Assessment of Process Robustness for Mass Customization

Kjeld Nielsen and Thomas Ditlev Brunø

Department of Mechanical and Manufacturing Engineering, Aalborg University, Denmark
kni@m-tech.aau.dk

Abstract. In mass customization, the capability Robust Process Design defined as the ability to reuse or recombine existing organizational and value-chain resources is essential to deliver a high variety cost effectively. We argue that there is a need for methods which can assess a company's process robustness and their capability to develop it. Through literature study and analysis of robust process design characteristics a number of metrics are described which can be used for assessment. The metrics are evaluated and analyzed to be applied as KPI's to help MC companies prioritize efforts in business improvement.

Keywords: Robust Process Design, Mass Customization, Flexibility.

1 Introduction

In any company it is essential to offer products which match the needs and desires of customers to achieve sales and profit. This is true for mass producers as well as mass customizers; however in mass customization this issue is somewhat more complex than mass production due to a much higher variety and a more complex product structure. As pointed out by Salvador et al., mass customizers need three fundamental capabilities to be successful: 1) Solution Space Development – Identifying the attributes along which customer needs diverge, 2) Robust Process Design – Reusing or recombining existing organizational and value chain resources to fulfill a stream of differentiated customer needs and 3) Choice Navigation – Supporting customers in identifying their own solutions while minimizing complexity and the burden of choice [3], [7].

In order for companies to be able to establish themselves as mass customizers or for existing mass customizer to improve performance, it is proposed that a set of methods for assessing the three capabilities is developed. In this paper, the focus is solely on the capabilities for Robust Process Design. The research question for this paper is: *What metrics can be used to assess capabilities for robust process design and how can these be determined?*

The research question is sought answered through first defining robust process design, and in overall terms, what should be assessed. Then a literature review is conducted to identify related metrics already defined in literature. These metrics are evaluated, whether they are descriptive in relation to the robustness of processes, and

V. Prabhu, M. Taisch, and D. Kiritsis (Eds.): APMS 2013, Part I, IFIP AICT 414, pp. 191–198, 2013.

a final set of metrics is developed. The metrics developed is a preliminary set of metrics, and should be regarded as an assessment framework which will need further validation and refinement in order to be applied in practice.

2 Robust Process Design

The capability robust process design is defined by Salvador et al. [7] as "*Reusing or recombining existing organizational and value chain resources to fulfill a stream of differentiated customer needs*". Hence this capability is related primarily to the capabilities of the manufacturing system, and its ability to manufacture a variety of products. The robustness of the processes, both on a detailed level as well as on enterprise level can be perceived as the ability to adapt to manufacturing a variation of products efficiently, both in terms of time and in terms of cost. However, the robustness of the processes can be interpreted in two different ways:

- The ability to manufacture a variety of products within a fixed solution space, i.e. the current product portfolio / variety – *Robustness towards existing variety*
- The ability to adapt the manufacturing system to accommodate new variety, e.g. when the solution space changes due to new product options - *robustness towards new variety* This has a close relation to solution space development.

Both dimensions of the capability are relevant and critical to MC success; however they are not necessarily correlated. For example would a purely manual production be highly flexible towards new variety compared to a highly specialized and automated production, whereas the latter would probably be more efficient in manufacturing a predefined variety. Hence in order to assess the robustness of processes, we will need to distinguish between these two dimensions.

A study by Wildemann [8] investigated the ratio between product variety and manufacturing unit costs for different manufacturing technologies. This study found that for factories with conventional manufacturing technologies, doubling the variety would imply an increase in unit costs of 20-35%. Flexible automated and segmented plants however would only increase unit costs by 10-15% when doubling the variety. This indicates that there are great differences between the costs of increasing variety. The goal of robust process design is to minimize this ratio, so that increasing variety increases unit costs as little as possible. In the following, the existing literature addressing metrics for process robustness will be reviewed.

3 Literature Review

It is generally acknowledged that a late differentiation point or customer decoupling point is an enabler for an efficient MC production. Martin & Ishii [4] defined the

Differentiation Point Index (DPI) as a measure of how postponed the variant creation is in a manufacturing process:

$$DPI = \frac{\sum_{i=1}^{n} d_i v_i a_i}{n d_1 v_n \sum_{i=1}^{n} a_i}$$

v_i: #of different exiting in process i
n: number of processes
v_n: final number of varieties offered
d_i: average throughput time from process i to sale
d_1: average throughput time from beginning production to sale
a_i: value added at process i

Similarly the Setup index (SI) was introduced by Martin and Ishii [4] as a measure of how the setup costs contribute to the overall manufacturing costs. The SI metric is defined as:

$$SI = \frac{\sum_{i=1}^{n} v_i c_i}{\sum_{j=i}^{v_n} C_j}$$

v_i: #of different exiting in process i
n: number of processes
v_n: final number of varieties offered
C_j: Total cost of Jth product
c_i: cost of setup at process i

Blecker et al. [1] argue that capacity utilization (CU) is an important metric for mass customization and the definition from Mueller [5] is adopted as:

$$CU = \frac{Processing\ time}{Processing\ time + idle\ time}$$

The CU metric can be calculated for process or aggregated factory level, but in either case, a higher CU would imply a more efficient manufacturing setup implying lower manufacturing costs.

Blecker et al. also defines a production process commonality (PPC) metric, which indicated to what extent manufacturing processes are common to all product variants manufactured. The metric is defined as:

$$PPC = \frac{Number\ of\ common\ production\ processes}{Number\ of\ all\ production\ processes}$$

A delivery time reliability (DTR) metric was further introduced by Blecker et al. [1] . This is relevant as a high DTR will indicate a robust system able to deliver the necessary variety of products. The metric is defined as:

$$DTR = \frac{Agreed\ delivery\ time}{Actual\ delivery\ time}.$$

Pine [6] argued that a key metric for Mass Customization production is the work-in process turnover (WIPT), which indicates the value of goods in the manufacturing system compared to sales for a given period:

$$WIPT = \frac{Sales}{Work\ in\ process}$$

Daaboul et al [2] also introduced a number of metrics for mass customization. The Customization Process Indicator (CPI) indicates the relationship between the actual manufacturing time of a customized product and the time a customer is willing to wait for a custom product:

$$CPI = \frac{Total\ time\ for\ customization\ process}{Max\ allowed\ time\ for\ customziation\ process}$$

The metric Quality of Order Reception (QOR) indicates how well the production performs in terms of on time delivery and the defect rate [2]:

$$QOR = \frac{\#\ of\ orders\ delivered\ on\ time\ \cap \#\ of\ orders\ with\ zero\ defects}{total\ \#\ of\ orders}$$

Finally the Order Delay Time (ODT) indicates how fast a manufacturer is able to deliver a customized product:

$$ODT = Time\ elapsed\ between\ order\ placement\ and\ order\ reception$$

The metrics defined in literature to some extent all support the assessment of process robustness, however in different ways, and not necessarily towards both existing variety and new variety. In the following section, it will be evaluated which metrics can support the assessment of process robustness.

4 Metrics for Process Robustness Assessment

4.1 Robustness towards Existing Variety

Two of the metrics found in literature are related to standardization of the manufacturing processes; those are differentiation Point Index (DPI) and production process commonality (PPC). PPC gives an indication of to what extent manufacturing processes for different processes are common and DPI indicates the postponement of variants and on the other hand how many manufacturing processes have to change due to product variety. The most postponed manufacturing setup is expected to support highly robust manufacturing processes and therefore a very good indicator of robust process design. Because of that the DPI metric is chosen.

The Setup Index (SI) addresses the cost of setup of manufacturing processes compared to the total cost of a product. Since a high setup cost would be an indicator of a low robustness, this indicator can contribute to the assessment of process robustness.

In the literature review, three different metrics were identified which are related to time performance of the manufacturing system, i.e. the delivery time reliability (DTR), Quality of Order Reception (QOR) and the Order Delay Time (ODT), Customization Process Indicator (CPI). Although these metrics are not direct indicators of process robustness, it is expected that highly robust manufacturing processes will have a good time performance and good performance within these metrics will indicate robust processes. The metrics QOR and DTR however are very similar, and it is thus chosen only to include the QOR metric since it not only takes into account delivery performance but also quality of the product.

The metrics Capacity Utilization (CU) and work-in process turnover (WIPT) are considered important metrics which can indicate the state of a manufacturing system; however they are not considered essential in relation to assessing process robustness and are thus not included in the final set of metrics.

In addition to the metrics identified in literature we propose two additional metrics for process robustness which are defined below:

The metric Number of different modules manufactured per process (NMP) gives a measure of the average number of modules manufactured in the different manufacturing processes:

$$NMP = \frac{\sum_{i=1}^{n} m_i}{n}$$ m_i: # of different modules manufactured at process i
n: : # of different processes

A higher NMP will indicate robust processes, since each process will be able to manufacture more different modules and thus a higher number of end variants.

The metric Degree of manual labor (DML) can be used as an indirect indicator of process robustness, since a low need for manual processing will indicate that the non-manual manufacturing processes are able to supply a high variety. The DML metric is defined as:

$$DML = \frac{\sum_{i=1}^{n} \frac{lc_i}{tc_i}}{n}$$ lc_i: labour cost for manucaturing product i
tc_i: total cost of manufacturing product i
n: #of different products

4.2 Robustness towards New Variety

Only the SI metrics found in the literature were considered good measures of process robustness towards new variety and is chosen as metrics which could be useful in assessment of robust process design. This metric however is not considered sufficient for assessing the robustness towards introduction of new variety and hence four additional metrics are proposed:

Process variety increase (PVI) indicates how much the variety of manufacturing processes increases when a new product option or product is introduced in the manufacturing system. The PVI metric, calculated as an average during a period in time, is defined as:

$$PVI = \frac{\sum_{i=1}^{n} p_i}{n}$$ p_i: # of new processes introduced for product option i
n: #of new product options in the period

A low PVI will indicate a high robustness since this implies that few new processes need to be introduced when a product option is introduced and thus that the existing processes can accommodate new product variety.

In addition to the PVI metric the Capacity expense (CAPEX) increase when introducing a new option (CAPIV) is introduced. This is done since a high PVI does not necessarily come a high cost, given a new process is implemented on existing flexible equipment. The CAPIV metric, also calculated as an average over a period of time, is defined as:

$$CAPVI = \frac{\sum_{i=1}^{n} capi_i}{n}$$

$capi_i$: Percentual CAPEX increase from introducing product option i
n: #of new product options in the period

The time and cost to introduce new product variety are also important metrics to assess process robustness, since robust processes will imply low cost and fast introduction of new product variety. The metrics Time to introduce a new option in the manufacturing system (TIV) and Cost of introducing a new option in the manufacturing system (CIV) are thus defined as:

$$TIV = \frac{\sum_{i=1}^{n} ti_i}{n}$$

ti_i: time from product design finish to manufacturing system ready
n: #of new product options in the period

$$CIV = \frac{\sum_{i=1}^{n} ci_i}{n}$$

ci_i: cost of introducing product option i
n: #of new product options in the period

5 Conclusion

In order to support the development of production in mass customization, metrics are needed in order to assess the robustness of processes. To establish these metrics, relevant literature was reviewed and several applicable metrics were identified. Further metrics were defined in areas where no sufficient metrics could be identified in literature. The following list compiles the metrics identified in literature and newly defined metrics within the two areas robustness towards existing variety and robustness towards new variety:

<u>Metrics identified in the literature</u>

- Differentiation Point Index (DPI)
- Setup Index is the cost of setup of manufacturing processes (SI)
- Quality of Order Reception (QOR)
- Number of different modules manufactured per process (NMP)

<u>Newly defined metrics</u>

- Number of different modules manufactured per process (NMP)
- Degree of manual labour (DML)
- Percentage point increase in process variety (PVI)
- Capacity expense increase when introducing a new option (CAPIV)
- Time to introduce a new option in the manufacturing system (TIV)
- Cost of introducing a new option in the manufacturing system (CIV)

The reason why new metrics were introduced is that the metrics identified in literature were found insufficient for a number of purposes. In relation to process robustness towards existing variety, the metrics NMP and DML were introduced because the existing metrics focused on the robustness of a manufacturing system as a whole. The new metrics seek to assess the robustness on individual process level. The four new metrics PVI, CAPIV, TIV and CIV were introduced simply because no existing metrics were found in literature supporting the assessment of process robustness towards new variety.

It is the intention that these metrics can be used to in MC companies for different purposes. One purpose is benchmarking against "best practice" mass customizers, in order to identify areas with the greatest potential for improvement. Another purpose is to use these metrics as key performance indicators which are continually calculated to monitor performance to continuously improve. In relation to research in mass customization it is the intention to apply these metrics in different types of mass customization companies to analyze what distinguishes successful mass customizers.

It is evident that the application of these metrics poses certain requirements related to data availability and quality. However, most MC companies already have systems in place which are very likely to contain the data required for calculating the metrics presented in this paper.

As mentioned in the introduction, robust process design is one of three fundamental capabilities for successful mass customizers; the other two solution space development and choice navigation. There are strong relations between these three capabilities, and phenomena experienced in a company cannot necessarily be attributed to only one capability, and as such, the metrics defined in this paper can also be influenced by other factors than the robust process design capability.

When research of identifying existing metrics with further literature review and defining metrics for all three capabilities has been finalized, the future research should establish the links between all three capabilities. Furthermore, the relations between metrics performance and specific methods should be addressed so that an assessment could point out not only what a company should do to improve but also how.

References

1. Blecker, T., Abdelkafi, N., Kaluza, B., et al.: Variety Steering Concept for Mass Customization. Munich Personal RePEc Archive (2003)
2. Daaboul, J., Da Cunha, C., Bernard, A., et al.: Design for Mass Customization: Product Variety vs. Process Variety. CIRP Annals-Manufacturing Technology 60, 169–174 (2011)

3. Lyons, A.C., Mondragon, A.E.C., Piller, F., et al.: Mass Customisation: A Strategy for Customer-Centric Enterprises. Customer-Driven Supply Chains, 71–94 (2012)
4. Martin, M.V., Ishii, K.: Design for Variety: Development of Complexity Indices and Design Charts, pp. 14–17 (1997)
5. Müller, V.: Konzeptionelle gestaltung des operativen produktionscontrolling unter berücksichtigung von differenzierten organisationsformen der teilefertigung. Shaker (2001)
6. Pine, B.J.: Mass customization: The new frontier in business competition. Harvard Business School Press, Boston (1993)
7. Salvador, F., Forza, C.: Configuring Products to Address the Customization-Responsiveness Squeeze: A Survey of Management Issues and Opportunities. International Journal or Production Economics 91, 273–291 (2004)
8. Wildemann, H.: Das just-in-Time-Konzept: Produktion Und Zulieferung Auf Abruf, 5. Aufl., München (2001)