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FRONT-END/BACK-END INTEGRATION IN MASS CUSTOMIZATION – A RESEARCH FRAMEWORK

Lars Skjelstad, Børge Sjøbakk, Maria Thomassen, Ottar Bakås
SINTEF Technology and Society, Dept. of Industrial Management, Trondheim, Norway

Abstract: *Manufacturing in Norway is expensive due to high costs and long distances. Still, some Norwegian manufacturers are amongst the most profitable in Europe. Some have found that mass customization (MC) can be a suitable business strategy in high cost countries, and have become top-notch performers of MC. Despite this success, there is a need for tighter linking of customer preferences and co-creation with internal operational activities in order to remain competitive. Therefore, the project CustomR will develop integrated solutions for mass customization. This paper presents the framework and research challenges guiding the research activities of the project.*

Key Words: ***Mass Customization, Research Framework, Solution Space, Choice Navigation, Visual Factory, Mass Customization in Networks***

1. INTRODUCTION

Many successful companies in Europe utilize mass customization principles. By focusing on solution space development, choice navigation and robust processes, these companies are able to compete globally despite the high cost levels in the West. In Norway, especially four companies have worked actively with mass customization over several years. These are goods manufactures of home and office products in metal and wood, such as office chairs, kitchen ventilators, doors and windows, and metal products. They have developed their skills of producing customized products over many years, and are performing well within their markets. As an example, one of the companies is able to manufacture more than a billion variants in a fully automated production line, with a true one-piece flow of goods. This is within an industry where traditional make-to-stock batch production is the standard. The company can deliver customer specific products from Norway to main European markets within 5 days, often faster than their competitors in Western and central Europe. At the same time, the profitability of the company is the best within its sector.

Even though the companies perform well, they face multiple challenges. For instance staffing issues, lack of coordination and disrupted product and information flows result in weakened deliverability and excess capacity in periods. Such challenges can be ascribed to insufficient integration of *front-end* (e.g. customer choice navigation processes, product configuration, user interfaces and customer behavior patterns) and *back-end* (e.g. order management, purchasing and production planning and control) systems. For instance, the companies rely heavily on dealer networks, which severely influence how the customer is exposed to the solution space and how efficient order information is transferred to the shop floor. In addition, the companies receive little feedback from both the choice navigation and use phases of their products, providing little basis for solution space adjustment.

Such challenges are not unusual. Often, companies pay extra attention to specific technologies, or aim for the ideal product mix. Much of the research on mass customization reflects a functional focus, considering e.g. product design, marketing and manufacturing individually [1]. However, in order to truly succeed as a mass customizer, customer/manufacturer integration is key [2]. For many companies there is still an untapped potential in tighter integration of front- and back-end systems; i.e. linking customer specifications with operational activities [3].

With that in mind, the companies and research team was recently awarded with a new research project, *Custom^R* (2016-2019), funded by the Research Council of Norway. The project's overall idea is to develop integrated solutions in the interface between customers' preferences and the internal processes of the company. The companies aim to improve their abilities to develop tomorrow's products and services, based on real customer choices and usage patterns, through tighter integration of front- and back-end elements. In addition, the project aims to investigate potential effects of network collaboration in mass customization. So far, the academic discussions of network-related issues in mass customization have focused on the relationship a company needs to have towards its suppliers in order to provide customized products and services to its customers [1,4]. The project will look further into how mass customization can be obtained from a network perspective. In particular, we aim to investigate the potential of offering joint solutions that the customer need, more than offering choice navigation within a single product segment.

The purpose of this paper is to present a research framework and some core research challenges for front-end/back-end integration in mass customization. This includes looking further into core areas such as solution space development and choice navigation, together with

less established topics such as the visual factory and network-based mass customization. The framework primarily serves as a reference framework in Custom^{R}, where it will be used by the research team and the involved companies to find better solutions to integrate front- and back-end systems in their specific context. However, the authors believe that the framework can also serve as a starting point for complementary future research on such integrated mass customization.

2. EMPIRICAL BACKGROUND / RATIONALE

The four partner companies of Custom^{R} are different in terms of design, marketing, sales, modularization, manufacturing, distribution etc. Over the last years, their improvement effort has differed, due to e.g. varying focus and starting points, and some are more mature mass customizers than others. However, they all share the need to integrate and visualize front- and back-end operations to a larger degree. The four companies are further described below. Table 1 summarizes some of their characteristics and past and future improvement efforts.

2.1. Company A – Doors and windows

Company A combines good workmanship with modern production processes when they make custom doors and windows in its new production facilities. The business is set up for industrial production of quality products in a market where architects design individual solutions for an ever-increasing share of the houses and windows. The products vary by type of glass, insulation degree, shape, size, crossbars and posts, opening possibilities, hinges and fittings, sealing and colors.

Even with a growing proportion of the windows made with special dimensions, a few orders each month still includes what is called standard windows, i.e. standard dimensions and a predefined white color. For Company A this makes no difference; they still make windows according to each customer order. However, a small stock of standard windows is built in low volume periods, for consumption again in high seasons.

In the last years, Company A has reduced its delivery times, and this work continues as the benefits for customers and internal departments are vast. Further reduction of delivery times will require better utilization of equipment and management system. A main challenge is to give employees tools that keeps them updated in their dynamic situation, without leaving their workstations. Company A foresees a growth in demand for windows specified exactly to the building owner's preferences.

2.2. Company B – Office chairs

Company B produces approximately 250,000 office chairs per year, or more than 1,000 every day. All chairs are commissioned by clients with personal wishes with respect to how their chair should look like. The office chairs are produced based on individual needs in relation to the height of lift, whether it should be armrests and headrests or not, what upholstery method to be used, and of course both metal and textile colors and textures. The products consists of modules (wheel base, gas lift, seat widths, back heights, arm rests, head rests etc.), which all offer some customer options to a small or large degree. The modules have the necessary common interfaces to be connected. The solution space is enormous compared to the number of module variants, due to all possible combinations and types of upholstery etc.

The workforce is accustomed to the everyday alternation of customer orders, and that each days plan is different; tomorrow contains a completely different order mix than today. Employees realize that all chairs are potentially unique, yet they are all the same when it comes to manufacturing. Manufacturing set-up is designed for batch size of one, and the goods flow is efficient regardless of which chairs are coming down the line. Everything is made to order, and components for one day's production are made and delivered the day before to minimize stocks.

Automation and a flexible workforce makes it possible for Company B to have production in Norway. Despite the country's high cost and potentially long distance from the market, the company actually considers production in Norway as an advantage. Here, operators have communication skills and are used to take responsibility. When introducing new technology, it comes into operation quickly. Further, conditions for continuous improvement are beneficial, as operators are willing and eager to contribute to increased competitiveness.

As the daily demand may vary significantly with respect to customer orders and manufacturing throughput, the workflow load moves, and hence operators need to go help where needed. This calls for responsibility awareness, and modern communication technology. Today, quick coordination meetings at lunchtime solve the total capacity consideration. However, Company B sees the need to visualize the flow of goods and information, as well as transforming customer orders to production orders more automatically. The latter calls for more sophisticated choice navigation solutions.

2.3. Company C – Kitchen ventilators

Company C offers a wide range of kitchen ventilators. There are model series for every purpose; from straight walls to corners, and free hanging units. In the recent years, the company has noted a shift in the market – from standard products towards individual variants. Therefore, all models can now be customized according to individual requirements, such as height, width, depth, color and type of wood/metal. The company works with many materials to offer something for every taste and style, and can even measure the color of the customers' existing kitchen and recreate this if necessary – enabling retrofitting that does not conflict with the kitchen's wear and tear.

Production takes place in modern facilities. Standard components can be made partly unmanned at night. The company postpones most customization to the final operations of its manufacturing value chain, in the assembly- and paint- departments. However, it also offers custom measures, and then components must be made from scratch. Such special sized products are made individually in programmable machines, where paths for milling machines etc. are generated automatically by the control programs when appropriate measures and parameters are entered. Company C assembles, packs and sends products with customer labelling several times a week.

Company C has worked on improving its production processes in recent years, and currently has a high degree of automated metal and wood working. The company's next step is to better manage its product portfolio, and improve and more tightly integrate the choice navigation process with production.

Table 1. *Overview of companies*

Company	A	B	C	D
Products	Doors and windows	Office chairs	Kitchen ventilators	Waste handling & cleaning
Solution space	"Infinite" (only limited by physical size)	More than 1 billion	Thousands (full NCS/RAL color range)	Thousands (full NCS/ RAL color range)
Primary sales channel	Builders' merchant	Office furniture dealers	Kitchen suppliers	Large scale projects
Important stakeholders	Carpenters, architects, end customers	Interior architects, company buying departments, end users	Kitchen suppliers, interior architects, end customers	(Interior) architects, Project owners (e.g. airports, schools), end users
Demand and production characteristics	Mostly make-to-order, some standard dimensions make-to-stock due to seasonality and predictable demand, batch production for large orders, otherwise one-piece flow	Make-to-order, varying order sizes (from one to hundreds), satisfies in average more than 1000 customers per day, one-piece flow	Make-to-order, one-piece flow	Mix of make-to-order (project orders) and make-to-stock (predictable demand), mostly batch prod.
Product variety determinants	Glass, insulation degree, shape, size, crossbars and posts, opening possibilities, hinges and fittings, sealing and colors	Gas lift, wheel base, seat width, back height, armrests, headrests upholstery method, metal and textile colors and textures	Model type, material, size, color	Model type, color/ design
Main improvement focus in the last years	Reduction of delivery times, process improvement	Workforce training, continuous improvement, material flow automation	Production process improvement and automation	Production planning and control, automation
Main challenge/ future focus	Visualization of goods and info. flows, visual tools that keep employees updated about production progress and priorities	Visualization of goods and information flows, tighter integration of customer orders and production orders	Solution space development, choice navigation, visualization of goods and info. flows, integration of customer and production orders	Visualization of goods and info. flows, materials handling, choice navigation, product smartness

2.4. Company D – Waste handling and cleaning

Company D produces steel products for waste handling and cleaning, like public waste bins and trolleys for e.g. hotel cleaning staff. The company designs its products from steel plates and pipes. With laser cutters, punch presses, bending machines and welding equipment, all products are efficiently produced in small series.

An increasing portion of Company D's customers wants to be able to customize products according to its needs. For instance, it is increasingly common that an architect whilst drawing defines stations for waste containers. Waste separation requires several containers in proximity to each other. Increasingly, such waste stations are made to match the profile of the restaurant, shop or service near to which it is located. Company D is able to handle such customization in its paint and assembly processes, which has made it a preferred waste furniture partner in the planning of new buildings. The company's transformation towards mass customization over the last years has been very successful.

Company D manufactures mainly according to customer orders; however, some high volume products and components with predictable demand are made to stock. The company's visual management system shows in real time how the actual workload situation is in its four production departments. This helps utilizing the capacity for the benefit of customers. The business has grown steadily in recent years, and Company D's ambition is to satisfy even more customers in years to come.

3. RESEARCH FRAMEWORK

While a lot of research exists within core areas of mass customization, such as choice navigation, solution space and robust processes [5], there is still a large potential in further integration of important functions and activities. Broadly speaking, there is an identified need for tighter integration between customer preferences and internal processes, i.e. the front-end and the back-end. Relevant activities include, but are not limited to, the customer's choice navigation, order management, production planning and control, customer relationship management and product and service development. Based on this need for integration, we have developed a research framework for mass customization (Fig. 1). We argue that the front-end and back-end should be tightly integrated by the choice navigation and solution space, and that big data should be used to continuously monitor and refine, if necessary, what is offered to the customer and the processes in place to deliver what is offered. Core elements of the framework, as well as examples of research challenges, are further described below.

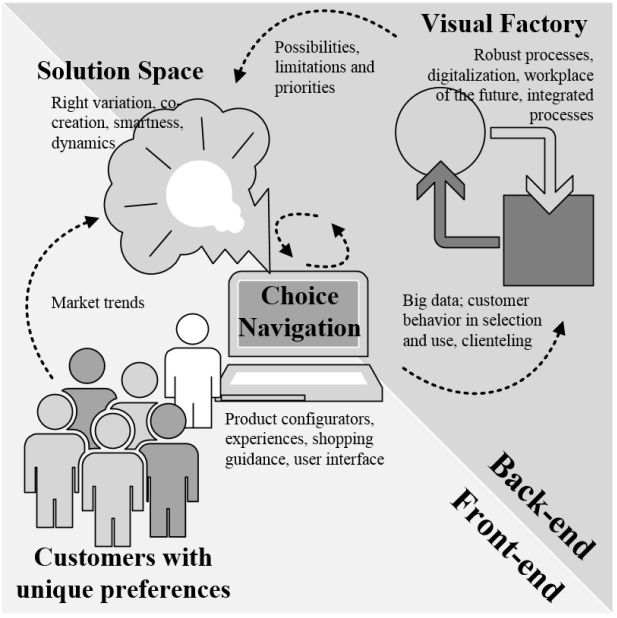

Fig. 1. *Research framework*

3.1 Choice navigation

Choice navigation is about supporting the customer in choosing the solution that maximizes customer value within a predefined solution space [6]. Solutions for choice navigation are essential for many reasons. First of all, it guides the customer in locating the product or service that best fits his or her preferences. Second, the process of configuring can itself be considered a customer experience [7]. Third, the customer's choice is a basis for technical specifications, like bill of materials, production sequences and technical drawings needed to provide the required product or service [3,8]. Integration between these systems are a critical success factor in mass customization [7]. A key challenge is that the customer in the face of too many choices will experience choice navigation as a cost, due to e.g. the time it takes and frustration from cumbersome solutions [9,10]. Therefore, it is important to minimize the complexity of choice navigation [5]. Some core research challenges related to choice navigation are:

- How can companies systematically build choice navigation capabilities?
- How can product configurators be designed to best guide the customer and maximize the experience of choice navigation?
- How can information efficiently be used to integrate the front- and back-end through the use of product configurators, and how can this information best be exploited?

3.2 Solution space

Being able to specify products is essential in mass customization. In situations where the range of variants is too small one will often experience loss of sales. At the same time, variation comes with a cost [11]. In mass customization, there is a tendency to quickly reach an astronomical number of theoretical product variants. Often, only a fraction of the variation offered to the customer, the *solution space*, is exploited. This can be caused by e.g. poor choice navigation, where one offers sufficient variety but is unable to communicate this to the customer, or that the offered variety is not in demand by customers; i.e. one is offering the wrong products [12]. The solution space must be carefully defined to provide the *right* level of product variety. Defining the solution space is a dynamic or iterative process, as customers may change their preferences over time. In this respect, data collection through choice navigation and external market trends may be a valuable source of information. Another approach is to offer smart products; i.e. products that contain information technology like microchips, software and sensors that enable collection, processing and production of information [13]. Smart products can adapt to their environment and user patterns. As such, they can ease the choice navigation process, as a company is able to offer more standardized products (i.e. a smaller solution space) which adapt to the customer's type of use. This user data can be used to adapt the solution space and increase the robustness of the back-end production system. In this way the customer is involved in a form of 'cocreation' [14] product development process. Some challenges related to the solution space are:

- How can companies efficiently scale the solution space, and how can market trends and data from choice navigation and customer use contribute to this?
- How can mass customization companies release the product smartness potential?
- How can customers to a larger extent be involved in development of front- and back-end solutions, e.g. through sharing of user data?

3.3 Visual factory

In most companies the access to information is not a problem. However, the internal sharing of this information is often inefficient. This poses a challenge in a time where changes become the norm, and input from the front-end is ever more important for back-end efficiency. Increased visibility is a means for increased performance [15]. A visual factory is well-organized, tidy, in good condition, standardized and disciplined. Visual workplace practices drive productivity through empowerment of operators – allowing them to make decisions based on right information available at the right time [15]. Increased digitalization makes it easier to rapidly share information to both employees and visitors in the factory. Further, it enables seamless transfer of information from customers' choice navigation and use phases, e.g. as product specifications directly uploaded to manufacturing technology like 3D printers. Core challenges related to the visual factory are:

- How can information from the front-end seamlessly be transferred and communicated to back-end functions, and how can these exploit this information in the best way possible?
- How can the workplace and workforce of the future look like?
- How can increased visualization help increase operator productivity and, at the same time, increase visitors' understanding of the value creation?

3.4 Mass customization in networks

Supply chains play an important part in mass customization, as suppliers, distributors and retailers need to adapt to the business strategy and what follows from it in terms of closeness and lead time requirements [4]. However, there is arguably an untapped potential in having a network of complementary mass customizers that can collaborate to offer a larger package deal to customers. For instance, doing choice navigation in a product configurator containing products from multiple producers may be a better experience than having to use multiple systems. At the same time, the solution space if expanded without adding any further variation in each producer's processes. While not depicted in Fig. 1, this is an area that will be further explored in Custom^{R}. Core challenges are:

- How can products from multiple producers be collected in the same product configurator to offer the customer a customized package deal?
- What synergies could be realized from mass customization in networks, for instance in terms of increased buyer power, collective shipment and additional sales?

4. DISCUSSION

4.1 Key innovations

The framework highlights key mass customization areas associated with a high level of innovation potential. Regarding choice navigation, a significant amount of solutions exist that support the customer choice process, and the use of product configurators is widely applied in many industries, especially among large companies. There is however limited understanding of determinant factors of a successful choice process. A practical roadmap for the development of appropriate choice navigation tools is expected to help companies to establish direct contact with end-customers and ensure a highly efficient product configuration process.

A method for developing a company's solution space is another expected key innovation from the project. Such a method will help companies to establish a right balance of the scale and scope of variants to be offered. It involves the combination of data from the choice navigation process and use phase of the product, and information of production process capabilities.

A new visual factory concept that is based upon advanced technologies and high level of automation will be developed. Norway has a strong position with regards to the application of new technologies, with high usage of computers, internet and smart phones. The concept is expected to improve a company's mass customization capabilities including production planning and control, learning and development, leadership, and employee responsibility and involvement.

As mentioned, the supplier perspective of mass customization is widely dealt with in literature. However, there is limited research on e.g. coordinated deliveries in supplier networks. The model of network based mass customization is a groundbreaking innovation by addressing the coordination of a complete delivery including individual deliveries of custom products from multiple companies.

Finally, existing research typically addresses issues isolated to specific mass customization areas, such as either choice navigation or robust processes, rather than taking a broad and integrated perspective. There is also a lack of practical tools and example cases for companies aiming to become excellent mass customizers. Therefore, a roadmap for integrated mass customization is expected to constitute a key innovation.

4.2 Potential value creation

The companies expect to achieve major benefits in terms of increased revenues and market shares, reduced operational costs and shorter delivery time. They experience an increased demand concerning customized products and product configuration choices, and seek to strengthen their position as customer-oriented suppliers of high quality products. Increased revenues and market shares are expected due to numerous improvements, such as: increased delivery precision and reduced delivery times of customized products; better offering through improved knowledge of customer preferences, as well as easier and more entertaining choice navigation; improved solution spaces, offering the right amount of product variety.

With respect to the latter, web-based configurator tools may enable access to the assortment to new customer groups as well as facilitate sales to both professional and private customers. In terms of operational improvements, better control of the product portfolio and production lines by tools for visualization, monitoring and tracing is expected to improve utilization of production capacity, delivery precision and shorter delivery lead time. Also, increased digitalization of current information flows is expected to reduce costs related to sales, order management and production control. Solutions for visualization of capacity and resource needs in the factory combined with new organizational models are expected to contribute to increased responsibility competence and flexibility among employees.

5. CONCLUSION

In order to truly succeed as a mass customizer, we argue that a tight integration between front-end (e.g. customer choice navigation processes, product configuration, user interfaces and customer behavior patterns) and back-end (e.g. order management, purchasing and production planning and control) systems is a critical success factor. This forms the basis for the research project Custom^{R}, which is supported by the Research Council of Norway. The project will develop ICT-based solutions for managing the interface between customer co-creation and internal processes, as well as explore the potential of network based mass customization.

This paper has presented the research framework and some key challenges guiding the project. The framework also serves as a suggestion for a research agenda, where we encourage others to pursue innovations within the scope of integrated mass customization, possibly complementing and expanding the scope of our research. Even though the framework is developed for goods manufactures of home and office products in metal and wood, the framework may be relevant also for companies of other sectors, such as the healthcare and the food industry, where customer information play an important part in reducing lead times and optimizing what is offered to individual users and customers.

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CORRESPONDENCE

Lars Skjelstad
SINTEF Technology and Society
Dept. of Industrial Management
S. P. Andersens veg 5
7465 Trondheim, Norway
lars.skjelstad@sintef.no

Børge Sjøbakk
SINTEF Technology and Society
Dept. of Industrial Management
S. P. Andersens veg 5
7465 Trondheim, Norway
borge.sjobakk@sintef.no

Maria K. Thomassen, PhD
SINTEF Technology and Society
Dept. of Industrial Management
Forskningsveien 1
0373 Oslo, Norway
maria.thomassen@sintef.no

Ottar Bakås
SINTEF Technology and Society
Dept. of Industrial Management
S. P. Andersens veg 5
7465 Trondheim, Norway
ottar.bakas@sintef.no