Review

Advances in Consumer-Oriented Product Design Engineering of Foods

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This text reviews briefly the main methodologies of consumer-oriented design engineering used by the Food Industry. The most relevant implications of the recent developments in cognitive and neuro-science in this context are then analysed and it is concluded that incorporating the human, cognitive, dimension and its influence in food choice is the major challenge for further improvements. A vision of the “ideal final result” of a product design engineering system for foods is outlined and it is stressed that the development of kansei engineering in Japan seems a most promising emerging concept to be followed in this respect.

Keywords: cognitive science, geisha, kansei engineering, new product development, sensory science

1. Introduction

Food product development strategies in Europe, as elsewhere, have shifted completely in the last couple of decades, with what is known as “chain reversal.” The success of farming policies in terms of boosting overall production created a significant excess of food supply, further enhanced by greater international trade. As markets became inundated with products well above what could be reasonably consumed, it was no longer true that if a company would produce and market a food product it would sell it. The food chain therefore needed to be re-designed, not being any more from farm to the consumer, but from the consumer as the driver force, upstream to production. The EU 6th Framework Programme of Research (which was launched in 2001) expressed this as “from fork to farm” (European Commission, 2001).

Long before this, the most dynamic and forward looking companies, along with the research community, acknowledged the tremendous increase of competitiveness and therefore developed methods and strategies to fight the market, that is, to ensure that new products would beat the competition and sustain the added value.

Competition can be won on price: to produce cheaper than others. Improvements in process efficiency, productivity, procurement, logistics and production management are obvious solutions to lower production costs in hope of maintaining margins. Economies of scale usually come next (mergers & acquisitions, focus on product winners, etc.). The loss of margins is however inexorable. It is a fundamental basis of market economies that when the market is flooded with comparable products, their unit value decreases. At present, food manufacturing is basically living out of miniscule profit margins, with the distortions caused by protectionism (and mainly the Common Agricultural Policy in the European context) even allowing for the “miracle” of negative margins. Price competition is important and remains a fundamental drive of food manufacturing, but in the end it becomes a destructive force, continuously eroding value and thus contributing negatively to the wealth of the nations.

A more promising market-fighting tool is the continuous development of higher value products. Quality has been the first flag in this fight: a higher quality product can fetch a higher price. The next obvious step was to incorporate service in the value of the product, that is, to explore convenience and ready-to-use products. Consumer needs and requirements continued to be added to the portfolio of options for increasing added value: safety assurance, health concerns, indulgence, etc. Market competition therefore led to a prime concern for the consumer, asking the question “what does the consumer want?” Companies are only too happy to identify products that the consumers really want, so they can produce them and beat the competition. This is a very difficult and never-ending battle, because there are few opportunities to protect intellectual property—a new product cannot be patented, and can usually be imitated in no time.

Modern, dynamic, food companies therefore needed to develop an excellent interaction with the consumers, and find methods and enabling tools that allow to translate consumer needs and requirements into product characteristics. Consumer studies are at the cutting edge in food research (Schifman & Kanuk, 2000).

The approach has however been very rational until recently. The focus has been on answering the fundamental question “what does the consumer want?” in hope of finding an objective answer. Companies and researchers look for that “thing” which the consumer wants. This means they assume that the consumer knows what he/she wants, and has a rational and logical explanation for the choice(s). Little thought has been given to the fact that the consumer may not know what he/she wants. Or that he/she may want different things at different times. Or that he/she does not like to give too much thought to it and when forced to verbalise a rational answer to a conceptual question in some market survey, will come up with virtually anything. The 1990’s were heralded as the “decade of the brain” as cognitive scientists made huge advances in understanding how the brain functions. It is a pity that little of that has permeated food product develop-
ment and market studies until recently (Koster, 2002).

2. Overview of Customer-Oriented Design Engineering Tools

Marketing research has produced a variety of methods and tools to incorporate consumer response in product design. Kaul and Rao (1995) usefully divided them in two approaches: product positioning and product design. In the former the objective is to identify the optimum product attributes (that is, the qualities that the product should possess to satisfy consumers) while in the latter the objective is to identify the optimum product design options. For product positioning the factors are classifications given by the consumers, while for product design the factors are those variables which the manufacturer can change/manipulate. Product positioning methods can handle fuzzy data, while product design will require a more deterministic or probabilistic approach based on a solid mathematical handling from a suitable experimental design (Kaul & Rao, 1995). The most popular methods used in modern food research are subsequently reviewed briefly.

Focus groups This most favoured method of qualitative research (Krueger & Casey, 1988) can be summarised in allowing a directed but openly flowing discussion between a group of 6–12 typical consumers, which is normally moderated by a facilitator (Casey & Krueger, 1994). Transcripts are then processed and used to identify opportunities for product improvement/development. Consumers may also be asked to provide some analytical result, such as consumer profiling/preference mapping of an existing class of products or samples provided.

Questionnaires and surveys Quantitative research is generally preferred to involve large numbers of respondents, to ensure statistical certainty. A large number of consumers is requested to fill in questionnaires with more or less rational questions about products, either conceptually, or after actual sampling. There are various methods to analyse the data, and particularly to give some structure to the results so that objective conclusions can be taken from what may be rather fuzzy data. These were reviewed by Dijksterhuis (1995). A market survey may involve hundreds of respondents, though only product concepts and opinions are assessed. Work involving sensory analysis rarely goes over a hundred respondents or so. Panelists are therefore selected more critically and it is usual to have a pre-screening phase to rule out individuals with lower taste acuity. Koeferli et al. (1998) reviewed dietary analysis methods in food research. Questionnaire results may be interpreted directly when the questions are very direct and rational (e.g. “which sample is preferred”), or the data may be used for further processing in consumer profiling/preference mapping (Risvik et al., 1997).

Quality Function Deployment (QFD) Developed in Japan in the late 1960s by Professors Shigeru Mizuno and Yoji Akao, QFD is a fairly comprehensive system which pinpoints improvements at various levels of interaction within a company, its processes, its products and its customers, with a view to maximise consumer’s satisfaction. Their seminal work was introduced in the west only in the 80’s (Mizuno & Akao, 1994), and became popularised as the “House of Quality,” although this is just one element of the overall QFD method (Herrmann et al., 2000). The name stems from the matrix of correlation between the voice of the customer and the voice of the company (that is, between product attributes and design factors). Many QFD applications have not gone much beyond this simple House of Quality matrix, although it already provides good qualitative information on how a product fairs from the perspective of its users, and how to improve their satisfaction. Its application in food research has been reviewed by Costa et al. (2000). This basic QFD table has a lot more potential, particularly when combined with the concepts of contradictions and systematic inventivity which have spinned-off from the Theory of Inventive Problem-Solving (TRIZ), as suggested for instance by Teminko (1998) and the WOIS (Contradiction-oriented innovation strategy) system (no publications available, but general information can be found at www.wois-innovation.de).

Conjoint analysis The marketing technique that provides more clear results regarding best choices of design options (Green & Srinivasan, 1990) has been suggested by food researchers since the late 80’s (Wittink et al., 1994). Consumers assess different product concepts which differ in the combination of design options, in search of the one they prefer. Usually, the questions asked are very direct and rational. Results are interpreted with multivariate models.

Biomimetics Methods involving consumer testing are generally time and resource consuming, and it is therefore obvious that efforts would be made to try to automate their application, i.e. to develop analytical equipment that in some way could mimic the assessment that consumers would make of the products. The greatest efforts have been channelled to develop systems that could mimic consumer testing regarding texture, aroma and taste. The latter have given rise to the concepts of the electronic nose and the electronic tongue, respectively. Generally, they consist of a bio-sensor system which emits a pattern of electrical signals resulting from the interaction between the sample and the sensor elements, and a mathematical interpreter of the results, which correlates the pattern with consumer attributes. In virtually all existing biosensor systems the comparison is not straightforward and therefore neural networks give better results than multivariate models, as the network can be made to learn from a large set of data. Different biosensor systems have been developed and applications vary widely (a search for “electronic tongue” in the Web of Science database—popularly known as the Citation Index Database—which covers most literature sources of interest, retrieves 41 references, while a search for “electronic nose” retrieves 264). Electronic nose technology was reviewed by Snopok and Kruglenko (2002) and some applications in the dairy area were reviewed by Amueño and Bosset (2003). Bleiwan et al. (2002) have recently analysed the validity of an electronic nose and an electronic tongue versus consumer testing for quality assessment of apple juices. In practice the reliability and predictive capabilities of these systems is still just fair at best.

3. The Cognitive Dimension of Product Design and Its Implications

Inputs from cognitive science The most relevant limitation of the methods described above, including current work with biomimetics, is an insufficient incorporation of cutting edge knowledge from cognitive science. In many works it is basically assumed that there are rational judgements being made by consumers, who are relatively unaffected by factors other than the product descriptors. The underlying theoretical framework is basic behaviourism, as pioneered by Watson in the 1920’s (Pink-
er, 1999). Essentially, this implies a mind model (relation between stimulus and response) which is linear and conscious. Cognitive science, making use of modern neuro-science methodologies such as F-NMR, PET and EEG's, has however demonstrated a very different reality (Wilson & Keil, 2002, Gazzaniga et al., 1998). Very briefly:

- The brain performs a large variety of cognitive processes in parallel, of which individuals are conscious of only one at a time. The brain processes all inputs from the 5 senses and from memory, but “filters” them to the conscious level.
- Different brain areas specialise in different functions. Emotional responses are more strongly associated to the frontal right cortex, while verbalisation and language are processed mostly in regions of the central left lobe. The processes that generate emotions are therefore different than those used to express them verbally and are performed largely by different neurons and neuronal pathways.
- Conscious thought utilises language and hence verbalisation strongly. Emotions that need to be taken to the conscious level are therefore further processed by areas of the brain more prone to rationalisation.
- Conscious thought must find justification for actions. When asked to express their opinions or justify their actions in consumer questionnaires, individuals are asked to rationalise what could have been until then a non-rational reality.

Koster (2003) has very eloquently explained the fallacies of consumer research methods by analysing their underlying assumptions under the light of cutting edge cognitive science knowledge, highlighting in particular five:

- consumer uniformity, the fallacy of which most researchers are indeed aware, though generally underestimating its influence. It is not just a question of market segmentation: individuals from a same market segment may respond to a questionnaire/survey following different thought patterns, and bringing their own experiences, memory and belief system to the process (for instance, Degel et al., 2001 have shown that individuals that recognise an odour as being lavender expressed strong liking of it, while those that did not recognise it expressed dislike).
- consumer consistency. Individuals change in time—preferences, opinions, beliefs are continuously adjusted. A recent paper by Koster et al. (2003) reviewed a series of works where individuals were exposed to a given stimuli over several sessions, and that have shown that less than half the individuals would stick to their first choice in subsequent sessions.
- conscious choice. Our society overvalues rationality and belittles emotionality. Individuals will rarely accept that their choices are not rational and will rationalise their actions, even when they were performed for mostly unconscious or emotional reasons. In questionnaires or focus groups, they may also be more interested in pleasing the interviewer or giving a good image of themselves than in confessing their real beliefs, as shown for instance by Knasko, 1993.
- neglecting the importance of memory. The brain functions strongly by analogies—that is in fact what makes the human brain so much more powerful than a computer. Memory (and past experiences) therefore play a fundamental role in cognitive processes of evaluation, assessment and choice decisions.

However, consumer research has been essentially focused exclusively on perception. Mojet and Koster (2002) describe an experiment which illustrates very clearly the importance of memory and its implication on consumer test results.

- situation unaffected by intent. The response of an individual is affected by his/her own interests and concerns, and system of values and beliefs, and therefore, the way that a particular aspect is being looked into will affect the result. The context in which a question is asked can strongly affect the answer. The importance of context in cognitive modelling has been substantially studied by Suchman (Adelson, 2003). In research to be soon unpublished (Pagidas & Oliveira, 2004), the author performed sensory tests with consumer panels using information on the product as an independent design factor (this implied that in some samples the panel was evaluating a same product believing that there was a difference that did not actually exist, and in others it could be assessing different products believing they were the same). In the example described by Pagidas and Oliveira (2004) samples of orange juice, mixed in some cases with caffeine and taurine (in the same concentration as present in the Red Bull beverage), were provided to a panel to take home and assess in their own time, and one of the responses being measured was the energy boost effect. Results showed that whether there were indeed stimulants mixed in the drink or not had a statistically negligible effect on reporting the boost when the panel believed that the drink was pure orange juice, while when believing that the drink contained stimulants provided a statistically positive response even in the samples that were in fact plain orange juice.

Implications for product design engineering of foods An important conclusion to be taken is that in fact there is no answer to “what is the product that the consumer wants.” People do not know rationally how specific characteristics of food products will meet what they want and they do not always know rationally what it is they want and why. If forced to provide a rational answer to a rational question, they will rationalise their beliefs and experiences and the result may or may not be correct, as it will certainly give too much weight to rational factors and tend to ignore emotional ones. Furthermore, what individuals have to say may change with intent, information provided, framework of analysis and time; and specially if asked in a different time and place to when they really need to take the buying decision.

Another important conclusion is that emotional and unconscious factors play a far more important role in choice and assessment of food products than current research methods account for. Implications regarding food product development were explored by Oliveira (2002).

An immediate recommendation spins-off of this discussion: consumer studies need to be performed in real conditions of use, and not in isolated “ivory towers.” Marketing theory uses the Japanese work *gemba* to express this concept. The word itself means “real place” and is also used in lean management theory to designate the factory floor. In the present context, G. Mazur’s expansion of the concept in the sense of “seeking the *gemba* of the product” is being used, which means to seek the consumer assessment in real conditions of use (Ronnie et al., 2000).

The state of the art regarding the psychological behaviour analysis of consumer choice can be found in Foxall (2003).
Improved methods are emerging in food research, for instance, Costa et al. (2003) developed a consumer study which recognised the implications of cognitive science advances in its improved methodology, using the method of collages combined with focus groups to identify feelings, emotions and experiences of consumers towards home meal replacements.

In addition to the implications in the methods used in product design engineering, there is a more far-reaching conclusion to ponder, which challenges the way that the food supply chain operates. If one accepts that there is no answer to “what the consumer wants,” and that whatever that is changes with time, situation, mood, etc., than the ideal supply chain should be designed for production-on-demand. Some industrial sectors (e.g. electronics) have been developing production-on-demand supply chains. The industry sees itself as being contracted to manufacture a particular product according to the customer specifications: it does not take decisions on what it should produce, it only takes actual production orders from the clients. The customer is empowered to request what he/she wants and the industry has sufficiently flexible processes to do that and sufficiently streamlined production systems and supply networks to do so within a reasonable time. This requires the application of the lean manufacturing concept (Womack & Jones, 2003) in both supply chains and in the more flexible manufacturing operations. Flexibility in this context means mass customisation capabilities, which will further imply the application of concepts such as Single Minute Exchange of Dies (SMED) in food manufacturing. Production-on-demand for industrial food products is however a complex concept to develop, due to the particular realities of perishable foods and ideally short order lead times (Oliveira, 2002).

In addition, the industry must have a product design system that interacts with the customer so that specifications can be made in the terms that the consumer wishes to express, with the system being able to translate that immediately into design options and manufacturing orders. This takes us back to the necessity of developing customer-oriented product design engineering systems for foods, but while previously we would envisage these efforts as improved forms of product development operating in autonomy with actual production, order and manufacturing, we can now conceive that the ideal direction is towards an integration of product design with manufacturing, orders and sales. This is exactly the concept of “Product Lifecycle Management” that top industry consultants, such as IBM, are recommending (IBM, 2003).

Product design engineering system for foods In order to integrate existing consumer research methods with cognitive science for effective product design engineering, it is useful to follow a systems engineering approach. A simple outline was proposed by Oliveira (2003). In general terms, a conceptual model is composed of factors and parameters: the former influence the system externally, while the latter influence the way that the system will respond to the factors, and may be affected externally or internally. The response is first and foremost unconscious and emotional, and then translated into a rational judgement or choice.

The system factors originate in the product formulation and in the package, which stimulate one (or more) of the five senses as well as a series of unconscious cognitive processes which bring in memory and belief system to compose the situation and context. The system parameters include the system of values and beliefs of the individual, context, expectations, mood, information and intent. The exact same combination of factors will result in a different response if the parameters change. Like in any systems engineering problem, knowledge of the parameters is as important as knowledge of the factors.

The most appropriate conceptual model is a neural network (see for instance, Ishihara et al., 1994), although some useful results have been published with simple multilinear models using basic kansei engineering techniques (see for instance Jindo et al., 1995). Kansei engineering provides a most appropriate methodology for a product design engineering system for foods, as argued by Oliveira (2003), with the ability to go “beyond the voice of the consumer,” and avoid asking rational questions. The objective of kansei engineering is to translate ill-defined emotions or feelings that are not verbalised into design factors (Nagamachi, 1995; see also the webpage of the Japan Society of Kansei Engineering at www.jske.org). It is the methodology itself that must extract from consumer data the descriptors, emotions and feelings.

The most advanced research approaches in Europe, incorporating cognitive science knowledge about mental processes, is getting closer to the Japanese kansei engineering concept. However, the latter has a very well defined and neat systematic organisation, which some research in Europe (and the US) does not always have, as a result of its origin being closer to social sciences methodologies.

Conclusion

Consumer preferences, needs and requirements, are at the centre of food product development. However, how to find what these are and how to actually incorporate them in product design choices are not trivial issues. There have been many improvements in sensory analysis and consumer testing methods, and the most essential at present are those that account for the cognitive nature of assessment and choice processes. It is imperative that cutting edge procedures are widely disseminated in industrial R&D.

The development of product design engineering systems for foods is essential for the food industry to build value-added mass customisation capabilities. The combination of cognitive modelling, biomimetics and principles of conjoint analysis would basically lead to similar objectives and results to those of kansei engineering. It would therefore be most valuable if co-operation between kansei engineering research in Japan and consumer science research in Europe and the US in the food area would emerge in the near future.

References


