 Manufacturing Systems 2nd ed. Netherlands: Kluwer Academic Publishers
67. Womack, J. P., Jones, D. T. and Ross, D. (1990) The Machine that Change the World, Rawson Associates, New York.
68. Yang, B., Burns, N.D and Backhouse, C.J (2004). Postponement: a review and an integrated framework, International Journal of Operations and Production Management, **24**(5) 468-87.
69. Yang, B., Burns, N.D. (2003), Implications of postponement for the supply chain, International Journal of Production Research, **41**(9), 75-90.