Management and Production Engineering Review
Volume 12 • Number 3 • September 2021 • pp. 97–105
DOI: 10.24425/mper.2021.138534

The Way of ETO SMEs to Mass Customization – Overview from Real Production Systems

Bartosz Ciesla[1], Janusz Mleczko[2]

[1] *Redor Ltd., Poland*
[2] *Faculty of Mechanical Engineering and Computer Sciences, University of Bielsko-Biala, Poland*

Received: 19 August 2020
Accepted: 13 August 2021

Abstract
In this article conclusions from nearly 10 years of collaboration with Polish and German Engineer-to-Order (ETO) small and medium-sized enterprises (SMEs) from mechanical sector was presented. Research objective was to highlight common organizational problems they are dealing with, which prevent them from transition to Mass Customizers. As a result, a concept of 5 foundations for robust process design was proposed: procedures, product selection, machining philosophy, planning and storage, cross-functional teams. More practical solutions from this field have to be published to fill the research gap.

Keywords
production planning and control, mass customization, robust process design.

Introduction

The concept of Mass Customization (MC), has emerged in the late 1980s. It may be perceived as a natural adaptation of industry businesses, to rapid increase in flexibility and broad optimization regarding modern products, their quality and costs (Fogliatto et al., 2012; Da Silveira et al. 2001). It is a response to unprecedented pressure on manufacturers, to deliver a highly customized product, at a highly accelerated speed and a highly reduced cost (Ulrikkeholm and Hvam, 2014). Before that, the fundamental objectives for most companies were to produce as cheaply and efficiently as possible, reaching with the same product as large customer group as possible. Technological advances, in manufacturing as well as in information systems, provided the impetus for change in many paradigms, including customer expectations. Customers have become more demanding and want products that can fulfil their specific individual requirements. Producing customized products at a relatively low cost, which seems to be a paradox, become the purpose of many enterprises. This results in transformation at mass production systems to single unit and small batch processing (Mleczko and Bobinski, 2017). For many companies it is a challenge to become and sustain as Mass Customizers.

The concept of MC has received considerable attention in the research literature with a significant increase in the 2001-2010 decade (Fogliatto et al., 2012; Da Silveira et al. 2001). The foundation for development of MC methodology was the Engineer-to-Order (ETO) production strategy. Moreover, mix of these two was named later in the literature as hybrid MC-ETO strategy, emphasizes its uniqueness in terms of MC (Haug et al., 2009). For small and medium-sized enterprises (SMEs) which use ETO strategy, modern economy implies a need of design and production in short cycles while keeping a cost criterion (Koren et al., 2015; Da Cunha et al., 2007; Moon et al., 2010). It is why MC appears as an alternative to SMEs operating in a highly competitive and segmented market (Nielsen et al., 2017; Mleczko, 2018). Reducing the time from the point of customer decision to the product delivery, may involve many aspects: a presentation of an attractive offer, an acquisition order, a design process, a process of product data preparation, a manufacturing process and shipment of the product to the customer.

The inspiration for this research was (Salvador et al., 2009), in which foundations for the MC approach

***Corresponding author**: Janusz Mleczko – Faculty of Mechanical Engineering and Computer Sciences, University of Bielsko-Biala, Willowa Str. 2, Bielsko Biała, 43-300 Poland, phone: +48 33 827 92 53, e-mail: jmleczko@ath.bielsko.pl*

and three fundamental capabilities were specified. In this article, the authors deliberate if that study of transition to MC from 10 years ago are still valid, especially for SME. The authors focused on the difficulties and obstacles in SMEs in their way to become Mass Customizers.

Literature review

As suggested in (Salvador et al., 2009) the companies are finding it extremely difficult to manage MC conflicting priorities. They are looking for innovative ways to optimize their systems, so that they can satisfy the demanding customers. The changing world economy caused an increase in the use of just-in-time manufacturing, which resulted in a trend toward short-run, multiple-product manufacturing (Salvador et al., 2009). The authors investigation of real production systems confirmed, that this transformation is still at the early stage in the most of ETO SMEs. In fact, coordination in ETO industries was considered of significant importance to avoid budget overruns, delays escalation and insuficient quality (Larsen et al. 2019). However, despite of this focus, when looking into project performance in the construction industry, cost escalations, time overruns and bad quality often occur (Larsen et al. 2019).

MC requires from a business to develop three fundamental capabilities (Salvador et al., 2009): 1) the ability to identify the product attributes along which customer needs diverge, 2) the ability to reuse or recombine existing organizational and value-chain resources, 3) the ability to help customers identify or build solutions to their own needs. Admittedly, the development of these capabilities, mandates for organizational changes that are often difficult, because of powerful inertial forces with a company. In fact, that makes the argument more compelling: those who are able to develop these capabilities will be able to enjoy long-lasting competitive advantages. In addition, the authors believe that these obstacles can be overcome by using a variety of approaches, for example as in concept presented in the Table 1.

Essential fact is that even small improvements can reap substantial benefits, especially for ETO SMEs. The trick is to remember that one best way to mass customize doesn't exist: managers need to customize their approach, in ways that make the most sense for their specific businesses (Salvador et al., 2009).

Table 1
Three Fundamental Capabilities of MC (Salvador et al., 2009)

Capability	Approaches to develop capabilities
Solution Space Development: Identify the product attributes along which customer needs mostly diverge	Innovation toolkits: Software that enables large pools of customers to translate their preferences into unique product variants, allowing each customer to highlight possibly unsatisfied needs. Virtual concept testing: An approach for efficiently submitting scores of differentiated product concepts to prospective customers via virtual prototype creation and evaluation. Customers experience intelligence: Tool for continuously collecting data on customer transactions, behaviors or experiences and analyzing that information to determine customer preferences.
Robust Process Design: Reuse or recombine existing organizational and value chain resources to fulfil a stream of differentiated customers' needs	Flexible automation: Automation that is not fixed or rigid and can handle the customization of tangible or intangible goods. Process modularity: Segmenting existing organizational and value-chain resources into modules that can be reused or recombined to fulfil differentiated customers' needs. Adaptive human capital: Developing managers and employees who can deal with new and ambiguous tasks.
Choice Navigation: Support the customers in identifying their own solutions, while minimizing complexity and the burden of choice	Assortment matching: Software that matches the characteristics of an existing solutions space (that is, a set of options) with a model of the customer's needs and then makes product recommendations. Fast-cycle, trial-and-error learning: An approach that empowers customers to build models of their own needs and interactively test the match between those models and the available solutions. Embedded configuration: Products that "understand" how they should adapt to the customer and then reconfigure themselves accordingly.

Materials and methods

A research problem is Robust Process Design – one of the three fundamental MC capabilities described in Table 1. The subject of the research is the identification and examination of ETO SMEs operational problems in regard of research problem. As a result, the authors proposed a concept of 5 foundations for robust process design in ETO SMEs: 1) procedures, 2) product selection, 3) machining philosophy, 4) planning and storage, 5) cross-functional teams. The authors provide practical solutions from real production systems at this fields, based on their professional and academic experience. A brief characterization of the 4 investigated companies is presented in the Table 2.

Table 2
Description of the analyzed SMEs, own study

Employment	Products	Leading production strategy
approx. 50	Industrial mixers	Designing and manufacturing
approx. 65	Gear parts	Manufacturing upon the clients documentation
approx. 90	All purpose mechanical parts	Manufacturing upon the clients documentation
approx. 200	Reducers and motoreducers	Designing and manufacturing

Results – five foundations for Robust Process Design in ETO SMEs

First foundation – procedures

First foundation is about rational procedures supported with information system. ETO SMEs have very flexible production systems, capable of carrying out difficult tasks from multiple, various and often prototype projects (Ruta and Zbrowski, 2011). This is achieved with flat, informal structures based on high degree of independence and self-responsibility of the leaders (Hudson et al., 2001). But when endeavor to MC, lack of formal discipline in some operating aspects become an insurmountable barrier. Standardization is in fact very challenging aspect for ETO SMEs, as from the one side they are quite strong in adoption of ISO procedures or elements of Lean manufacturing, but from the other side, weak in consistent, strenuous plan-do-check-act (PDCA) circle. As observed during investigation of different production systems, the cause for this weakness is mostly in the leadership attitude. Attention given by SMEs Operation Managers to all forms of continuous improvement is usually periodical, and general reason for this state of affairs is twofold: their inability or ignorance to sustain newly established standards (limited knowledge aspect) and shortage of valuable deputies to support them in day-to-day duties (limited resources aspect). Moreover, development of flexible as well as unambiguous procedures is an oxymoron which could be achieved only with well-trained, self-conscious and committed personnel. Again, establishing standardization-friendly environment is a task for SMEs leaders and they are responsible for initiation of company's interior procedures redesigning process.

Another recognized obstacle in establishing balanced formal-flexible structures in ETO SMEs is poor knowledge passing on single-man positions. When it comes to labor turnover, necessary recruitment period could take even few months, thus no time is left for training new worker by outgoing one. Regardless of job characteristics, this results in discontinuities in the operational activities and surely causes future mistakes. It is also very devastating in the context of developing SMEs know-how. Impact of this phenomenon can be partly mitigated with formal working instructions and with job rotation, but this is very difficult in SMEs reality, especially in terms of their limited assets. As a top enabler of excellence in standardization area, effective enterprise resource planning (ERP) system was found during this study. In companies at which day-to-day tasks were supported with user-friendly information system, with high quality, verified data, things seem to go much smoother and less labor intensive. Also, better process harmony was visible at a glance. Managers of this companies claim, that it was achieved through a general processes review, done during ERP system commissioning. Solutions proposed by software supplier were mixed with company's verified historic practices and the unique tool was compiled. They also emphasized the importance in this process of company's personnel, which already had experience in ERP system commissioning from other businesses.

As a result of difficulties at areas discussed above, some operational sins are committed by ETO SMEs, which prevent them from recognizing perspective of MC way. More specifically, effective expertise of commonality cannot be carried out, for products structures and families. Furthermore, even basic analysis for rationalization in the areas of raw materials, components and machining operations, become a challenge. Most common operational mistakes, noticed during investigation of different ETO SMEs from machining industry were gathered in the Table 3. At the bottom of each section, negative results in context of mass customization transition where highlighted.

With respect to the first foundation the authors recommend to provide advance training to SMEs Operational Managers in areas of project management and work standardization. In most cases the recruitment of extra co-manager will be necessary during SMEs transition to MC. He or she should be responsible for procedures improvement, thus must have great general knowledge about company and simultaneously present a very critical view at its present performance.

Second foundation – product selection

Second foundation is about choosing the appropriate products. Since the key in transition of ETO SMEs into mass customizers lies in refactoring legacy products along with modularization concept, company has to know first which products and components, from the existing portfolio, have to be redesigned. Undoubtedly, for a reliable analysis of this dilemma, sales statistics and strategic plans combined with products structures (BOMs) are necessary, and this is nontrivial issue. The goal is to recognize potentially most popular and most promising products families from various, bespoke manufacture range and avoid wasting limited resources on occasionally salable goods.

Table 3
Summary of ETO SMEs operational mistakes in context of MC transition, own study

Mistakes	Description of circumstances
Lag or skip of warehouse documents	When producing prototypes in SMEs their bills of materials (BOMs) can be very dynamic during manufacturing stages. Production systems don't keep up with these changes in technical documentation and warehouse documents. Eventually no one knows exactly which raw materials (outside diameter and even grade!) were used and why some changes were made (long material delivery period, high price etc.). As a result, warehouse workers are confused and warehouse documents are made approximately. Also prefabricated components if used, are sometimes exchanged for others variants without inventory Goods Issue/Goods Received notes.
Result: Inventory rotation cannot be duly connected with products and sales.	
No feedback to process designing engineers	Again, due to the uniqueness of prototype production, but also other reasons (e.g. human nature), changes made in BOMs during production process are not communicate to process designing engineers. During this study this was noticed many times, even in case of repeatable components or products (the same changes made at manufacturing level by production or warehouse personnel in every few weeks!). Modifications were related mostly with different DIN standards, material grade, rod outside diameter (also switching to metal sheets or forging) or revision/version of prefabricated components.
Result: Product BOM doesn't includes real used raw materials and trade parts which are budget and commercially of-the-shelf (mostly outside diameter), as well as real configuration of prefabricated components. Commonality in raw materials and components cannot be calculated.	
Blurred new components versions	When components are upgraded, this fact is not registered in all BOMs containing old versions. It was even observed that two versions of the same component (old and upgraded) were simultaneously produced to prefabricates stock due to MRP demand. Companies have also problem with clear designation of old components versions, and as a result less experienced engineers are using them in new products BOMs.
Result: Real commonality of components cannot be established through BOMs.	
Time recording for labor cost accounting	At most investigated ETO SMEs poor accuracy of processing times for different machining operations was observed. Exceptions were companies which reward workers for high efficiency. They achieved higher accuracy with personnel (extra resources) designated for current and continuous analysis of machining times and performing adjustments. In some other cases, even fourfold variation in standard machining times was observed. As an alternative, start/stop time recording for every operation can be applied but this is connected with registration discipline among crew. In this variant, also some level of control is needed and extra personnel to make adjustments in machining time specifications.
Result: Labor profits from increasing batch quantity are impossible to calculate.	

This could sound easy but in fact is very tricky in realities of SMEs, where strategic decisions making process are based on personal outlook of company's owner or CEO (Hudson et al., 2001).

It was observed during this study, as through wrong "marketing analysis" or rather precognition or ambition of owner, contrary to their intentions, level of components complexity was increased rather than simplified. All of this with thousands of engineering work hours invested in redesigning of product families. Such phenomenon was a result of only partial replacing of old products with newly redesigned ones, among regular customers. As a result, both old and new version must be produced, which consequent in higher products diversity.

Through discussions with Sales Managers and Salesman, main causes of this situation where recognized and discussed below.

First important factor during redesigning ETO mechanical equipment is substitutability. New product has to be mountable at place of old one without extra effort from the user, otherwise switching can be difficult to persuade to client, even with better price or product parameters. For instance, this can be achieved through complimentary attached adapters, free of charge installation service or free of charge design support of customers infrastructure.

Second factor often mentioned by Sales Managers and Salesman is customers willingness to make changes. In cases when customers were using many same products (e.g. 5, 10, 15, depends on the product characteristics), Sales Departments were completely impotent in convincing them to transition to new products families. Customers explained their decisions with avoiding complexity of spare parts (how ironic for enterprise seeking MC!) and existing experience in maintaining and repairing already owned products.

Hence, under ETO SMEs market conditions, when obtaining new big clients is a long-lasting process, designing of new product family may cause long distance increase in complexity, effecting even in the need of penetrating completely new markets. An essential success factors for MC in this area are: operational strategy tailored to above circumstances and appropriate timing (e.g. opening of new market).

Underestimated issue at this field, that was investigated during interviews with regular employees, is that probably nothing can stop efforts and involvement of working crew more effectively than sense of doing something useless. Bad strategic decisions at this field could be devastating not only from financial aspect, but also for future personnel motivation.

With respect to the second foundation the authors recommend to engage service workers or other workers who are in the close contact with final users of the device in the MC product selection process. They are able to make quick intuitive initial assessment of CEO or Sales Managers propositions.

Third foundation – machining philosophy

Third foundation is about revision of machining philosophy in accordance with concepts like Lean manufacturing or Project management. When implementing strategy of modularization in ETO company, production goal is to lower machining costs through benefits from increased quantity in manufacturing batches. This is connected with reduction in number of setup times, lower variety in tools, jigs and fixtures as well as reduction of internal transport and other non-value-adding operations (like order documentation printing etc.), executed in relatively high quantity characteristic at single-unit production. Another important factor is the phenomenon of training effect, which is that in the tenth repetition of the operation, the time required to do the job could be only about 60% of one that needed the first time (Ehrlenspiel et al., 2007).

As observed during this study, medium batch (minimum 100 pieces a year) machining savings are quite a challenge for ETO SMEs. It is because their production systems are generally based on individual capabilities of comprehensive workers rather than standardized, refined process instructions. Systems designed for single-unit or small batch production are oriented on setup times minimization and capability of handling with high volumes of single-unit components, rather than processing efficiency. This includes methods of processed material tracing at workshop, its transportation, job planning and sequencing, etc. When visiting ETO SMEs production shop floors, very common are numerous cabinets, cases and racks with various equipment which are next to machines, so they are available readily. Also popular are different transport trolleys and palettes with aggregated heterogeneous components on very different stage of production. Hence, ETO SMEs transition to medium-sized or large batch manufacturing is a radical change in work philosophy and existing equipment. Main machining aspects recognized during this investigation at this area, were presented in the Table 4.

Best achievements during transition from single unit to medium batch production, were observed in companies which chose to manage transformation along with principles of Lean manufacturing (LM) or Project management (PM) concepts. All Managers successful in this manner, when asked about this phenomenon, replied in accordance that they knew what

Table 4
Transition to batch machining, own study

Machining aspect	Recognized causes of aspect
No equipment	Occurs when equipment (jigs, fixtures, etc.) is expensive or unfamiliar and seldom needed. Risky fixtures are used instead of dedicated ones so machining parameters are lowered.
Inadequate equipment	Equipment designed for single-unit production is easy to attach in the machine but exchanging of processed material is long-lasting (e.g. difficult centering or complicated fixing). In batch production fast fixing is preferred.
Inadequate tools	Versatile tools adjusted to a wide variety of material grades and variable machining in small volume production are less efficient with respect to specialized ones (but expensive tools are not economical for small quantities).
Large machining allowance	Single-unit or small batch castings are bought from workshops with extra “supplier-safety” allowance, since molds are dedicated for craft production. Also, extra allowance is left during rough machining for finishing operations, which are usually more expensive and less efficient (Dodok et al., 2020). This is preferred in small volume production to avoid costly, time-consuming defects resulting from unstable processes.

is wrong in production philosophy but they didn't know how to improve whole system rather than individual cases. With these concepts, framework for efficient way of leading enterprise through far-reaching changes was given. The important thing is that most of Managers didn't adapt all principles of these concepts, but adjusted them to companies' capabilities and main objectives.

With respect to the third foundation the authors recommend to train production leaders and process engineers in concepts like PM, LM or SMED and support them in their implementation.

Fourth foundation – planning and storage

Fourth foundation is about stable production planning and components stock management. Most of the savings from transition ETO company to Mass Customizer come from increased quantity of universal components in production batches. Under conditions of investigated ETO SMEs this usually means no more than 500 pieces a year and depending on material costs and sale forecasts, average batches size between 10 and 50 pieces. Sounds not very impressive but it causes operational difficulties even in experienced companies, and results in significant untapped potential of medium batch production. Without stable production planning which provides rational order of tasks, ongoing jobs are often disrupted at ETO SMEs shop floors so economic effects of larger quantity are wasted. There were cases, when alarmed Managers decided to focus on analyzing statistics of needles setup times resulting from job disrupting, and findings were frightening – nearly 10% of total working time was lost because of this reason. Further taken actions were twofold: absolute rigor in finishing already initiated tasks and attempts to improve production planning and plan execution. First part is simpler but without second puzzle it certainly provides to future inevitable delays, affecting clients and posing a risk of losing them. Typical observed dilemmas were about interrupting just started 3–4 days lasting machining of stock batch, because it blocked machining of “forgotten” short operation that is needed to finish the last part from urgent order. From the other hand there were delayed stock batches, constantly postponed due to unjustifiable priority of short jobs. Eventually they were split into urgent micro batch satisfying temporary demand and still awaiting remaining lot.

These problems are connected with failure of ERP system in combining deadlines of stock production with deadlines of final products orders, under investigated conditions. Generally, under the investigated conditions, internal manufacturing stock orders are generated in ERP systems by the planners. They deduce established deadlines from the first MRP demand at time of generating the order (which is often suggested by information system automatically). Batches size are deduced from sales forecast or other, more sophisticated tools, that company has developed. Deadlines of new internal stock orders have to be constantly compared from this point, with new external orders. If demand with earlier deadline than set before appears, then revision has to be done manually. It becomes complicated and time consuming when company is dealing with hundreds of internal and external orders. Moreover, outcomes form planning process are difficult to understand by someone from outside of production department (a salesman for example). Planned terms of external orders have to be compared with planned terms of internal stock orders to discover “real” planned execution term. Enterprises have their own, better or worse solutions for this dilemma. The conclusion is that universal procedure and planning algorithm should be developed in the future research, dedicated for ETO SMEs. The research question is: "How under conditions of variable production load, batch size and deadline of internal stock orders should be estimated, for the best fulfillment of stock components demand? How this deadline can be automatically adjusted when new external orders occur?". Elements of Theory of Constraints seems to be useful in solution development of this dilemma since ETO production systems are very dynamic and their bottlenecks are constantly changing (Mleczko and Bobinski, 2017; Mleczko, 2018). This problem is also connected with calculations of savings, from different number of pieces in the batch, and costs of storage. For quick worktime savings calculations under ETO SMEs conditions, below concept can be use. Let $\mathcal{F}n_{Id_i}$ be the duration of processing operation Id_i at machine m_a for quantity n. It can be decomposed into two components: setup time $\mathcal{F}s_{Id_i}$ and machining time for one piece $\mathcal{F}w_{Id_i}$ as in (1).

$$\mathcal{F}n_{Id_i} = \mathcal{F}s_{Id_i} + \mathcal{F}w_{Id_i} \cdot n\,. \tag{1}$$

Reduction of machining time of n lot size due to training effect can be calculated using (2), where piece machining time for the j-th run is estimated $\mathcal{F}_j w_{Id_i}$ (Ehrlenspiel et al., 2007).

$$\mathcal{F}_j w_{Id_i} = \mathcal{F}_1 w_{Id_i}\left(\frac{0.685}{j^{0.322}} + 0.315\right). \tag{2}$$

Using (1) and (2) average piece processing time $\mathcal{F}A_{nId_i}$ for n batch size can be estimated as in (3).

$$\mathcal{F}A_{nId_i} = \frac{\mathcal{F}s_{Id_i} + \sum\limits_{j=1}^{n} \mathcal{F}_1 w_{Id_i}\left(\frac{0.685}{j^{0.322}} + 0.315\right)}{n}\,. \tag{3}$$

With (3) planners can easily estimate savings potential from increasing batch quantities induced by implementing MC principles. There are procedures in ERP systems for standard calculations based on (1) which can be modified by (2) so the savings analysis will be done nearly automatically. Coefficients 0.685 and 0.315 may change for different manufacturing systems. Presented values were calculated in researches mentioned in (Ehrlenspiel et al., 2007). They should be perceived as an example but not certainty. Moreover, reduction of machining time due to the training effect is limited and the threshold has to be defined, for different types of machining operations.

To calculate gross savings, savings from increased batch quantity have to be reduced by costs of capital tied up in produced components inventories and their storage costs. To do so, average inventories have to be calculated for different batch sizes. This should be done using sales forecast for measuring future stock value. Depending on company characteristics, measuring periods can be defined as years, months, weeks or even days. Let s_{np} be the stock value of part p at nth period and n_p will be the number of measuring periods. The average value of stock for part p – av_p, can be calculated as in (4)

$$av_p = \frac{\sum\limits_{1}^{n} s_{np}}{n_p}\,. \tag{4}$$

Costs of capital tied up in produced parts inventories can be calculated by multiplying value calculated with (4) by company's weighted average cost of capital ($WACC$) and number of forecasted periods of time, the parts stay in the warehouse. Let Cc_p will be the costs of capital tied up in produced parts p which will stay in the warehouse for f_p periods of time, it can be calculated as in (5).

$$Cc_p = WACC \cdot av_p \cdot f_p\,. \tag{5}$$

To calculate storage costs company should establish storage unit cost (e.g. for kilograms, square meters, boxes, etc.). The storage costs are often ignored in SMEs if they have free space with no purpose. Regardless of whether company holds free warehouse space, it should be prepared to expand it, and be aware of potential costs. During investigation it was noticed that companies are often not prepared for increasing stock balance and don't have proper storage space. There were also cases, when the space was available, but no proper shelfs, racks or forklifts were there. Also, when procedures were investigated for receiving and issuing manufactured stock parts, fundamental questions as: who is responsible, when it has to be done and where it has to be done, have left without clear answers. As a result of the above unnecessary costs are incurred and frequent mistakes are committed. Moreover, the same repeated errors and delays in stock components issuing are leading to irritation and decrease in the productivity among assembly crew. Hence managers should always remember that gathering parts manufactured on stock, to complete external orders at ETO SMEs, is challenging in setting up and sustaining.

With respect to the fourth foundation the authors recommend to develop ERP systems that ETO SMEs are operating. The problem solution must be tailored to the individual needs of particular SME so this must be done in close cooperation with software supplier. It is easier and cheaper to carry it out with smaller software supplier than in case of global leaders. An alternative would be to develop complete and universal production control framework for ETO SMEs, and implement its algorithms in dedicated ERP system.

Fifth foundation – Cross-functional teams

When rationalizing existing components variation, contribution of personnel with working experience form various departments is invaluable. Thus, combination of products assembly knowledge, supply possibilities and production capabilities are enabling smooth decision-making process, when reducing components variants. Otherwise, wrong conclusions could be drawn from available information and further wrong actions could be taken. For instance: too expensive in production components are designed, inaccessible parts are added to BOMs or common components don't match after modifications of other, unique one. Below at Fig. 1 and Fig. 2 simple examples from the real production systems have been presented to enlighten the scope of decision-making processes complexity at most of investigated ETO SMEs. At Fig. 1, two types of connectors ("A" and "B") were presented. They were designed by two different constructors, at different stages of product family development. As a result, these parts are unnecessarily different. They differ with one of the holes diameters which is 17 and 14 mm. After a brainstorm with cross-functional team at the assembly department, connector "A" was selected as a universal one. This is a typical example of lack of standardization and knowledge passing in SMEs. Moreover, lack of standardization in making of drawings could be also noticed. Dimensions of connectors are marked in a different way which could be confusing for machining personnel.

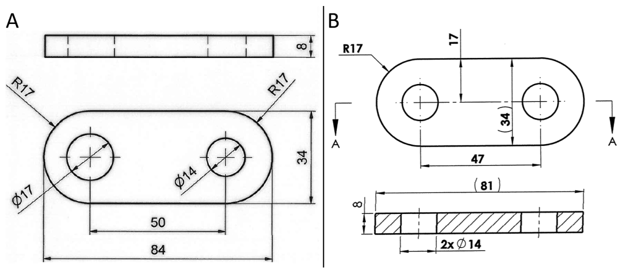

Fig. 1. Two versions of connectors, own study

Second example, presented on Fig. 2, is about different versions of cover designed by the same constructor. He decided to change position of side threaded hole in various variants of final device. At first variant the threaded hole is located 5 degrees below the symmetry axis and in the second variant 5 degrees over it. The purpose of this design was to assure easier emptying of old oil from inside of the device during maintaining.

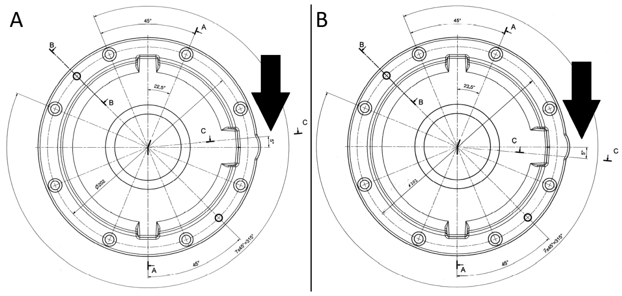

Fig. 2. Two versions of connectors, own study

Again, after brainstorm with cross-functional team, it was deduced that one universal version with whole in the middle is sufficient enough for all product variants. Representative from assembly department pointed out, that this 10-degree difference is not making the task of emptying oil any easier. Moreover, long time before that, Production Manager ordered personnel from CNC drilling center to produce these parts at only one universal version (inconsistently with documentation), since he was unable to reach an agreement with constructor about change in the documentation. Eventually, when the CEO initiated transition toward MC and noticed this problem during one of audits (there were two symbols of the same part in storage) he right away set up a cross-functional team, and solve the problem in less than 15 minutes. Hence, power of cross-functional teams is in agile decision making combined with a sense of responsibility – the duty to take actions leading to solutions.

With respect to the fifth foundation the authors recommend to encourage personnel to initiate even small changes in the company and provide them tools to do that simply and efficiently. One of the possible solutions is to establish the rules of agile setting up of the cross-functional teams, under conditions of ETO SMEs, and give them power to take the binding decisions.

Conclusions

ETO companies are called pure customizers since they deliver individually designed products – the highest possible level of customization (Fogliatto et al., 2012) (Da Silveira et al. 2001). They are offering more expensive goods than mass production, which are dedicated for customers that are willing to pay higher price for a biased extra value. As ETO enterprises transform to Mass Customizers they can spread out from their niche and explore new markets, offering distinctive products at competitive prices. This paper applies in particular to ETO SMEs which due to their knowledge and resource limitations, despite of different markets, suffer similar organizational difficulties in transition to mass customizers. The authors believe that with relatively little guidance and dedicated flexible information systems, determined leaders can use adjusted MC principles and achieve rapid company growth. Purpose of this paper and presented 5 foundations is to make ETO SMEs Managers aware of possibilities of MC and operational mistakes they make. Although, development of product design and order elicitation are important part of MC and very popular trends in the literature, the authors consider that they are not a priority for ETO SMEs. Future researches should be focused on real successful operational transformations in ETO SMEs and discerning description of recognized enablers or specific actions taken. First milestone is to achieve at least rough, step by step, transition framework for practical use and further investigation. This concept could be called Small Mass Customization since the scope of organizational strategy will rather not be the same as is in case of mass producers.

References

Da Cunha, C., Agard, B., and Kusiak, A. (2007). *Design for cost: module-based mass customization.* IEEE Transactions on Automation Science and Engineering, 4, 3, 350–359.

Da Silveira, G., Borenstein, D., and Fogliatto, F.S. (2001). *Mass customization: Literature review and research directions.* International journal of production economics, 72, 1, 1–13.

Dodok, T., Cubonova, N., Cisar, M., Ivanov, V., and Wiecek, D. (2020). *Influence of CNC milling strategies on complex surface machining.* IOP Conference Series: Materials Science and Engineering, 776, 012002.

Ehrlenspiel, K., Kiewert, A., and Lindemann, U. (2007). *Factors that influence manufacturing costs and procedures for cost reduction.* Cost-Efficient Design, 143–384.

Fogliatto, F.S., Da Silveira, G.J., and Borenstein, D. (2012). *The mass customization decade: An updated review of the literature.* International Journal of production economics, 38, 1, 14–25.

Haug, A., Ladeby, K., and Edwards K. (2009). *From engineer-to-order to mass customization.* Management Research News, 32, 7, 633–644.

Hudson, M., Smart, A., and Bourne, M. (2001). *Theory and practice in SME performance measurement systems.* International journal of operations and production management, 21, 8, 1096–1115.

Koren, Y., Shpitalni, M., Gu, P., and Hu, S.J. (2015). *Product design for mass-individualization.* Procedia CIRP, 36, 64–71.

Larsen, M.S.S., Lindhard, S. M., Brunoe, T.D., Nielsen, K. and Larsen, J.K. (2019). *Mass Customization in the House Building Industry: Literature Review and Research Directions.* Front. Built Environ, 5, 115.

Mleczko, J. (2018). *Production planning of single unit and small batch production in SMEs.* Wydawnictwo Centrum Nowych Technologii, Bielsko-Biala (in Polish).

Mleczko, J. and Bobinski, P. (2017). *Production planning in conditions of mass customization based on theory of constraints.* Applied Computer Science, 13, 4, 35–44.

Moon, S.K., Shu, J., Simpson, T.W. and Kumara, S.R. (2010). *A module-based service model for mass customization: service family design.* Iie Transactions, 43, 3, 153–163.

Nielsen, K., Brunoe, T.D., Skjelstad, L. and Thomassen, M. (2017). *Challenges in Choice Navigation for SMEs.* Managing Complexity, Springer, Cham, 127–137.

Ruta, R. and Zbrowski, A. (2011). *The concept of the system for management support for production process of individual technical objects in the prototype center of the research institute.* Problemy Eksploatacji, 205–215 (in Polish).

Salvador, F., De Holan, P.M. and Piller, F. (2009). *Cracking the code of mass customization.* MIT Sloan management review, 50, 3, 71–78.

Twarog, J. (2003). *Logistic meters and indicators.* Poznan: Institute of Logistics and Warehousing (in Polish).

Ulrikkeholm, J.B. and Hvam, L. (2014). *The cost of customising: assessing the performance of a modular product programme.* International Journal of Product Development, 19, 4, 214–230.