8th International Conference on Mass Customization and Personalization – Community of Europe (MCP-CE 2018)

Digital Customer Experience
September 19-21, 2018, Novi Sad, Serbia

MANUFACTURING CONSIDERATIONS IN SOLUTION SPACE DECISIONS

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Abstract: *In this research we focus on both strategic and practical sides of managing the solution space more actively, hence turning it into a tool for development and positioning for the manufacturer. It is common to classify available customer choices into the categories of function-, form- and fit- choices, covering all the product -performance, -design and -size issues. This research suggests two new views on the solution space to help balance the customer and manufacturing perspectives. One is what we denote solution space archetypes, and the other is a 4-step process to better adjust solution space content to manufacturing capabilities and vice versa. We discuss how these views can help exploit existing systems and decision making regarding future solution space development, and how increased awareness of the existing solution space can help foster ideas for developing new offerings. The research is based on co-operation with three Norwegian case companies.*

Key Words: Solution space, mass customization, customer centric

1. INTRODUCTION

Mass customization (MC) is a business strategy in which companies profit on the fact that customers prefer specific and individualized products over standard ones, and that a premium price can be justified for these items referring to the higher level of customer satisfaction these adjusted offerings represent for the buyer [1]. To succeed, businesses must strive to put their customers in the center of all activities, to become customer centric businesses. Only when all processes are focused towards the needs of the paying customer, the company can fulfill the task of serving every customer uniquely [2]. And, customer interests change over time. This implies that the situation for the company becomes dynamic in terms of ever changing daily order mix and also on the long run due to the continuous development of new offerings to meet customers changing needs.

Customers' reasons for wanting individual products are many, including personal style, the need to differ from others, adjustment of size or proportions, the personal satisfaction of being a designer, the adjusted performance of the product etc. Previous work has classified types of customer choices into the categories *fit*, *form* and *function*, covering all areas of interest and simultaneously contributing to simplicity and focus for the companies. To cope with the situation of satisfying all customers, companies must master the three core capabilities; *solution space design*, *choice navigation*, and *robust processes* [3].

The solution space is a term used to describe what a company can offer in a mass custom scenario and not. Products not suited must be treated as either "one of a kind" with higher costs and longer delivery time, or even a solution that is not possible or desirable to make. Also, product configurations that are not appropriate in terms of functionality or design can be excluded from the solution space. The solution space must be concidered to be dynamic and developed continuously, and of course, todays boundary is always excluding future bestselling products not yet developed. If a range of different products are offered, separate solution spaces will exist for each product family. All companies have one or more solution spaces describing their product range. Mass producers might have a small one, containing their limited range of products, but still their offering constitutes their space of solutions, however tiny it might be.

Choice navigation is the capability to support customers in identifying their solutions, whilst minimizing complexity and burden of choice. Offerings can easily be presented in a non-structured way, in a wrong order, or with too many choices at the same time, all resulting in an overwhelming process [3]. Suppliers cannot involve to much in customers purchasing process (journeys), since they should compete with mass producers on costs. A proper choice navigation system makes the customer journey an experience itself, leading to solutions that satisfy individual needs better than standard products, and also giving the company a chance to increase revenues. Choice navigation include brochures, web-pages and digital configurators, and helps define a preferred solution by matching the

characteristics of an existing solution space (set of options) to the customer needs [3].

Robust process design encompasses the capability to reuse or re-combine existing organizational and value chain resources to fulfill a stream of differentiated customer needs [3]. It can be achieved by flexible automation, process modularity and adaptive human capital. New technologies make it easier to communicate with customers and to manufacture a wide range of products, whilst education and training in new operations and technologies empower people to create more flexible operations. The goal is a factory with capablity to manufacture according to *series-of-one* thinking.

All three capabilities are comprehensive to develop, and more so if done simultaneously in a seamless way [4]. Researchers [5] discuss that the strategy of mass customization hasn't been adopted as much as expected in industry, and mentions market awareness, complicated value chains, burden of choice etc. as reasons for lack of spread. Also, not placing customers at the centre of all activities, or changing the mindset sufficiently from the mass production outset, could be reasons behind that some struggle [6]. Others document that the strategy of MC is applicable to more industries than first considered.

Recently, also the issue of open innovation is suggested as part of the invitation to customers when circling in what kind of solution they demand [7].

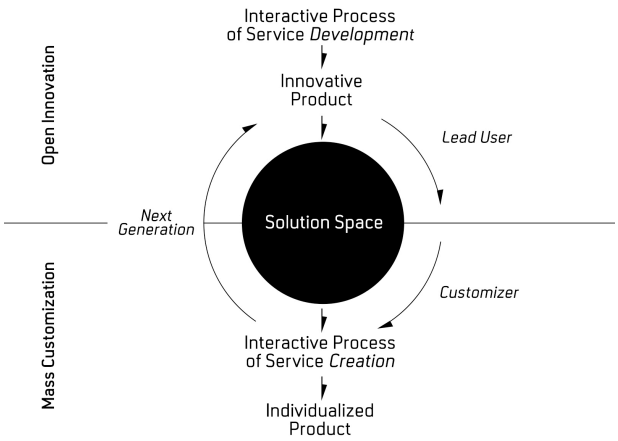

Fig. 1. *Open innovation and the solution space*

With the introduction of open innovation (Fig. 1), the need to know own capabilities in physical and administrative processes is becoming even more essential. With the core capabilities in mind, companies must manage their effort within MC to be able to offer superior performance to customers. The performance criteria for MC is simultaneous high score on *short deliverytime*, *low cost* and *sufficient degree of customization*. The two first stems from mass production, whilst degree of customization is added to cover the contradiction already embedded in the term mass customization, as it was coined by Stan Davis in 1987 [8]. High score must be simultaneously achieved on these three performance criteria to be a true MC executer [9].

Between the three core capabilities, one might suggest that dealing with the solution space is the less operative of them. Both *robust processes* and *choice navigation* are more hands-on topics that involves physical systems or digital tools, whereas the solution space is more abstract, although it represents products and their attributes.

There is a set of trade-offs to be dealt with when addressing the development of a solution space. Trade offs between increasing or decreasing the solution space, and trade-offs between customer and company interests. A two by two matrix covers the span in interests;

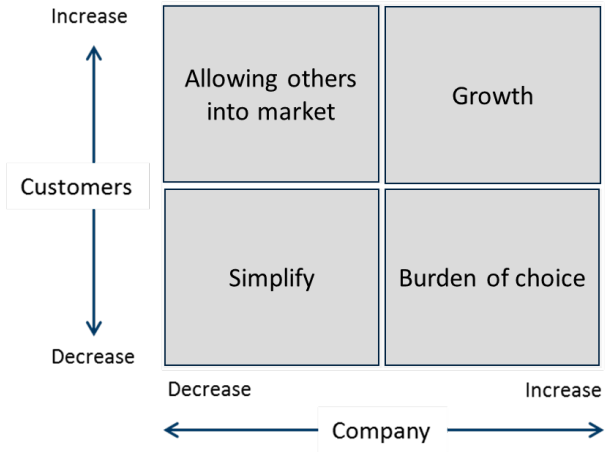

Fig. 2. *Trade-offs in solution space design*

The matrix in Fig. 2 indicates that both customers and companies have reasons for increasing and decreasing the solution space. There might even be a situation of equilibrium, where both customers and company are satisfied with the offerings, but a situation that demands no actions is expected to be just temporarily and hence not discussed here. If the solution space is too large from the company's perspective, because of i.e. increasing costs or complications, the response to decreasing the space would be depending on the customer's expectations. Either customers too want it smaller, leading to a simplification of the situation, or if they expect it to increase, leading to a situation where other companies could enter the arena more easily. If the company sees that it might increase their offerings towards customers, again two scenarios could be possible; Either customers want an increase two, leading to a positive growth situation. But if they want to decrease, maybe because of a need for simplicity, the so called burden of choice would increase.

Even if the main challenge is to satisfy customers, there is a need to be effective in manufacturing. Initial questions include; what defines the as-is solution space? Is it what's offered to customers or what customers end up ordering? Or is it what the company is capable of providing given existing processes and capabilities? And, has the space a sharp border towards what is not included, towards offerings outside the space, or is it a bit flexible concerning about what is on the inside and the outside?

A screening of the literature concerning solution space development was done, looking into topics such as; what are the characteristics of a well developed solution space, who are the different target groups for the solution space, what methodologies for development of solution spaces exist or is in common use, how to

visualize the space itself, how to involve customers and open innovation into a continuous development process, and what can be learned from *big data* about use. Much of the literature seems to set out from product development and modularization. There is a need for simple useful methods for SME's [10].

This research focuses on the solution space, and suggests new considerations to increase the awareness of the solution space and discuss how to help exploiting existing possibilities from a manufacturing point of view. It contributes to the discussion by introducing two new ways for companies to better consider their solution space and to be more aware of their limitations and possibilities. Both for strategic longterm planning, and for short term decisions involving pricing.

The paper first introduces the reader to the trade offs that stems from managing a dynamic solution space. Then the research method is described including introduction of four cases, before a discussion and presentation of our conceptualisation of how to get to know the limitations and possibilities of the as-is solution space. Future work is pointed out after the conclusion.

2. RESEARCH APPROACH

The research is a combination of empirical and conceptual work. In a project funded by the Norwegian Research Council, different improvement areas for mass customizers are investigated together with three manufacturing companies. Our action research approach is conducted in close co-operation between researchers and company employees and managers, addressing issues of general character amongst the companies. A literature screening about solution space development and related topics was conducted. The awareness of how existing processes influence the solution space design is not dealt with to a large extent in literature, and the companies signal a need for better co-operation between product and process development, how to best describe their existing solution space, and how to estimate a cost/saving connected to increasing or decreasing the AS-IS solution space. They claim that they find the solution space management as the least operational of the three core capabilities mentioned earlier, and hence signal the need for even more work on the topic in the future to e.g better determine what the next attribute offered means in terms of manufacturing complication and costs, and also how to best exploit the limits of what existing processes can do.

Our work included discussions, workshops and an internet search for topics like solution space - development and -visualization.

The three partner companies represents different industries, but have in common that a large amount of their sales is done through distributors and retailers. They don't necessarily have first hand dialog with customers.

Our focus has been on awareness of the solution space content, mostly from a manufacturing point of view. Companies report on the need for more tools and considerations about deciding on the content and borders of their solution space.

3. RESULTS AND DISCUSSION

For mass customizers, some of the operations in the long process from getting customers awareness to supplying them with a specific product or service, are more demanding than for other types of manufacturers such as mass producers or those who deliver defined variants. Maybe even so demanding that potential mass customizers are holding back on their adoption of the strategy of mass customization in fear of overwhelming tasks and costs. The need for examples and tools is still prominent, also on how to manage the three core capabilities of MC, in order to score simultaneously on the performance criteria cost, time and customization.

Companies must create robust processes and communicate what is inside and outside of the solution space, not to end up selling products that are not easy to make. In this context the solution space development is important for many reasons. There are several functions that need to be addressed to get a conscious and active use of the solution space. Examples of drivers for customers to wish for a bigger solution space can be changed needs or trends and fashion. A reduced space can be motivated from burden of choice, where confusion might occur instead of increased satisfaction. Companies might want to reduce the offerings due to cost issues or brand considerations such as reputation or design flops. Reasons for increasing might be that they have the possibilities already in their process to more variants or they fear competition.

When designing the solution space, the company defines which parts of the product can be designed by the user, and what parts are determined. Our own list of drivers for considering changes in the solution space was generated in workshops with case companies and include;

- Offerings should be affordable to most customers, need for efficiency
- Exploit own capabilities
- Customer needs and trends change
- Match solution space with current needs
- Interest in reducing or simplifying the solution space in terms of keeping costs down
- Need the choice navigation tool to be simple, but still present all available options to customers
- Old solutions might need old technology or suppliers, must define if it is possible
- Sometimes we face a dramatic increase in raw material costs
- The process of moving from as-is towards to-be calls for internal resources, not possible at all times in SME's like ourselves
- It seems natural to include customers in developing the solution space (i.e. Fiat 500)
- Important to apply a different strategy for items outside the solution space. Must know when to say no or charge a *one-of-a-kind* price

- Strategic dispositions sometimes influence our thinking concerning the solution space, like if we want to be connected to the new proposed solution
- We need better visualization of the as-is space. To see what we have, and possibly foster new ideas. Would like to see where our strengths and weaknesses are
- The business has ideas for service development, stepping up from products to services and experiences

Sometimes customers ask for products that are outside the solution space, and the companies still respond positively to manufacture them. For instance a request for too large windows. It will lead to a series of internal questions and discussions like; can we assemble and do the glassing manually, outside the normal process? Is it a strategic customer? Will the delivery bring more work later? How big is the order? etc. In some of these situations the companies choose to actually say yes to these orders they feel is outside their primary solution space, for different reasons; First, they are not always sure about their manufacturing limitations (solution space borders), and second, they consider strategic issues in addition to the MC arguments.

To start working on solution space issues, the companies first created a table describing attributes and type of choices pr. attribute for their own products. Not a difficult task to perform, knowing their products well. Parts of one result is shown in Fig. 3 below.

Fig. 3. *Part of the attributes overview for Coupled windows*

Then this first table was turned into a Tree of External variety (TEV's) [11] for each company, which is a view of the attributes available for a product (Fig. 4). In this view, the options described can also be classified into the categories of -function, -form and -fit, leading to a standard looking TEV. Still, the tasks were considered easy to do also for SME's.

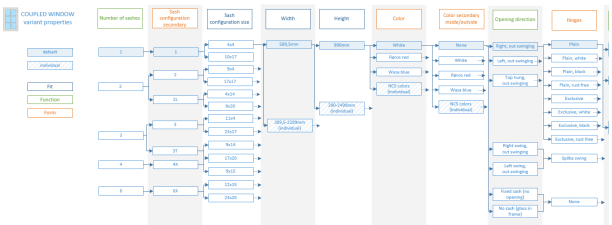

Fig. 4. *Part of the tree of variety (TEV) for Coupled windows*

In this view one can indicate in top of the columns which of the -function, -form and -fit category the attributes are sorted within, by applying different colors. From this outset, which is a first view of the solution space, we decided to go in two directions;

1. defining and viewing solutions space archetypes, and
2. defining steps to identify todays manufacturing limits on the solution space

Manufacturing limits are necessary to be aware of in terms of defining quickly what is inside and outside the defined room. Being able to communicate to customers the limits within which they can design their product is essential. Also, to be able to respond rapidly the new leads with respect to correct pricing calls for knowledge of limits in the organization and processes.

3.1. Identified solution space archetypes

During this work we have seen different types of solution spaces with respect to what is offered within the categories -function, -fit and -form. This observation is interesting because it can help in the discussion about how the solution space is shaped, what are the predominating choices available to customers now, and what should be investigated for further development. We denote the different solution space types available for *archetypes*. In Fig. 5 below, all generic archetypes of solution spaces are shown as function of the dominating area of offerings.

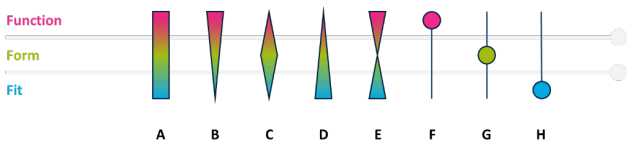

Fig. 5. *Different shapes of solution spaces as a function of how important the function, form and fit categories are for the offering.*

In Fig. 5, the solution archetypes are denoted A-H, with the most comprehensive being the A-type. For this type all of -function, -form and -fit categories are represented as choices for the customer. The case companies are also classified according to their solution space archetypes, to serve as examples of some of the archetypes, but first we look into the types not represented by a case company. These can be seen in Fig. 6.

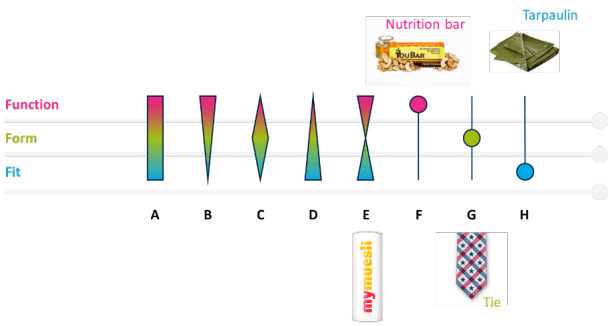

Fig. 6. *Examples of products of the types E-H solution space archetypes*

- MyMuesli serves as example of a solution space Type E. Their offerings are not so much about design, but rather customized content (muesli, representing unique function) and size on orders (number of tubes).
- Anthony Flynn's YouBar is a nutrition bar of your own choice, where individuals design the content of the bar with respect to allergic and caloric aspects. The size and design were not very important in the beginning, and hence we use it as an example of a Type F solution space here. However, the company later expanded their offerings to include design of packaging and label, in fact you can now name your personal brand of bars.
- A tie is all about design. Few functional- and size-issues are central for the user, but design varies a lot and can be customized. Type G solution space.
- Finally, some products are mainly about fit, Type H. A tarpaulin can be used as example, where *function* and *form* often are standardized, but the *fit* category is used to adjust to needs. In many cases even *fit* is offered in standardized steps.

The examples over are just constructed examples of what can be representative products to describe the types E-H. All these solution space archetypes have limited solution spaces in terms of the choice categories defined. From the participating companies the types A-D will be shown. It can be seen that the A-type is most comprehensive, using all categories of choice to full. Types B-H have one or two dominant areas of choice, indicating what is not exploited so far and hence a direction of thinking when renewing or improving offerings.

A way to make developers conscious about own offerings and to create awareness about what might not be thought of so far. Examples from discussions are provided in the case descriptions.

3.2. Case studies

Three Norwegian companies participate in these discussions, all applying a mass customization business strategy. They are relatively small companies, and find themselves in a process to investigate use of online configurators. So far, sales mostly happen through dealers and projects. Being in different businesses, they constitute an interesting research setting that allows for describing different types of solution spaces, as well as expressing their thoughts about better solution space management.

1) Company A, windows and doors

Company A manufactures windows and doors for Norwegian homes and offices, and are a professional mass customizer with a wide range of offerings within their brand. All products are made according to customer orders in a modern semi-automatic manufacturing plant. The windows can be manufactured with different shape, size and color, but also with several less known functions, such as impregnation of wooden parts, sun protective glass, self-cleaning glass, non-fog capabilities, different levels of insulation etc. Also, by offering a range of window posts, mullions and opening mechanisms, customers can most often find what they need within the solution space provided. Sometimes the new windows are going into an existing house, and the design must be kept in the same style as the old ones. Mostly, the windows are sold through dealers of building materials, and often these are the only ones to meet the end customer. The company has no online configurator so far, so to get an overview of all options (the full solution space) customers must read brochures or rely on sales personnel at the building material shop. Feedback from customers back to manufacturing and design is not necessarily stimulated or provided.

Fig. 7. *Solution space for windows offers customer choices within all categories of -function, -form and -fit*

The solution space for windows is a Type A (Fig. 7). Meaning that available choices are within all categories; functional options include ventilation type, degree of glass-insulation, anti-fog covering, sun protection, opening mechanisms, etc. Form-options include color, shape, mullions, type of hinges etc. The fit-category allows customers to specify dimensions like height, width and to some degree depth. To move forward, all categories must be developed further, but since the shape-, color- and dimensions- aspects are very flexible already, new functions are of extra importance. But, when it comes to big windows, the process has some limits today.

2) Company B; cleaning trolleys and Waste bins

Case company B designs, manufactures and sells waste bins and cleaning trolleys on the Scandinavian market. Customers of the cleaning trolleys are normally hotels and public offices, where the need for different cleaning devices is evident.

When it comes to waste bins, a wide range of models are offered, all that can be designed and adjusted to best

fit needs of the customers, who primarily are public buildings such as schools, offices, hotels and airports etc., and even passenger ships. Also, some of the waste bins are designed for outdoor use, as in front of buildings, in parks, or at rest places alongside main roads. On these products, customers mostly change colors, type of throw-in slit and labels, besides considering how many they need for a "pre-separation at source" function.

The archetype can be clasified as type B;

Fig. 8. *Cleaning trolley, function- and form- based solution space, Type B*

The interest in the cleaning trolleys is primarily configuration of functions to make it suited for the job at hotels or business at hand, whilst the fit (size) is not exploited to a large extent today (Fig. 8). Could the height or width be selected? The handle bar angle is adjustable today, covering parts of the hight flexibility needed amongst customers.

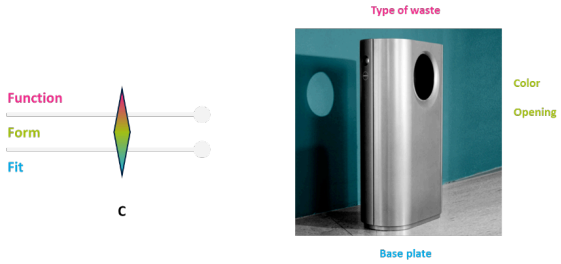

Fig. 9. *Waste bins, form- based solution space, Type C*

The solutions offered for waste bins are primarily within the form- category, due to some standardization issues with volumes and since the prime function is holding a bag and offering a practical throw-in hole (Fig. 9). There is a wide variety of models, colors, stickers etc. that allows customers to personalize their bin. Future options within the function category could maybe be comprimation of content or sensors for filling level. The fit-category could expand in offering more heights, adjusting to surroundings like washstands etc.

3) Company C; Kitchen ventilators/cooker hoods

Many new kitchens are now modularized and the cooker hood might very well be ordered in standardized measures to fit into the row of cabinets. But another trend is to reduce the number of cabinets in the kitchen, to create open wall areas, and hence customers order free-standing ventilators, either hanging from the roof or as an independent installation on a straight wall or in a corner. The manufacturer of kitchen ventilators has been doing customization for many years. The products are sold in several European countries, mostly through kitchen suppliers. Cooker hoods can be customized in many ways, such as size, color, type of ventilation, adjustments to where it is mounted etc. After choosing a model, the configuration starts, often together with the kitchen supplier. The manufacturing is flexible and is designed to operate with a batch size of one. Also in the painting area. Even when delivering to large building projects, each end user in every flat might order specific solutions and receive deliveries in their appartment.

Fig. 10. *Solution space for a cooker hood, mostly fit, but also color and material, a Type D case*

Again, offerings differ only to a limited degree on the function- category. For the fit-category, the solution space is continuous between a lower and higher size limit. Functionality offers some variants of ventilation, and some safety equipment, but is not really customized. For future solutions, the company should bring the Type D outset into consideration when planning for new models and attributes.

With these examples, we want to illustrate that products naturally have different types of solution spaces with respect to which choices are offered. Discussions about how to best use these in terms of stimulating radical product development have still not concluded.

3.3. Exploiting manufacturing capabilities

A 4-step process for linking solution space to processes and identifying physical limits and improvements areas is suggested;

Step 1: Products and Attributes (TEV)
Step 2: Attributes and processes – *where*
Step 3: Attributes and process limitations – *what*
Step 4: Processes and performance indicators

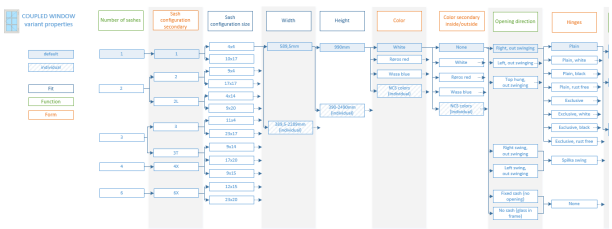

Fig. 11. Step 1, TEV, *Listing of product attributes, data (selection) from window example*

Step 1 is to create a table of attributes for one product group as seen earlier. A selection of such a view is shown again in Fig. 11, for the so called coupled window. This step is also called tree of external variants (TEV).

The next step (2) will be to show what processes that influence the different attributes. In Fig. 12 a table show part of the information collected about where the

attributes belong in terms of process influence. The *green check* means no influence, whilst the *red cross* means this process determine something for the attribute discussed.

	Size Length	Size Width	Size Depth	Sun-protection	Color	Impregnation	Shape	.....
Saw	✗	✗	✗	✓	✓	✓	✗	
Mill	✗	✗	✗	✓	✓	✓	✗	
Vacuum	✗	✗	✗	✓	✓	✗	✓	
Frame	✗	✗	✗	✓	✓	✓	✗	
Paint	✗	✗	✗	✓	✗	✓	✓	
Glassing	✗	✗	✗	✗	✓	✓	✗	
....								

Fig. 12. *Step 2, Product attributes and processes, data selection*

In Fig. 13 the findings from step 2 is replaced with facts about the process limits as we know them. In this view we have identified physical limitations in all process steps and related them to today's product attributes, called step 3 (numbers anonymized).

	Size Length	Size Width	Size Depth	Sun-protection	Color	Impregnation	Shape	.....
Saw	5m	0,2	0,2	-	-	-	Straight	
Mill	2,6	0,15	0,15	-	-	-	Straight	
Vacuum	4	1	1	-	-	4 h/night	-	
Frame	2,4	2,4	0,1	-	-	-	Angular	
Paint	2,6	2,6	0,2	-	4h	-	-	
Glassing	2,8	2,8	0,3	10 min	-	-	Straight = auto Curve = man	
....								

Fig. 13. *Step 3, Process limitations*

Now we have a view that shows which operations that holds the limitations for the existing process and (numbers anonymized). For new requests, now it is easier to say where the challenge might occur, and how big it is with this information at hand. If customers ask for new products outside identified limits, either the company can refuse to give an offer or consider what can be done to get around the bottleneck identified. Sometimes, process steps can be executed manually outside the normal process, and sometimes only small corrections or investments opens new possibilities if interesting. The pricing can be adjusted accordingly. For future product development initiatives, the image of process limitations is valuable input.

Also, to reach new performance levels in the manufacturing, a view of how suited the processes are with respect to mass customization performance criteria is needed. We consider listing mass- and custom-capabilities respectively for each process as our step 4 of the process. Not only process limits are of interest, but also i.e. the speed of operations and their ability to change between setups. This work is in the thinking, and our conceptual model is to create a value-stream-map type known from Lean Manufacturing [12] of picture of the process capabilities as can be seen in Fig. 14 below.

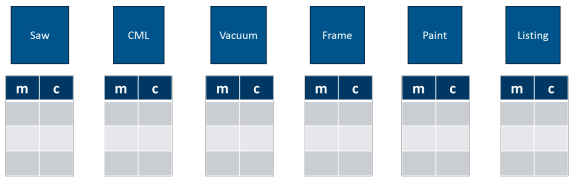

Fig. 14. *Step 4, Process's MC-capabilities*

The view in Fig. 14 is still an idea and needs to be developed as a tool and proven in practice. Besides, some of the qualities in a mass customization set-up is about what happens in-between operations. Like the supply of materials and components, the one-piece-flow, the efficient handling etc. This is still to be discussed in the project.

4. CONCLUSIONS AND FUTURE WORK

The case companies use brochures to describe their solution space, and have only little concern about the borders towards what is not included into the solution space. The solution space seems to be treated as a set of existing products and known customer interests. The solution space development is not as operational as the two other fundamental capabilities.

This research suggests increasing the awareness of the solution space development function by visualizing it in terms of choice categories, and hence introduces the term solution space archetypes as a new way of considering todays offerings. The eight archetypes identified might help foster new perspectives when developing new offerings. To better consider future potentials a 4 step process to determine manufacturing process limits and MC-capabilities are suggested. The paper provides company-based insights that managers may use when developing their own mass customization practices.

The idea of determining the solution space borders came from three case companies and set of a discussion about what constitutes the as-is solution space. It is our suggestion that it is determined by process capabilities and not what is currently offered or ordered. The awareness of the space borders (identifying bottlenecks) helps making quicker decisions about taking on a specific job or not, and when to argue for a premium price, but it also help start the strategic discussion on the back-office about trends and future developments.

Visualization of the Solution Space needs to be dealt more with in cooperation between academia and companies to increase awareness of strengths and weak points.

In future, the solution space management should be turned into a strategic tool for companies. Knowledge about possibilities and shortcomings still needs to be elaborated.

Also, further development of the 4 step process into finished tools for SME's is needed.

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