The Chain of Quality through Integrated Product Development

A.J. Robotham

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Abstract

Today, it is almost impossible to find a manufacturer who has not been significantly influenced by the quality culture, but it is evident that some are doing more to improve their product quality than others are. The so-called "Chain of Quality" through integrated product development is a useful metaphor since it recognises that quality is a continuing topic of attention throughout the product development process and that discrete, quality related activities in the process are inter-linked. Depending upon how the product development process is modelled, the chain can be viewed as open or closed with single or parallel threads. In this paper, the overall purpose of the chain, the nature and identity of its many links and the relationship of the chain to the product development process will be discussed. In so doing, this paper will present an overall picture of important product development strategies and practices that can have a key impact on product quality.

1. Introduction

The goal of integrated product development is to enhance the competitive advantage of a company. This necessarily requires a company to create value for its customers that differentiates them from their competitors (Figure 1). One study of market leading SMEs [1] found that the competitive advantage of successful companies is due to their superior product quality, value for money, service and closeness to the customer. These characteristics are also the priority of the customer and related to the central topic of this paper - Quality. Consequently, adopting a quality focus for product development will go a long way to helping achieve the competitive advantage required to succeed in the market place.

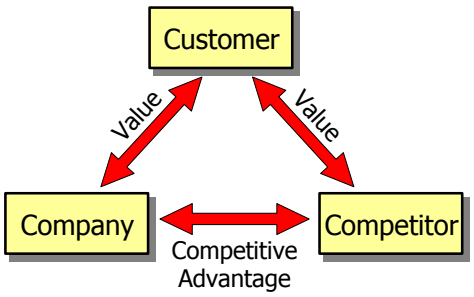

Figure 1: Competitive Advantage (*After* Simon [1])

However, this idea is not new to any self-respecting manufacturer - quality has been high on the product development agenda for over forty years. Japanese manufacturers were the early adopters of the work of Juran, Deming and Feigenbaum and have been using quality to drive their product development activities since the 1950's, whereas North American and European manufacturers only began to wake up to the importance of product quality in the 1970's. At this time, they were suffering large losses of sales in home markets because consumers were exhibiting a preference for the superior quality of Japanese product [2]. Since then, the principles of Total Quality, and the methods and tools used by Japanese manufacturers have been studied, adapted and implemented by Western manufacturers.

Initially, considerable effort was given to enhancing production quality by improving manufacturing speed, repeatability, reliability, cost, and waste. However, the creation of a high quality product relies upon more than just manufacturing quality. The significance of design on product quality was soon recognised and attention shifted to improving the upstream activities of the product development process. "Design for Quality" recognises that product quality starts in the design process and is embodied into the product by the design team. The goal of Design for Quality is to create customer value by understanding the so-called “voice of the customer”, which enables the design team to identify the quality requirements and so help the creation of products with "designed-in" quality. However, identifying the totality of quality requirements and creating products with the appropriate functions, properties and structure is not a trivial task.

The intention of this paper is to consider how product developers create customer value by using quality as the driver for the product development process. It will focus on the creative process of designing quality in to the product, rather than the verification and validation process more normally associated with quality assurance. To enable discussion of the relationship between quality and the product development process, it is useful to use the concept of integrated product development (IPD) created by Andreasen and Hein [3] during the 1980's, which has acted as a guide to many companies ever since. Their model (Figure 2) highlights the need to concurrently address the product, production and market situations when developing products. The focus of IPD was to develop good business outcomes via a process that began from the recognition of needs. Whilst it is understood that this model is no longer an accurate reflection upon modern product development practice [4,5], the co-ordinated strategy that combined design with the roles of marketing and production is still valid. The "fuzzy front end" of the IPD process will be the subject of much of the discussion in this paper, since the "chain of quality" begins with the recognition of needs.

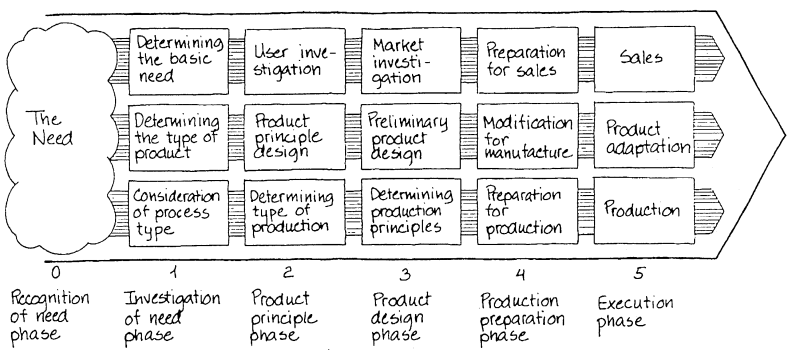

Figure 2: A model of Integrated Product Development (After [3])

2. Some Fundamentals of Quality Related Practice

In order to proceed, this section will consider some of the fundamental elements of Design for Quality, which will form the basis of discussion in the following sections.

2.1 What is Quality?

It is essential to have a clear understanding of what quality is. The 17th century philosopher John Locke (see Ayers [6]) provides an early and highly relevant discussion. Locke defined the quality of an object as *"its power to stimulate the senses and produce an idea in the mind of the observer".* He adds that prior knowledge and previous experiences help create more complex perceptions of an object, enabling the observer to anticipate qualities that cannot, as yet, be perceived.

In the context of product development, this definition of quality concurs with the opinion of Mørup [7] who states that *"quality is experienced when the customer interacts with the product".* Consequently quality is the perception created in the mind of the customer by the product. When their prior knowledge and previous experiences influence this, the quality perception becomes coupled with prejudices, status, nostalgia, value, etc. This leads us to a valuable quality concept introduced by Monö [8], namely that of the "meta-product".

Since quality is a perception in the mind of the customer, then product quality is a highly individual, qualitative judgement which is difficult to predict. The task of the designer is to create a product with properties that appeal to the emotional and reasonable, i.e. rational, states of a customer's mind (Figure 3). Often we say that a product must have a balance of "hard" and "soft" properties.

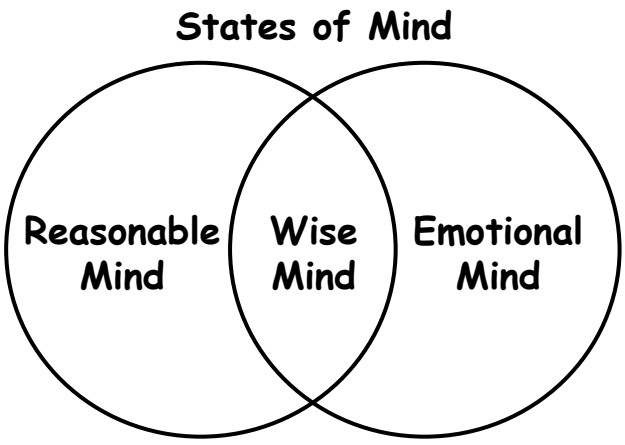

Figure 3: States of Mind (After Linehan [9])

The implications of this understanding of quality are significant for product development. In their pursuit of competitive advantage, Hughes [10] says that product developers must create differentiation between themselves and their competitors "*in the mind of the customer"*. Consequently, they need "*customers to perceive and believe"* their products to be better than their competitors.

The implications of this concept of quality are that the "chain of quality" begins and ends with the customer. Thus the product development process must ensure that the product fulfils the quality expectations of the customer. To do this, the process must start with identifying and understanding what those quality expectations are.

2.2 Focusing on the Customer

The current product quality paradigm is founded upon a customer-focused product development process, in which the functionality and behaviour of a product are designed to fulfil the needs of customers. However, *"customers have become much more sophisticated in the factors which they include in the purchase decisions"*, and product developers *"need to find those extra factors which will deliver such a high level of customer satisfaction"* [10].

The quality models of Kano [11] and Andreasen and Hein [12] (Figure 4) show us how to describe different classes of quality characteristics. Basic/Obligatory qualities are the functions and properties that effectively define the product. The customer has an almost unconscious expectation that they are provided - if they are not then the customer will be highly dissatisfied. Performance/Expectation qualities are those functions and properties, which a customer is specifically asking for and expects to find in the product. The level of customer satisfaction is proportional to the level of achievement of the product in this class of qualities. Excitement/Positioning qualities are those extra features that enhance the customer's interaction with the product, create "delight" and differentiate the product from those of competitors. In particular, it is expected that new product generations would have innovative features to delight the customer and ensure market differentiation. The Kano model shows us that the quality expectations of customers are continually rising, e.g. today's "delighters" become tomorrow's expectation qualities. In the second model, we are also introduced to two different types of quality known as Big-Q quality and Little-q quality. These are discussed in a little more detail below.

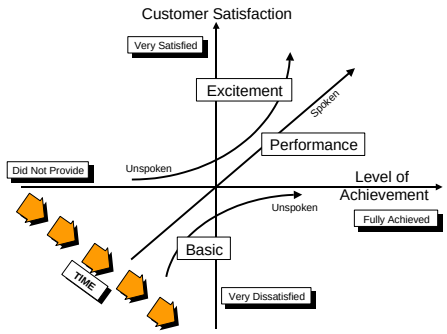

Figure 4a: Classes of quality (after Kano [11])

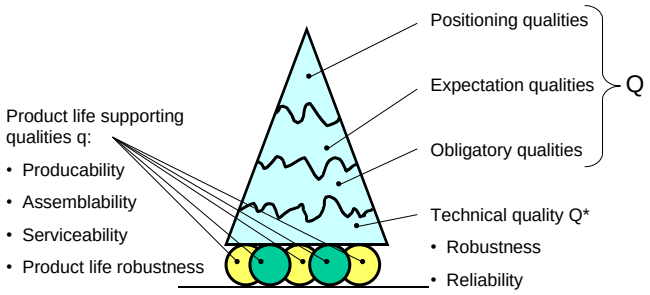

Figure 4b: Classes of quality (after Andreasen & Hein [12])

Developing knowledge of what customers want can be achieved using many different methods. Griffin [13] reports that US companies have shown an increased use of market analysis tools, e.g. voice of the customer (VOC), customer site visits, concepts tests, beta site testing, focus groups and conjoint analysis, to develop this knowledge.

2.3 Life Cycle Oriented Design

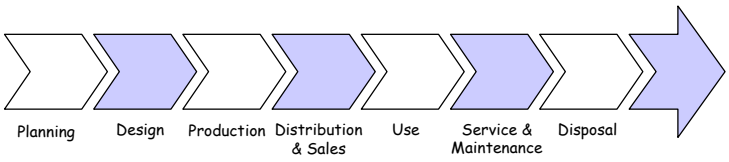

Figure 5: Cradle to grave life cycle of a product

A life cycle oriented design approach recognises that, during the "cradle to grave" life of a product (Figure 5), many different people will interact with the product, each in a different context and with a purpose different to the others. These people are known as stakeholders and each will have a set of needs to be satisfied. Mørup [7], fully describes the relationship between product quality, the product life cycle, and stakeholders. Life cycle oriented design requires the designer to consciously consider the totality of the life cycle of the product and all the stakeholders who interact with the product, and create a product that will satisfy everyone, whilst maximising the customer value. Mørup also introduced two new quality concepts:

- *Q-quality*: Q is the customer's qualitative perception of the product.
- *q-quality*: q is an internal stakeholder's qualitative perception of the product in relation to their product-related tasks.

The quality concepts of Q-quality and q-quality enable the perceptions of the product to be divided according to stakeholder type. This approach recognises the necessity to satisfy the needs of the internal customers, but not at the expense of the needs of the external customers.

In order to create a model of the product life cycle, it is necessary to determine each of the discrete meetings, which will occur between the product and the stakeholders. Clearly some meetings occur only once in the life cycle, e.g. those associated with the original manufacture of the product, whereas others occur many, if not several thousands, of times, e.g. those in the use life phase. Understanding of the events which occur in each meeting enables the needs of the stakeholder to be identified, the functions of the product to be determined, and what properties the product should have to satisfy, and even delight, the customer. Scenarios are a highly relevant means for describing what occurs in these meetings and, if organised in a sequence, can be used to map the product passing through all the phases of its life

With this detailed understanding of the product life cycle, functions, needs and properties, the design task is then to create a solution that best satisfies all of these requirements. During the design process, the performance of new ideas will be evaluated for all life phases, and successful solutions for one function synthesised with solutions for other functions. By continually comparing design results with life cycle needs, it is possible to maintain a check upon whether a design solution is emerging with the appropriate quality properties.

If life cycle oriented design is to be successfully implemented in product development, then a working approach is required that can support the product definition and the creative, synthesis, evaluation and process control aspects of product development. One approach, which provides a significant step forward in this direction, we refer to as the "Multi-Board Concept" [14].

However, despite all the efforts that can be made during the product development process to validate the design solution, the true quality of the solution can only be verified when the product is realised and each stakeholder can interact with it.

2.4 Modelling Products

During the product development process, a design team will utilise many different types of model to gain insight into the product that they are creating [15]. In a life cycle model, each phase may be thought of as a sequence of discrete transformation processes [16]. Andreasen's Domain Theory [17] provides insight into the relationship between the transformation processes that occur in the product life cycle and the elements of the product, which carry the required functionality and properties. The three domains are transformation domain, organ domain, and parts domain (Figure 6).

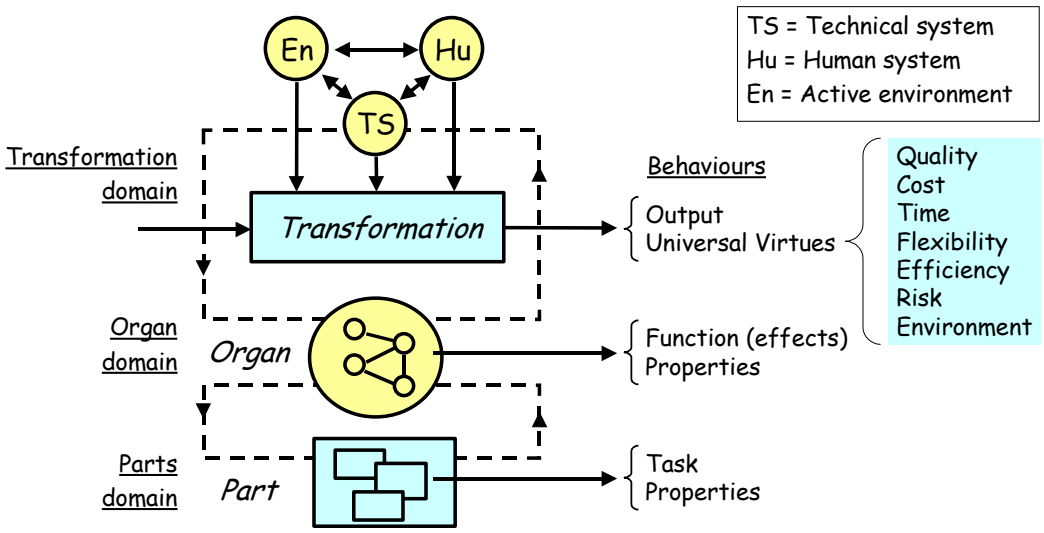

Figure 6: Domain theory (*After* Andreasen [17])

In the transformation domain, there are interactions between the technical system (TS), the human operator (Hu), the active environment (En) and the operand, e.g. the thing that is being transformed. The so-called 'seven universal virtues' [18] i.e. quality, time, cost, efficiency, flexibility, risk and environment, may be utilised to measure the effectiveness of the activity which occurs in each phase of the product life cycle, to compare alternative design solutions, or to clarify product development objectives.

The quality related properties of a product are carried by organs and parts. An organ is an element of the functional structure of the technical system. The behaviour of an organ is characterised by the function it realises (e.g. the effect it creates) and its properties. A part is a discrete unit of the structure of the TS and is a carrier of elements of one or more organs.

2.5 Technical and Semantic Functions

In the product modelling approach described in Section 2.4, technical functions are the purpose functions that are realised by the technical system (TS), e.g. the product. The

transformation domain shows both the TS and the human operator (Hu) directly exerting effects on the operand of the transformation process. Consequently, it is necessary to differentiate between those functions that are performed by the TS and those by the Hu. The Human-Machine Interface (HMI) enables interactions to occur between the TS and the Hu, e.g. for control and sequencing purposes.

Additionally, a product must clearly show its purpose, way of functioning, origin, kinship, properties, etc. The semantic function of a product is its ability to create signs, which will deliver specific messages about the product to the customer. Attention to semantic functions in design will yield products that are easier for people to understand and, since quality is a perception in the mind of the customer, enhance the likelihood that they will perceive its qualities positively. Monö [8] proposes four semantic functions:

- To describe purpose, way of functioning, and using the product.
- To identify product, origin, and kinship.
- To exhort reactions.
- To express properties.

Semantic functions do not create active effects like technical functions, but influence perceptions in the mind of observers, e.g. customers. Consequently, semantic properties must be evident throughout the product, and especially so at human-machine interfaces. The recipients of the semantic messages they deliver are the people who interact with the product.

The concept of organs being function carriers is still valid when extended to semantic functions, e.g. "visual gestalts" are examples of semantic organs [8,19]. The organs will be carriers of semantic related properties, which may often have to conform to statutory regulations or established norms - norms that are often heavily influenced by meta-products.

The integration of semantic and technical functions in a product model provides a complete classification of quality related functions, but bear in mind that technical functions generate physical effects and semantic functions influence perceptions in the mind of the customer.

2.6 A Framework for Design for Quality

Mørup [7] has published probably the most complete description of Design for Quality (DFQ). He recognised that *"the process of synthesis in product development is ultimately where the genesis of product quality takes place".* Mørup's doctoral thesis unifies existing and new quality techniques and theories into a framework for DFQ that contains eight main elements, arranged in three aspects:

- *DFQ Preconditions*:
  - Strategy deployment;
  - Quality organisation;
  - Product technologies; and
  - Measuring system for quality.
- *Structured Product Development*:
  - DFQ procedure.
- *Supporting Methods*:
  - Tools and techniques;
  - Methodical design; and
  - Quality mind-set.

2.7 The Quality Mind-Set

Interviews with expert designers show that innovation in product development can stem from adopting a quality mind-set [20]. One of the most effective mechanisms for creating a quality mind-set is to focus on the voice of the customer (VOC). Clausing provides a succinct description of how to collect the VOC and its relationship to the downstream product development processes [21]. The clear message he gives, is that designers must immerse themselves in the context of the product life phases, obtain the voice of the customer, and identify the values they have towards the product. The interaction with customers is essential for understanding "feelings", sharing experiences, and identifying cultural influences. The purpose is to establish the difference between success and failure in the mind of the customer.

Thus, the quality mind-set is very much related to the customer's mind-set and understanding the meta-product. But the quality mind-set must also reflect an awareness of the things the customer is unable to express or even have consciously thought about. This can be reflected in the following comment from an architect reported by Cross [22]. He said that *"our job is to give the client, on time and cost, not what he wants, but what he never dreamed he wanted, and when he gets it he recognises it as something he wanted all the time".* It is a theme mirrored by Cullen, who requires *"organisations which are tuned to the voice of the customer"* and products *"which respond to both spoken and unspoken wants and needs"* [23]. The consequence is that designers must work in a creative and innovative manner.

2.8 Practitioners of Design for Quality

Without exception, product development is a human centred activity, and the creation of product quality occurs in the synthesis of the solutions. The practitioners of DFQ must have the unique ability of synthesis guided by a "quality mind-set". Of interest here is to compare the differences between the education of engineering designers and industrial designers.

On the whole, engineering courses tend to focus upon the application of scientific and technological knowledge. Engineering design often follows a methodical approach, with tightly defined product design specifications. Often, there is little or no consideration of the complete product life cycle, nor an ambition to create quality solutions at the excitement level. Consequently, engineering students tend to create variant solutions, functional in nature, whose performance is demonstrated by calculation, analysis, simulation or test. Computer aided design, unless supported by rapid prototyping technologies, makes it even more difficult for students to interact with their solutions, and to experience and learn about product quality.

By way of contrast, the education of industrial design students is highly focused on the customer and emphasises the visualisation of the product and its use in many life phases. Concept design is not constrained by a tight specification, but encouraged to be searching and draw upon a wide range of influences to invigorate creativity. Concept selection is frequently based upon what the designer judges to be the most innovative and original ideas - ideas that can be formed into products that will excite potential customers. Sketching and drawing skills are well developed, and an emphasis is placed on making facsimile models or prototypes. The models allow customers to interact with the product, assess its quality, and demonstrate to the student how quality is perceived.

However, industrial designers are not consciously taught the principles of DFQ, and miss a proper understanding of quality supported by performance qualities like reliability, durability, etc. But, the design practices they learn clearly support the ambitions of DFQ and establish the foundations of a quality mind-set.

The contrast between the two teaching approaches is striking. Engineering courses focus on q-qualities and do not effectively prepare the quality mind-set, whereas industrial design courses are Q-quality focused and emphasise innovation and delight of the customer.

3. Observations of New Developments in Quality Related Practice

The following observations are based upon a review of the literature and discussions with a small number of manufacturers and researchers. Their interpretation has led to the identification some trends and speculation about issues that may be important to all product developers in the future.

3.1 The Current Quality Paradigm

The current product quality paradigm is founded upon a customer-focused product development process, in which the functionality and behaviour of a product are designed to fulfil the needs of customers, and technological innovation is used to extend capability, enhance performance, and ease the use of the product. A life cycle oriented design approach attends to the needs of all the stakeholders who interact with the product in some way and aims to ensure that each is fulfilled by the product in a manner that maximises the value to the customer. Products have different classes of quality characteristics and new generations must have new features to delight the customer, whose expectations are continually rising, and provide market differentiation. Quality assurance procedures and tools, e.g. ISO9000, QFD, FMEA, DFMA, systematise the design process and reinforce the "built-in" quality ethos of the current paradigm. But many companies are *still* striving to "close-the-loop" on product quality and ensure that they are able to meet all the expectations of their customers. Furthermore, the *kaizen* principle of continuous improvement ensures that within the current paradigm higher levels of quality performance remain desirable.

These key characteristics of the current product quality paradigm continue to be relevant and important to all product developers. But we observe that manufacturers are striving to improve product quality by using familiar tactics. For example, product value can be improved by increasing functionality to enable more tasks to be performed. Or else, functional behaviour can be improved, e.g. faster, quieter, lighter, easier to use, bigger, smaller, more flexible, better, less wasteful, or cost reduced to make the product better value for money. Another tactic is based upon continuous technological innovation in the product or production processes. This often leads to products that are more complex and which increasingly utilise technologies shared by competitors. The continued pursuit of technological innovation may be inappropriate if the customer has no perception of the improvement or considers it to be unimportant, i.e. better quality is not *valued*. Similarly as the technology matures the products eventually reach a plateau of quality performance. In all these cases, the functional behaviour of the product is going to indistinguishable form other products in the market and customers may be unable to differentiate between them.

Whilst, we respect that continuous improvement of product and product related processes will continue to be fundamental to product development practices of the future, we consider the focus on continuous technological improvement of the product is a defining characteristic of the current quality paradigm. We believe that new tactics are required and we observe that leading manufacturers are already implementing some new approaches to enhancing quality.

3.2 Total Solutions and User Experiences

The current product quality paradigm very much puts the emphasis upon the product as being the sole carrier of quality. This is changing and, rather than think in terms of a single product, leading manufacturers are providing customers with "total solutions". Total solutions are the consequence of innovative, life cycle oriented thinking by manufacturers who have taken a greater responsibility of the whole product life cycle and now provide an integrated system of related products and services. The product is no longer a stand-alone entity, but rather one that integrates with other products to form complex systems supported by complementary customer services. A consequence for the product developer is that they may have to make strategic alliances with other manufacturers and service providers.

Figure 7: Bicycling - a metaphor for the user experience

The focus is still on the customer, but the emphasis is shifted to creating customer value by providing a total "user experience". This is best illustrated by the metaphor of bicycling (figure 7). What is really important to the customer (the biker) and valued by them is the activity of *bicycling*, for which the bicycle (the product) is the means to the end. By focusing on the activity (i.e. the transformation domain), the product developer will gain insight into what the customer truly values, the context in which they use the product, and opportunities for adding value by provision of supporting products or systems. For example, the bicycle manufacturer might also provide specialist clothing, protective equipment, or child seats.

This move towards total solutions seems particularly important where the product is mature and operating in highly competitive markets. Integration with other systems is a relatively simple means to innovate, create new functionality, and offer the customer better value.

3.3 Product Branding

Product branding is not new, but historically associated more strongly with non-durable consumer products. However, it is evident today that manufacturers are placing a lot more emphasis on the brand identity of their consumer-durable and business-to-business products. We believe this is a consequence of products becoming mature and having very little to differentiate them from competitors in technical terms. A strong brand identity will enable customers to differentiate one product from another.

The significance of product branding is summarised by Richard Parry-Jones of the Ford Motor Company as follows [24]:

"Brand is an absolute key when we discuss customer choice. The more sophisticated customers become, the more they rely on brands as a surrogate for summing up all the benefits of the product or service they have bought. Consistent, strong, meaningful brands need to be at the core of any consumer company for the 21st century."

Brand identity is based upon the reputation of the company and its products, the embedded characteristics of past products, and common values and aspirations that are shared by the customer. Although the product is the prime carrier of the brand identity, the actions, behaviour, and attitude of the company that are perceived by the customer towards the environment, its customers, its workforce, and society at large are critical to its continued development. Although it is feasible to conceive a brand identity very quickly using, say, a marketing campaign, we perceive that manufacturers are placing more importance on mature brand names. Historically, these brands have well-known characteristics, which have been evident in past products and which distinguish them from other brands in the market.

The need to surprise and delight customers with new features implies that the brand identity is modified in someway with each new generation of products. However, the defining characteristics of a product, i.e. the Product DNA, must be carried over between each generation to ensure the sustainability of the brand. Whilst some features may be transient items of fashion, which are excluded in later generations, others will become embedded into the product and become the expectation qualities stipulated by customers. The challenge for product developers is to fully comprehend the DNA of their products, build future generations of products that reflect its distinguishing characteristics, and ensure it continues to fit the values of the customer.

Finally, Jesper Kunde [25] emphasises the role of the company in product branding:

"In the future, building strong market positions will be about building companies with strong personality and corporate soul."

3.4 Mass Customisation, Globalisation and E-commerce

Mass customisation, globalisation, and e-commerce are high profile concepts and strategies that cannot be avoided in any discussion of modern product development practice. Whilst a full discussion of their relevance will not be presented here, in the context of this paper their importance serves merely to underline the attention manufacturers are placing upon satisfying the customer and tailoring products to the individual, wherever they are in the world.

Mass customisation can be fulfilled by the adoption of product structuring strategies, e.g. modularisation and product family platforms, which allow the manufacturer to create a family of products by combining common parts with variant specific parts. Consequently, the specification of a product can be tailored to the specific needs of an individual customer by using a unique configuration of the parts. In the automotive industry, this strategy extends across brands, e.g. *"A Texan rancher can ride around in his F-series Ford pick-up, while a banking vice president can enjoy his Lincoln Navigator SUV. Under the skin ... you will find the same basic vehicle."* [24]. The tactic employed is for vehicles to share parts that the customer does not directly interact with, e.g. engine, transmission, suspension, and chassis. Those parts the customer does interact with, e.g. external body, interior trim, and the way they are configured determine the differentiation between variants in a family and brands. Although, carmakers have the capability to customise products to the individual customer, it is estimated that only 20-30% of European buyers custom-order their car [26].

The additional challenge of global product vending is to tailor products to customers with different cultural influences, educational backgrounds, and environmental contexts. Consequently, what might be acceptable in one culture may be inappropriate in another. However, if manufacturers are to compete in the global market place, their products, services and brands must reflect the values of all its customers and at no expense to others.

E-commerce is seen as a possible way of enabling more direct access to customers via the Internet, wherever they may be in the world. The company can show the customer the variants on offer and allow them to explore all the consequences of different configurations. It seems quite feasible to support both configuration and purchase using the Internet. However for some purchase decisions, we believe that customers will continue to prefer the direct interaction with the product, which occurs in a showroom. Only through direct contact with the product will the customer be able to make a thorough evaluation of its properties.

4. A New Quality Paradigm?

4.1 Key Elements of a New Quality Paradigm

The new quality paradigm does not focus on the product alone but rather on creating *customer value*. The attention moves up the value chain, away from the product, and concentrates on *user experiences*. The manufacturer aligns themselves more closely to the customers by providing *total solutions*, in which complementary *products and services* are integrated into a seamless system. Furthermore, the behaviour and attitude throughout the company in all that they do will mirror the customer's own behaviour and attitudes, in both individual and societal contexts. The *brand* will represent these collective values and signify to customers that the company and its products are sympathetic to their individual needs. *Closeness to the customer* will result in *tailored products* that continue to distinguish themselves from those of the competition whilst maintaining the core characteristics expected of the brand. The carriers of quality will be a range of products and services which support the customer throughout their lives, adapting with them as their needs change, and which build the brand through the innovation of *sustainable characteristics*.

4.2 Implications of the New Quality Paradigm

There are several implications of the new quality paradigm and, although is not feasible to provide exhaustive discussion of each in this paper, we will outline the main themes.

The creation of brand identity cannot be achieved overnight. Brand identity arises from the interplay between product presentation and market reaction. The enduring qualities of the product that the customer values will only be found after several iterations of the loop. The so-called core product DNA will have to be embedded in to future generations to ensure the continuity of the brand identity. However, the brand is not found in the product alone but also in the customer supporting services and of the actions and behaviour of the company as a whole. According to Jesper Kunde [25], the company must create a "Corporate Religion" in which a balance must exist between the internal and external perceptions of the company (Figure 8).

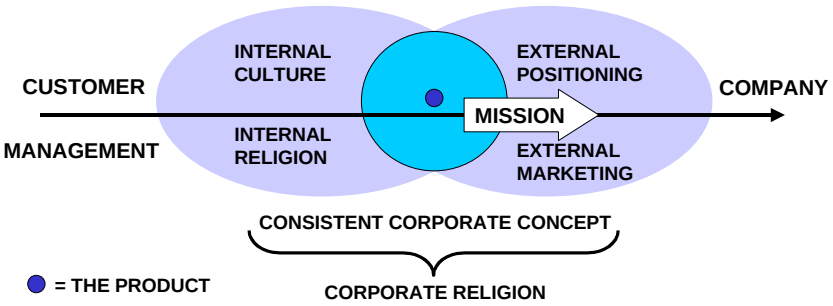

Figure 8: Corporate Religion (After Kunde [25])

From a product development viewpoint, product families must reflect the variation demanded by customers but have brand qualities embedded in their characteristics. The designer needs to be conscious of the historical and cultural context of the product line, and ensure that the enduring characteristics are identified and carried to the next generation. Close working relationships with the customer will allow accurate feedback of their quality reactions and insight into the changing nature of their needs, culture and environment. With this knowledge, the designers will still need to seek the "surprise and delight" factors that are essential to new products. However, the designer needs to be more conscious of creating innovative features that will evolve the brand DNA and develop the brand value. This necessarily demands that designers (like everyone else in the company) are immersed in its culture and have clear understanding of the business strategy for developing an intimate and sustainable relationship with their customers. The designer's task is to truly reflect the customer values in new products. They will need to work with others to create complementary services, which together with the product build the portfolio of brands. Consequently, we believe that product development in the new quality paradigm must look well beyond the product and embrace the total business activity of products, services, supporting functions, social and environmental actions, attitudes, etc. Product development outcomes need to properly mirror the individual customer, so that when they look at the company and its provision of total solutions, it is as if they were seeing a complete reflection of their own personality, values, culture, social aspirations, and product expectations. Such attention to the brand portfolio should enhance competitive advantage and lead to customer satisfaction, preference and long-term loyalty.

5. Challenges and Conclusions

The current product quality paradigm of continuous product improvement does not sufficiently reflect emerging practices in product development. Therefore, we have argued that a new quality paradigm is required to fully describe the trends we observe. The new quality paradigm takes a holistic view of products and services, which together provide customers with individually tailored solutions. Products must have an appropriate mix of technical and semantic functions with properties that appeal to the customer.

Furthermore, a strong brand identity ensures the customer can choose products with well-known characteristics and enduring qualities that will lead to delightful user-experiences. The brand identity must be enhanced not only by the product, but also by the totality of the company's activities in reflecting the values of the customer. The new quality paradigm demands that manufacturers mirror the values, aspiration and expectations of their customers. We believe that the new quality paradigm outlined in this paper is the new "guiding star" for value giving product developers.

To support this advance, the challenge for Design Research is to provide deeper insight in to the soft aspects of quality and DFQ. For example, understanding the quality mind-set and how it is developed, understanding the perception of quality and its relationships to the product characteristics, and the mix of skills and knowledge required to create high quality products. Thus, results are required about the relationships between quality, life cycle phases, the meta-product, innovation, and the education of designers.

In the industrial context, it is quite feasible to introduce tools or procedures to support quality, e.g. QFD, FMEA, DFMA, CAD, TQM, and ISO9000. Each has its place in the DFQ framework and, in particular, there is a strong belief amongst product development managers that TQM and ISO9000 takes good care of quality. In contrast, the industrialisation of procedures to deal with “perception”, “value”, “feeling”, and “mind-set”, is fraught with difficulties, and is not underpinned by a substantive body of research results.

If engineering designers are to become effective practitioners of DFQ, then aspects of their education needs to be revised. They must have more physical contact with engineering products, learn about product quality and how it is achieved, and develop a quality mind-set. They should put more emphasis on the visualisation and manufacture of prototypes, and be asked to create novel and innovative solutions. Industrial designers require a formal awareness and knowledge of performance qualities and the DFQ framework.

Finally, the "chain of quality" has been used as a metaphor to describe the complex interactions between the quality-related elements discussed here. No attempt has been made to formally describe the complex structure of the chain. However, the key characteristics of its critical links have been considered. Whether the chain is closed or not depends upon whether the model of IPD is understood to represent a repeated process of product development projects or just one project. The fundamental goal of quality in relation to integrated product development is to create customer value. Consequently the chain of quality truly begins and ends with the customer. As more effort is directed to the "fuzzy front end" of IPD, designers will gain a deeper, more accurate understanding of the customer. They will have to immerse themselves in the context, culture, and values of their customers and attain a level of empathy not previously demanded. In so doing, they will help define and enhance the brand identity.

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A. J. Robotham
Associate Professor
Dept. of Control & Engineering Design
Technical University of Denmark
Building 358
DK - 2800 Lyngby
Denmark

Tel: 00 45 4525 6259
Fax: 00 45 4588 1451
Email: tony@iks.dtu.dk