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MASS CUSTOMISATION, CHANGE AND INSPIRATION – CHANGING DESIGNS TO MEET NEW NEEDS

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Abstract
All design is a form of change, because all products are based on other designs or design ideas. This paper presents a classification of change processes occurring throughout the development cycle of a product and relates different products and ranges to each other. Individual customer needs are most obviously met in mass customisation, which is discussed here in relation to other change processes. New ideas are often derived from inspiration processes, where a solution concept is transferred from a different domain in a change process. All change processes are faced with common problems. By looking at change as a holistic phenomenon methods can be transferred between different change processes.

1 Introduction

Few, if any, products are designed from scratch. Most are based on other products and ideas from other designs. Here we provide a classification of the modification processes that are fundamental to so many design operations. All can be seen as kinds of change processes that share many important features. However, by differentiating between patterns of design situations, tailored methods can be selected to develop new products more efficiently.

Engineering changes can be defined as alterations after release, to products or to drawings, prototypes or software [1]. However, it is important to realise that change can occur at all stages of a design life cycle, from the conception of an initial idea (inspiration) to an in-service change, as illustrated in Figure 1. At the beginning of many new product families lies the transfer of core ideas between products and their integration into existing products. If the transfer occurs between different types of products, this is often thought of as an inspiration process, but many cross-product inspirations are essentially change processes. In the paper we will explain why mass customisation, change and inspiration are best understood within the same conceptual framework.

Change is becoming an ever more important issue, because the diversification of markets requires an increasing number of versions, thus fast and efficient changes to products. The border is blurred between unpredicted changes to generate new versions of the same product due to new requirements and mass customisation. Mass customisation shall be understood in a broader sense as a methodology and philosophy to extend the contingency of variants of a product rather than reduce the variants in order to manage complexity, which is in fact a natural principle of any evolving system. This is what differentiates mass customisation from variant management. The borders are of course blurred as well and mass customisation integrates methods of variant management. However, the main approach is to handle complexity by new and flexible technologies. Mass customisation in this context shall be generally regarded as any kind of "design for flexibility" – any measures to offer an increasing amount of variants to the customer with reduced internal efforts. Some companies see customisation as the generation of a new product version from a base product or a similar product (for example in the generation of customised rescue helicopters or made-to-measure garments). Others opt for the generation of a modular product architecture, which allows for the generation of a large number of different product combinations (for example fitted kitchens or personal computers), either by the manufacturer or by the end customers themselves [2].

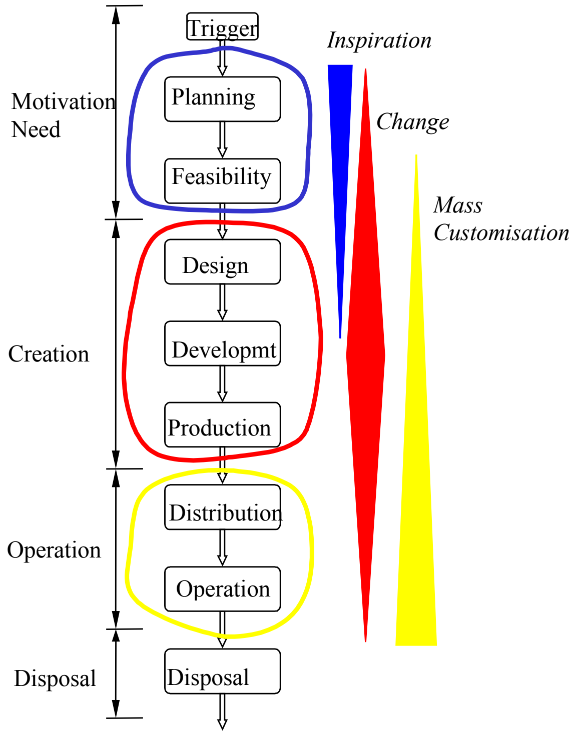

Figure 1 Change throughout the design process

One of the first industry sectors to bring mass customisation to the end user is the textile industry, where new body scanners and production machinery, allow the production of designs customised for individual body measurements using computer tools to adapt cutting patterns for garment shape. This industry also has a long tradition of generating a large range of designs for each season, many of which are changes to existing designs. Mass customisation in the context of this paper refers to mechanical or mechatronical engineering products, which are functionally and technically more complex than already customised products (to which the general statements regarding flexible design apply still as well). As a strategy to cope with the constant pressure to produce novel designs, designers frequently transfer design ideas from other design domains – they make systematic use of sources of inspiration. Designs are constantly modified throughout the entire design process. Engineering can benefit greatly from the experiences of the textile industry in the use of inspiration and mass customisation, whereas the textile industry could learn from the more scientific rather then serendipitous approach to design change.

2 Method

This is a theoretical investigation based on very detailed studies of industrial processes centred on the common theme of how products are modified:

- **Change in engineering design**: two interview studies were conducted with over 20 engineers in each company. The customisation of helicopters involves small runs of a very complex and very interlinked product, which is developed through a continuous series of changes. Change is the core business of the company: a new helicopter is only developed every 15-20 years and are often heavily based on existing designs [3]. The second study addressed change in the design and the customisation of diesel engines. Every 4 to 5 years new legislation requires the development of a new range of basic engines. Each time the company tries to change as little as possible from the previous generation. Each basic engine is sold in hundreds of different option packets to meet the needs of a broad customer base. In addition many small changes are made for specific customers throughout the life of the engine [4].
- **Mass customisation of engineering products**: the design of a mass customisable pressure washer for the mass market, which is currently mass-produced. The study is investigating how the design can be modified to add customer value by creating a configurable core product as well as accessories. Through a theoretical analysis, the study aims to understand the relationship between the effort involved in a change and the added value to the customer Techniques are being developed to allow cost effective flexibility within an envelop of acceptable customisation. This is completed by research on new manufacturing processes and new patterns of customer interaction.
- **Inspiration in the knitwear industry**: observations and interviews in over 25 companies to understand the various roles of sources of inspiration. Knitwear, other designs, artwork and images from nature are used throughout the entire design process as references points in context generation [4] and design communication [6] and starting points for new designs. In addition, experimental studies were conducted to analyse which strategies designers are using in selecting and adapting sources of inspiration [7].

3 A classification of change

This classification of change looks at the relationship between new and old products. Table 1 shows an overview of the classification [8] as illustrated Figure 1 does that change processes occur through the entire design process and overlap with inspiration and mass customisation processes. These two processes overlap in so far as that new concepts for mass customisation products are developed through inspiration processes. The classification follows the way designers intuitively divide change processes: error correction; product improvement; mass customisation; new product introduction changes; technology changes and cross-domain inspiration processes. The classification is built up around a starting design, which of course itself is likely to be the result of a change process.

Until recently, the topic of engineering change was only obliquely referred to in academic literature. Although now there is increasing interest in the area, relatively little has been reported that specifically addresses the issue. An extensive review of engineering change management literature published between 1980 and 1995 discovered only 15 ‘core’ papers [8]; other authors have also reported this scarcity (e.g. [10]).

Table 1Classification of Change

Change Type	Stage of Product Life Cycle	Main Change Activity	Predominant Type of Process
Innovation Change	Motivation / Need	Inspiration / Transfer / selection of starting designs	Inspiration, NPI
Developmenta l Change	Design/ Development/ Production	Error Correction / Improvement (maturation)	NPI, Customisation Mass customisation
Operational Change	Distribution/ Operation	Maintenance, Upgrade, Enhancement	Mass customisation

3.1 Products – Variants – Versions

A project is launched to generate a **new product or family of products** (Figure 2). For example the diesel engine company would launch a new engine to meet new requirements or legislation. The result is the launch of a new product - "A". Often several **variants** (Figure 3) are launched at the same time to cover the marketplace and accurately meet the needs of individual (or groups of) customers - e.g. structural and non-structural sumps.

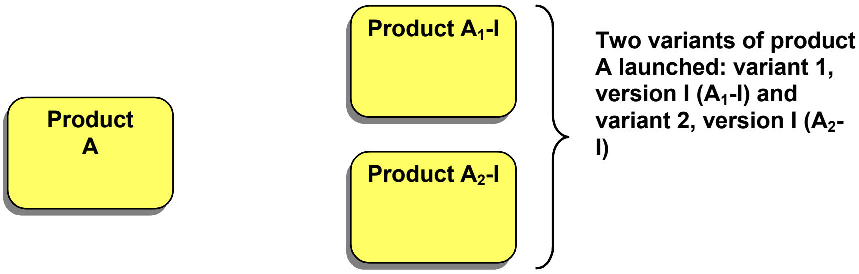

Figure 2 Product and Versions

The product works, but can be enhanced, so **new versions** are generated. Improvements are made for varying reasons (e.g. increase reliability, reduce cost, simplify assembly, etc.) triggered from various sources (customers, suppliers, manufacturing, etc.). The product is "matured". This will happen for all variants. During the development process it might become necessary to develop not just new versions, as it is often not possible to launch all versions at once. Also **new variants** of a product can be required if a version was overlooked initially or could not be launched at the same time due to a lack of resource. For example the diesel company created a naturally aspirated engine from the turbo version. **New products** can be added to the product range, either to reflect a staged introduction into the market or conquer new market segments: e.g. the engine family contains 3, 4 and 6 cylinder models.

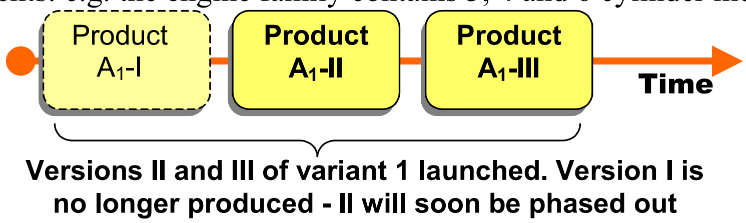

Figure 3 Version

3.2 Innovation

Innovation changes occur primarily during the planning and feasibility stage of product design, when companies develop products to meet new needs. However the need for innovation can also arise later in the process, when an innovative solution is required to prevent change spreading. For example the helicopter company invented a new vibration damper to avoid vibration spreading to a different part of the craft. One company interestingly termed this “emergency innovation”. These changes can be grouped into two categories, those changes where solution principles from within the company are used in an innovative way and those where ideas are taken from outside.

Internal Transfer happens between products in the company, when new innovations for one product are used for other products. For example new materials, such as lighter metal alloys are often introduced to an entire product range. Companies often try to avoid changing certain components or component groups and therefore have to be very creative to meet new requirements. For example, the engine company tries to avoid changing its engine block and its gear system; most innovation goes into the development of the fuel system or the ECM.

Inspiration from new technologies, rivals and products in similar marketplaces will also cause changes to be made to the fundamentals of the product. Sometimes these can be very radical e.g. the introduction of common rail technology in diesel engines or the introduction of a “fly by wire” equivalent in cars. Sometimes they can make slight improvements e.g. proposals to introduce pistons that do not require a gudgeon pin to link them to the conn rod. These new parts will need to be changed and adapted to fit the product. Besides idea transfer, innovation is often attributed to the application of first principle after framing a design problem in a new way (e.g. [8]). However companies still look for other examples of the same solution principle for reassurance and evaluation and are more likely to go with a solution alternative that already exists somewhere then with a radically new idea. So that it can be difficult to identify how much the other product served as inspiration or corroboration.

3.3 Changes in Development

Change in development can be split into two groups (see [3]). Initiated changes are enhancements to working products initiated by customers, suppliers or even the designers, who are often responding to new customer requirements, legislation, such as environmental legislation or technological innovations, such as new computer chips. This is a fundamental mechanism of product maturation. Emergent changes occur in response to problems with the product and can in turn lead to initiated changes in other products that could be afflicted by the same problem or enhanced by the solution.

3.4 Change in Operation

After the end of manufacturing, when the products have long been delivered to the customer they are still often changed to maintain or modify the product to adapt to new roles or expand its capabilities. Aircraft are frequently changed once they are in service, for example passenger planes retire to be cargo planes or are enhanced with upgraded engines to fly further and faster. These changes are often carried out by different companies, which are often licensed by the original manufacturer. During maintenance changes new parts or components are fitted to maintain the standard of performance. Careful design of the product architecture makes this form of change a simple and routine procedure.

4 Mass Customisation as change

Mass customisation aims to fulfil each customer wish ("customisation") at conditions and costs comparable to mass production ("mass") [12],[13]. It requires all sectors of the organisation to work fast and efficiently: marketing and sales must build up a clear picture of customers' needs and desires; production must become very flexible and all business processes, such as logistics, must be very smooth. Companies can take different approaches to mass customisation. A basic range of products can be changed to meet individual needs, as is the case for made to measure garments, where mass customisation is treated as change in development. The other extreme is to offer a modular product range, which is configured to meet customer needs. For example, fitted furniture is often offered as a modular stock range, where the customer might make changes during installation, akin to a change in operation.

However, most engineering companies will need to combine a well-planned product range with the ability to make changes quickly. This is already the case for companies, who customise their products for a large range of customers, such as the diesel engine company. To achieve real mass customisation existing approaches need to be improved and new strategies have to be implemented. The main idea illustrated in Figure 4 is to not develop a completed product with a definite amount of variants, but to design a comprehensive product spectrum, from which individual products can be easily derived [14]. The range of products that can be offered without further change grows increasingly. In this case Product development is divided into initial structure planning and the ongoing individual adaptation processes.

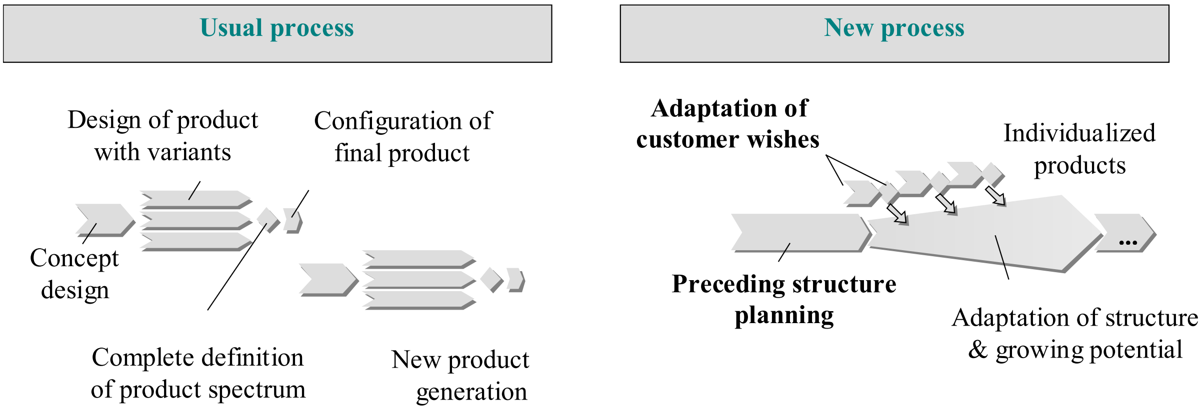

Figure 4 The development and adaptation process in mass customisation

Structure planning starts from existing product architectures or an idea of the new product as well as from predicted customer wishes; these can be derived from general customer characteristics, their use cases of the product, their need for social differentiation, or the underlying value system. A flexible and comprehensive product model is set up with a functionally structured modular architecture. The resulting product model need not cover a concrete product definition, except for marketing and testing purposes.

The adaptation process starts from the individual customer wishes and the product spectrum, which are mapped against each other. The process covers different (top down) cascades, placing the adaptation or change as late as possible in the value added chain, having the adaptation made by the customer himself, by a semi professional salesman, or by an expert designer, and using preferentially standard components, exchangeable modules, parametric parts, known principles, and finally individual concepts. Change due to adaptation can refer to general components, variants of the component, detailed and overall characteristics of the components or the product, relations and interfaces within the product, functions and principles, as well as requirements such as costs or the like. The experience of the single adaptation processes is fed back into the model of the product spectrum. Actually the focus is on that feedback and a continuously growing product spectrum; the spectrum need not be complete in the beginning, but after a while probably most of the possible customer wishes are covered, so that the plant's capacities can be concentrated on the new aspects. This continuously evolving product spectrum demands for an enhanced and integrated documentation of the product and the processes; new product generations might become obsolete or more infrequent [15].

Mass customisation might be regarded as a design for change, i.e. change is explicitly aspired to and answered by flexibility, transparency, as well as cascade classifications of process steps and realisations.

5 Inspiration as change

Mass customisation is a form of change in the later stages of the design process. A basic design has been created and now needs to be customised. Inspiration lies at the opposite extreme. It provides ideas for design at the beginning of the design process. The process is illustrated in Figure 5 (see [7]).

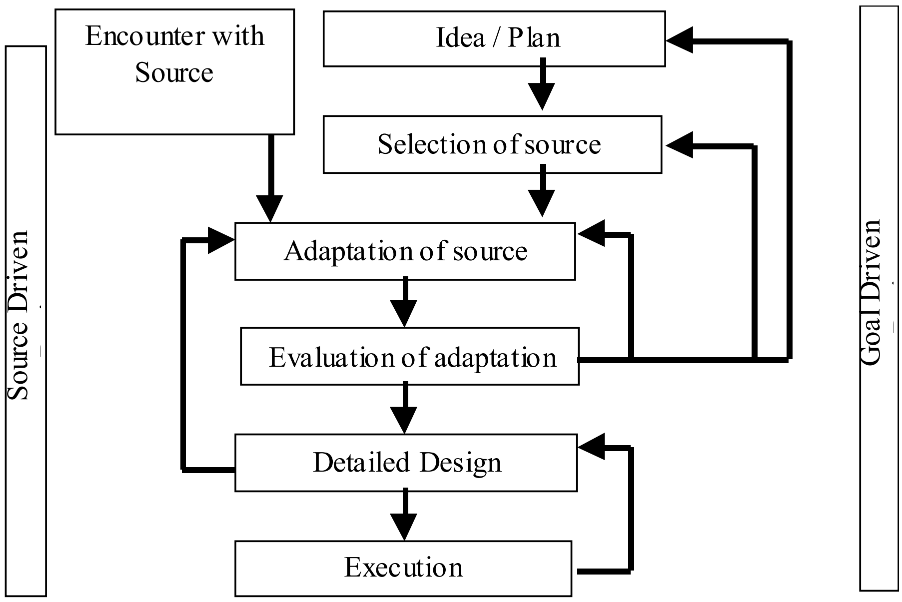

Figure 5 The use of sources of inspiration

Designers begin with either a conscious search for an idea for a problem or they come across an idea. Most of the challenge lies in the selection of a suitable starting design. In more artistic design domains, like knitwear design, designers look systematically through fashion magazines or books of designs from other domains, for example books on wall tiles; or they come across a design idea in their daily lives or when looking for something else. This process is systematic and structured; it occurs in a similar way in all companies at the beginning of the design phase for a new season. In engineering design no procedures for a systematic search for ideas exist, beyond a careful study of competitor products. For example car companies take their competitors' cars apart to look amongst other things for specific solutions to problem they are facing themselves. Transfer across industry sectors or product groups is usually highly serendipitous, and is most likely to occur when employees move industry sectors. Knowing this, companies often subcontract consultancies to develop novel solutions, because these forms can transfer more easily across industry sectors.

Transfer can rarely just occur without requiring major modification to the object that is changed. For example, in knitwear design a picture would need to be translated into a stitch structure. Designs are rarely based on a single source and either pull indifferent external sources together or more likely integrate a new idea with existing solutions. These in turn have to be changed to suit the new design idea. This is a frequent problem in engineering design, where every new innovation requires many follow on changes, for example if lighter material is transferred from a different industry for a key part, then the entire balance of the product needs to be recalculated. An inspiration transfer process can itself be quite iterative, because the adaptation and the integration can fail.

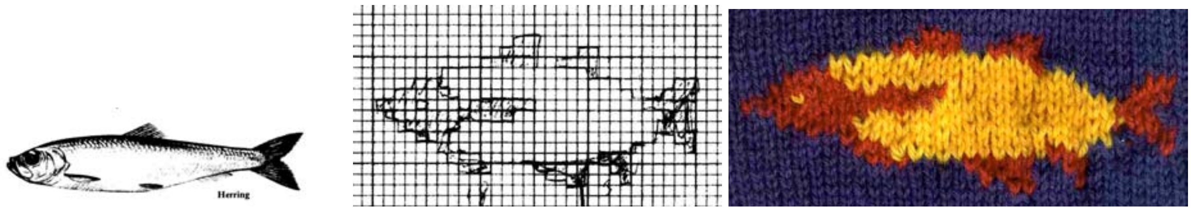

Figure 6 Example of an adaptation of a source of inspiration

6 Common problems

Most design processes can be seen as types of change process, which follow a similar process independent of the cause of the change. However the processes can be better understood and supported with tools and methods if the properties of the process can be characterised. The following discussing outlines some of the common problems (see [3]) that characterise change processes.

Most importantly change can propagate to other parts of the system through functional and behavioural as well as direct parameters. It is easy to see this with spatial links, for example if a pipe with a wider diameter is required, the diameter of the connector plug also has to change. It becomes much harder to predict for other product links such as thermal or electric links (see[4]). Further complexity is added because change can influence the procurement, manufacturing and maintenance. Change propagation is a difficult problem through the entire process. Of course it is easier to adapt to change at the beginning of a new product development process, than during development or operation. Therefore change propagation is perceived as a greater problem for mass customisation than for inspiration, but designers need to show awareness of the connectivity in both cases. Changes are almost always carried out under tight time, cost and resource constraints. Often the later the change, the greater the pressure. Here the greatest problem is to be able to predict the scope of the change early so that cost and resources can be allocated to the problem. This is most visible when companies need to tender for a new version of the product, for example a new version of a helicopter, or when a price needs to be provided for a mass customised option. If the options are costed more generally then the company must have awareness of the entire design space and all the expected interactions between all features of the product.

A big issue in all industry sectors is planning how a change process should be carried out. Some companies very carefully think through all the implication of a change using their best engineers. While they can come up with accurate estimates, this is rarely done for more then one change alternative. Other companies plan roughly using their expertise from past changes. This is possible for something like garments were the type of changes are well understood and the process can easily be costed. It is more difficult in complex engineering products, where small slips in the schedule can have huge overall implications. Designers need to decide whether they will treat the change as a structured design process or attempt to find a simple fix. Often it is tempting to underestimate the effort and assume if one just fixed one more part everything would be fine. The later the changes occur in the design process, the more likely designers are tempted into a quick fix rather than to address the problem systematically, so that an emergent change can persist over generations of products.

Parallel changes, when two more changes occur at the same time and interfere with each other, are often problematic. A simple example is when 5 mm clearance are available and three people want to use 2 mm each, not knowing about each other. These problems are often only spotted when different solutions are integrated and shift what could have been an early design change into a developmental change. It is important to look at different types of change processes within one framework, because many of them happen to occur at once or over the lifetime of a complex product, such as a helicopter. The challenge lies in the co-ordination of many changes, just as much in the best execution of every one of them.

7 Key Conclusions

Change spans all aspects of product development and occurs throughout all stages of a design process. Changes at the later part of the design process feature in mass customisation process. Mass customisation is at the forefront of developing techniques for designing products and product ranges, that can be changed easily. This design for changeability research will benefit the wider design community greatly, that has so far neglected design for change. Design processes in engineering begin almost always with the adaptation of existing products as well as the transfer of ideas from different products. This is very similar to inspiration processes in other industries, who have well worked out processes for keeping up to date with developments and searching for ideas. All of these changes share some of the same process challenges. Common methods to predict the impact of change, assist in planning change processes and handling parallel changes can benefit new product development, customisation and error correction just as much as mass customisation and inspiration.

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