4th International Conference on Mass Customization and Personalization in Central Europe (MCP - CE 2010)

MC&OI and the Financial Crisis - Challenge and Opportunity
September 22-24, 2010, Novi Sad, Serbia

PRODUCT CONFIGURATOR IMPACT ON TIME PERFORMANCE

Alessio Trentin, Elisa Perin, Cipriano Forza
Università di Padova, Dipartimento di Tecnica e Gestione dei sistemi ind.li, Vicenza, Italy

Abstract: *Anecdotal evidence suggests that product configurators may be crucial in improving time performance when offering customized products so as to overcome what has been termed the customization-responsiveness squeeze. Large-scale hypothesis-testing studies that either corroborate this finding or discover unpredicted boundaries of validity are still lacking, however. Our paper contributes to fill this gap by testing the positive impact of product configurator use on time performance on a sample of 238 manufacturing plants from three industries and eight countries. The results support the hypothesized impact after the effects of widely acknowledged antecedents of accelerated time performance have been removed. Implications of our findings for both research and practice are finally discussed.*

Key Words: ***Mass Customization, Operations Management-Information Systems Interface, Product Configuration, Time Performance, Survey Research***

1. INTRODUCTION

Because of intensifying competition and increasingly sophisticated customers, more and more companies nowadays are being squeezed between the need to offer more customized products and the need to develop, produce and deliver such products with greater rapidity ([1]-[3]). Several approaches have been proposed to increase compatibility between customization and responsiveness, including cellular manufacturing, set-up time reduction and product modularity, among others ([1]).

Anecdotal evidence formed through the examination of a few case studies points to the importance of using a product configurator in order to address the customization-responsiveness squeeze (e.g. [4]-[9]). Product configurators are a class of applications designed to help companies carry out the product configuration process ([10], [11]), where the latter is defined as the set of activities aimed at translating each customer's idiosyncratc needs into correct and complete product information supporting order acquisition and fulfillment, such as the description of the product variant that better fits the customer's needs, its price, its bill of materials, its production sequence, etc. ([12], [2]).

However, no large scale empirical test of the suggested positive effect of product configurator use on time performance has been done as yet. Prior research on product configurators has focused on technical or application development issues, such as the logic structures that improve the modeling of product configuration knowledge (e.g., [13]-[17]) or the algorithms that make product configurators faster and more accurate (e.g., [18]-[22]). Fewer studies have treated the impact of product configurator use on company performance ([6], [2], [23]), with most of them being single-case studies whose findings may be legitimaly questioned in terms of generalizability ([24], [25]).

The present paper contributes to fill this gap by testing the positive impact of product configurator use on time performance on a sample of 238 mid- to large-sized manufacturing plants from three industries and eight countries representing North America, Asia and Europe. The analysis results support the hypothesized impact after the effects of time-based manufacturing practices interfunctional integration and delivery priority on time performance have been removed. These results corroborates prior research findings on the time performance benefits of using a product configurator by providing empirical evidence with a higher degree of generalizability. These results also add to the wider debate surrounding information technology support to mass customization, where the latter is defined as the ability to fulfill each customer's idiosyncratic needs without substantial trade-offs in cost, time and quality performance ([26]-[28]).

The remainder of this paper is organized as follows. In Section 2, we review the relevant literature and develop our research hypothesis. In Section 3, we describe our data and the operational measures used to develop the research constructs. Section 4 presents the results of the empirical analysis, while Section 5 concludes by discussing the theoretical and managerial implications of this study as well as its limitations and the associated directions for future research.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1. Product configurator: an application support to the product configuration process

Companies offering a wider variety of predefined and/or customized product variants have higher information-processing needs during order acquisition and fulfillment ([29]). During order acquisition, more information has to be exchanged between the company and the customer in order to communicate what the firm is able to offer, how these offerings meet specific customer needs and on what price and delivery terms the transaction is possible. During order fulfillment, more information has to be processed within the company boundaries in order to translate the description of the product variant that the customer is willing to buy and the company agrees to supply into the product data needed to build the product variant (e.g., bill of materials, technical drawings, production sequence, etc.). As product variety and customization increase, therefore, the product configuration process, which translates the individual customer's specific needs into correct and complete product information supporting order acquisition and fulfillment ([12], [2]), is characterized by higher information-processing requirements.

Information technology has been used to cope with this problem since the 1980s, as documented in [30], [4] and [31]. In those years, manufacturers of very complex products such as Digital's minicomputers developed specific applications designed to support the product configuration process: namely, product configurators. More recently, these applications have become a standard package of all major ERP suites (e.g., SAP, Baan, J.D. Edwards) and many other software vendors offer numerous solutions for small companies ([2]).

The fundamental functions of a product configurator ([6], [32], [8]) can be summarized as follows: communicating the company's product offerings to the customer; checking the completeness and validity of the description of the product variant that the customer is willing to buy and the company agrees to supply; providing real-time information on price, cost, delivery terms, technical characteristics, etc. of a product variant; making quotations; generating the product data necessary to build the product variant requested by the customer. To implement these functions, product configurators rely on logic structures that model product configuration knowledge ([15]): namely, the sales configuration model and the technical configuration model ([29]). The former is a formal representation of the company's product offerings, or product space ([12]), and of the procedures according to which a product variant can be generated or selected within that space. The sales configuration model includes sequences of questions, possibly supported by images and films, which guide the customer in progressively defining all product characteristics and prevent inconsistent or unfeasible characteristics from being defined. In turn, the technical configuration model is a formal representation of the links between the product characteristics codified into the sales configuration model and the documents that describe each product variant from a manufacturing standpoint (product code, bill of materials, production sequence, etc.). Therefore, the technical configuration model includes all the information and rules necessary to generate these data for each possible product variant within the company's product space.

2.2. Time performance

Along with cost, quality and flexibility, time is one of the basic performance dimensions of operations (e.g., [33]-[35]). Various terms have been used in the operations/manufacturing strategy literature to refer to this performance dimension, including delivery, dependability, and speed (e.g., [33], [36], [34]).

Besides terminological differences, the lack of precise and shared definitions is another problem that have plagued the literature on operational performance dimensions ([37], [38]). As regards time performance, a distinction can be made between external and internal time performance, depending on whether performance outcomes are directly perceived by customers or not ([35]). Internal time performance comprises the four elements that typically make up production lead-times: namely, run time, set-up time, move time, and queue time ([39]). These lead-time elements are perceived exclusively within the firm ([35]), although they may be a major determinant of the delivery lead-time experienced by customers. External time performance obviously includes delivery speed and reliability. Speed of delivery is defined as the elapsed time between customers requesting products or services and their receiving them, while delivery reliability is defined as delivering products or services when they were promised to the customer ([40]). Another aspect of time performance that is directly seen from the outside of the company is the purchasing, production and distribution stacked lead-time ([35]). This is because the purchasing, production and distribution cumulative lead-time influences the positioning of the customer order decoupling point ([41]) and, therefore, the way a firm responds to customer requests (e.g., according to a make-to-stock mode of operation rather than in a make-to-order one). Finally, external time performance comprises time-to-market, defined as the time required to develop a new product or service ([35]). This is because engineering activities may be routinely performed prior to purchasing, production and distribution in the operational value chain ([42]) and, consequently, may influence the way a firm responds to customer requests ([35]).

2.3. Relating product configurator use to time performance

Three fundamental mechanisms explain the impact of product configurator use on time performance. A first mechanism is reduced reliance on ad hoc solutions to fulfill idiosyncratic customer needs. Product configurators enable automated generation of product data (bills of materials, production sequences, etc.) that univocally correspond to the set of product characteristics requested by the customer. Automated generation of product data makes the reuse of the same solution whenever the set of customer specifications is the same systematic ([43], [23]). Conversely, without the support of a product configurator, an ad hoc solution could be designed even when an adequate product variant already exists, just because it is too laborious to search for the related product data ([5], [44]). Product configurators also enable provision of real-time information on product price, cost and sometimes delivery terms to the customer. Such information may be used to drive the customer toward a pre-defined solution that costs less than an ad hoc solution and equally fulfills his/her specific needs ([6]). The reuse of validated solutions shortens manufacturing lead-times through faster learning ([45]) and by reducing complexity of production systems ([46]). Additionally, delivery may be accelerated also because increased requirements of pre-defined components and subassemblies may justify build-up of speculative inventory of these parts ([47]). Finally, engineering lead-times get shorter because existing parts require no development resources ([48], [46]).

Another mechanism linking product configurator use to time performance is reduction of product configuration errors. Product configuration errors in the order acquisition phase include specification of product variants that cannot be produced at all, specification of product variants that would not work properly, and specification of product variants that cannot be delivered at the quoted price and/or on the promised due-date ([23]). Product configuration errors in the order fullfilment phase include incorrect bills of materials, technical drawings, production sequences, etc. Product configuration errors may cause time-consuming iterations between customer and supplier or sales and manufacturing ([49]), production stoppages due to missing parts ([6], [44]), and fire-fighting activities that may account for even 80% of the total working time used in order processing ([5]). As a result, delivery performance deteriorates ([6]). Product configurators reduce or even eliminate product configuration errors and, consequently, inprove delivery performance by checking the completeness and validity of sales specifications, by helping salespeople promptly give either correct or good estimates of delivery times and/or prices and by generating the product data needed to build the product variant requested by the customer ([4], [6], [44], [50], [2]).

Finally, the use of a product configurator improves time performance by reducing workload for designers and process engineers during the configuration process. Product configurators support sales personnel during order acquisition by making product knowledge directly accessible to them ([32]). Consequently, technical personnel no longer have to support salespeople in sales specifications ([6], [44], [51]). Additionally, product configurators relieve technical personnel of the responsibility for generating product data ([18], [8], [52]). By automatically producing such information, product configurators enable reduction of the time required for order fulfilment ([53]), thus speeding up delivery. Moreover, by freeing technical personnel from carrying out time-consuming activities during order acquisition and fulfilment, product configurators give companies the opportunity to increase the amount of time that designers and process engineers devote to higher value-added activities ([32], [29], [52]), such as the development of new products and product families ([54], [44], [53]). As a consequence, the speed of new product introduction into the plant can be ehnanced. Reduced workload for designers and process engineers during the configuration process is therefore the third mechanism through which product configurator use may improve time performance. Based on the discussion of this and the other two mechanisms mentioned above, we propose the following hypothesis:

Hypothesis 1. *The use of a product configurator has a positive effect on time performance.*

2.4. Control variables

In this study, we control for three variables that are expected to predict time performance: namely, use of Time-Based Manufacturing Practices (TBMPs), interfunctional integration, and delivery priority. Time-based manufacturing is one weapon for time-based competitors ([55]) and lies in a set of practices designed to reduce throughput time ([56]). Based on literature and logical arguments, [55] developed a framework for time-based manufacturing and defined a set of seven practices, including re-engineering setups, cellular manufacturing; quality improvement efforts, preventive maintenance, dependable suppliers, pull production, and shop-floor employee involvement in problem solving. These practices cover management of the shoop floor and of the supplier network and enable reduction of sourcing and manufacturing lead times.

Another variable that is expected to influence time performance is interfunctional integration, defined as "a process of interdepartmental interaction and interdepartmental collaboration that brings departments together into a cohesive organization" ([57, p.56]). The positive effect of cross-functional teams on development lead-time is a robust finding of the empirical literature on product development ([58]). Moreover, interfunctional integration has been recognized as means to attack many troubles facing manufacturing, including delivery problems ([59]).

A third variable that may affect time performance is delivery priority, defined as the importance of delivery speed and reliability in the company's marketing strategy. Depending on a variety of contextual factors, the same performance dimension may be an order winner, meaning that it makes the product win customer orders in the marketplace ([60]), or an order qualifier, meaning that it must be provided by the company in order to enter or stay in the market ([60]). When delivery speed and reliability are crucial in winning customer orders, the firm will be likely to devote more resources to achieving superior time performance. It is reasonable, therefore, to control for the effect of delivery priority on time performance.

3. METHOD

3.1. Data description

The data used for the empirical analysis are part of the third round of the High Performance Manufacturing (HPM) study, an international research project investigating manufacturing practices, processes and performance ([61]). The sample selected for the project includes 238 mid- to large-sized manufacturing plants operating in three industries (machinery, electronics, and automobile supplier) and located in eight countries (U.S., Japan, South Korea, Finland, Italy, Germany, Austria and Sweden) representing North America, Asia and Europe. The breakdown of our sample by country and industry is reported in Table 1.

Table 1. *Sample profile*

Number of plants				
	Industry			Total
Country	Electronics	Machinery	Auto suppliers	
Finland	14	6	10	**30**
Germany	9	13	19	**41**
Italy	10	10	7	**27**
Japan	10	12	13	**35**
South Korea	10	10	11	**31**
Sweden	7	10	7	**24**
United States	9	11	9	**29**
Austria	10	7	4	**21**
Total	**79**	**79**	**80**	**238**

Twelve different questionnaires were developed by HPM researchers, which were directed to different respondents in each plant, such as managers, supervisors and production workers. To maximize the response rate, HPM researchers first solicited plants participation and then sent the questionnaires to those plants that had agreed to participate. In return for participation, each plant received a detailed report comparing its manufacturing operations profile to those of other plants in its industry. With this approach, the response rate was approximately 65% in each country, thus reducing the need to check for non-response bias ([62], [28]). Additional details of the data collection procedures can be found in [61] and in [28].

Not all plants returned the complete set of questionnaires. Where a particular plant was missing the responses required for our statistical test, it was excluded from the analysis. The final sample used in this study consists of 207 plants.

3.2. Measurements: constructs of interest

A subset of the HPM questionnaire items was employed in this study (see the Appendix). The measure of product configurator use was created from eight items, one intended to capture the availability of a product configurator and the others intended to capture the use of such an application for seven fundamental sub-tasks of the product configuration process. As shown in the Appendix, product configurator use is a binary variable, whose value is "1" if the application is employed for at least one product configuration sub-task, is "0" if the application is not available or, albeit available, is not employed. We deliberately chose not to measure product configurator use by the number of product configuration sub-tasks for which the application is employed, because not all these sub-tasks are meaningful in every context. For instance, the subtask "dynamically generating the bill of materials for new product configurations" is meaningless in a make-to-stock context. Similarly, the sub-task "allowing customers to select appropriate features" is meaningless if only salespeople are permitted to use the product configurator and, conversely, the subtask "allowing salespeople to select appropriate features" is meaningless where all products are on-line configured directly by customers.

The measure of time performance was created from four items based on [35] empirically validated framework for performance measurement system measures. These items are intended to capture the four aspects of time performance that are directly perceived by customers: namely, on-time delivery, fast delivery, cycle time, and speed of new product introduction. Factor analysis showed that all four items load on to a single factor with an eigenvalue greater than one ([63]) and that factor loadings are all greater than 0.50. Cronbach's alpha is above the value of 0.60 recommended for the newly developed scales ([64]). Responses were therefore averaged to obtain a single measure of time performance for each plant.

3.3. Measurements: control variables

We measured TBMP use based on the framework developed by [55]. Similar to [65], we focused on a subset of the seven practices proposed by [55]. We excluded both shop-floor employee involvement in problem-solving and pull production because [55] found them to respectively be an antecedent and an outcome of the five practices considered in this study: namely, reengineering set-ups, cellular manufacturing, quality assurance, preventive maintenance, and dependable suppliers. We measured these five practices by multi-item scales, choosing measures with demonstrated validity in the literature when possible (references are listed in the Appendix). In the same way as [66], we then measured TBMP use by averaging the values of the five scales for each plant. Factor analysis showed that both the composite TBMP use measure and the scales measuring the five underlying practices are significantly associated with only one latent factor and that factor loadings are all greater than 0.50, with only one exception. The one below 0.50, however, is well above the commonly recommended threshold of 0.30 ([67]). Cronbach's alphas are all greater than 0.70 for the established scales and above 0.60 for the newly developed ones ([64]).

As regards interfunctional integration, we measured this control variable by a newly developed scale of six items which exhibits very good psychometric properties. Factor analysis showed that all six items load on to a single factor and factor loadings are all greater than 0.80. Moreover, internal consistency among the six items is very good, with Cronbach's alpha well exceeding the cut-off value recommended for newly developed scales.

Similar to [68], finally, we measured delivery priority by two items intended to capture the degree of emphasis respectively given to fast delivery and on-time delivery as market goals. Both items load on to a single factor, with factor loadings well below the cut-off value of 0.50, and internal consistency between the two items is acceptable (α=0.70). Consequently, responses were averaged to obtain a single value for each plant.

4. RESULTS

To test our hypothesis, we conducted an analysis of covariance (ANCOVA) using TBMP use, interfunctional integration and delivery priority as covariates. This enabled us to determine whether the independent variable (i.e, product configurator use) was having a significant effect on the dependent variable (i.e., time performance), after accounting for the influence of other relevant variables affecting the same outcome (i.e., TBMP use, interfunctional integration and delivery priority).

Statistical assumptions for the ANCOVA test were all checked: homogeneity of the regression slopes (covariates not significantly interacting with the independent variable), homogeneity of variance (Levene's Test not significant), and normal distribution of the data.

The analysis results are shown in Table 2. The data suggest that the mean value of time performance is significantly different (F=4.032, $p<0.05$) when a product configurator is used, as compared to when it is not.

Table 2: *Results of Analysis of Covariance- Dependent Variable: Time Performance (** p<0.01; *p<0.05)*

Source	Sum of Squares	Mean Square	F
Corrected Model	9.962 [(a)]	2.491	8.213**
TBMP use	1.238	1.238	4.081*
Delivery priority	1.420	1.420	4.684*
Interfunctional integration	1.789	1.789	5.899*
Product configurator use	1.223	1.223	4.032*

(a) R Squared = 17.7% (Adjusted R Squared = 15.5%)

Table 3 reports the parameter estimates with the independent variable split into two dummy variables: [Product configurator use=0] indicating non-use of a product configurator and [Product configurator use=1] indicating the use of a product configurator. The assumptions required for parameter estimate were all checked, including linearity, homoscedasticity, independent errors, and normality of the residuals. We also examined collinearity diagnostics to test for potential multi-collinearity effects. Variance inflator factors are all below 10 and their average is close to one, thus ruling out multi-collinearity problems ([69], [70]).

The negative B-value for the [Product configurator use=0] variable suggests that the plants not using a product configurator have a significantly lower mean value of time performance than those using a product configurator, which supports our hypothesis.

Table 3: *Parameter estimates (*p<0.05)*

Parameter	B	Std. Error	t
TBMP use	0.205	0.101	2.020*
Delivery priority	0.186	0.086	2.164*
Interfunctional integration	0.212	0.087	2.429*
[Product configurator use=0]	-0.177	0.088	-2.008*
[Product configurator use=1]	0 [(a)]	.	.

(a) This parameter is set to zero because it is redundant

5. DISCUSSION AND CONCLUSION

While the relevant literature implies a positive impact of product configurator use on time performance, the discussion is generally scattered and disorganized. A first contribution of this paper is clarification of three fundamental mechanisms through which the use of a product configurator may improve time performance: namely, less reliance on ad hoc solutions to fulfill idiosyncratic customer needs, reduction of product configuration errors, and less workload for designers and process engineers during the configuration process.

Secondly, prior research findings on the time performance outcomes of product configurator use mostly rely on exploratory case studies designed to investigate a hitherto unstudied area. As the research matures, however, there is the opportunity for designing explanatory surveys that verify theoretical relationships in larger populations ([71], [72]) and, to the best of our knowledge, our study is the first to empirically test the positive impact of product configurator use on time performance.

By finding empirical support for the hypothesized relationship after accounting for the effects of recognized antecedents of superior time performance, this study also adds to the wider debate on mass customization. Mass customization denotes the ability to fulfill each customer's idiosyncratic needs without substantial trade-offs in cost, time and quality performance ([26]-[28]). Time performance has been empirically found as being negatively affected by product customization (e.g., [73], [74], [75]). Our large-scale empirical study corroborates prior research contention, mostly based on anecdotal evidence, that product configurator use may improve compatibility between product customization and time performance. Moreover, by clarifying the mechanisms underlying the positive impact of product configurator use on time performance, our paper contributes to a deeper understanding of how information technology may support mass customization (e.g., [32], [76], [77], [29]).

Future research could extend this study in at least three directions. Our paper focuses on the impact of product configurator use on the time performance of the operational value chain. Prior research, however, suggests that product configurators may enhance time performance in the sales area too (e.g., [23], [29]), though no large-scale test of this contention has been done yet. Future studies could therefore be designed to empirically test the time compression benefits of product configurator use in the sales area as well. Research on product configurator support to time-based competition could also be extended from manufacturing industries to service industries, where product configurators are increasingly being deployed. Finally, another opportunity for future research would be to investigate internal or external contingencies that may moderate the positive effect of product configurator use on time performance.

Pragmatically, we expect that the results of our large-scale empirical study will make companies more trustful of product configurator support to overcoming the customization-responsiveness squeeze.

6. APPENDIX: MEASURES

Items measuring *Interfunctional integration* and *TBMP use* are rated on a 1-7 Likert scale (7=strongly agree, 6=agree, 5=slightly agree, 4=neutrality, 3=slightly disagree, 2=disagree, 1=strongly disagree).

Product configurator use

Please check the activities for which you use a product configurator:

PC1 Allowing salespeople to select appropriate features
PC2 Allowing customers to select appropriate features
PC3 Dynamically generating the product code for new product configurations
PC4 Dynamically generating the bill of materials for new product configurations
PC5 Dynamically generating the production cycle for new product configurations.
PC6 Dynamically calculating the cost of new product configurations.
PC7 Dynamically pricing new product configurations
(Respondent: information systems manager)

Check if supported by software:

PC8 Product configuration
(Respondent: information systems manager)

Product Configurator Use =

$$\begin{cases} \mathbf{1} & \text{if } PC_i = Yes \quad \text{for at least one } i \\ & \qquad\qquad\qquad\qquad (i=1,\ldots,7) \\ \mathbf{0} & \text{if } (PC_i = No \ \ \forall i) \ OR \\ & ((PC_i = Missing \ \ \forall i) \ AND \ (PC_8 = No)) \end{cases}$$

Time performance (0.69[a]; 52.3%[b])

Please circle the number that indicates your opinion about how your plant compares to its competition in your industry, on a global basis. (5= Superior, 4= Better than average, 3=Average, 2=Equivalent to competition, 1= Poor, low end of industry).

On time delivery performance (0.80[c])
Fast delivery (0.75[c])
Cycle time (from raw materials to delivery) (0.71[c])
Speed of new product introduction into the plant (development lead time) (0.63[c])
(Respondent: plant manager)

Interfunctional integration (0.91[a]; 69.3%[b])

The functions in our plant are well integrated. (0.84[c])
Problems between functions are solved easily, in this plant (0.83[c])
Functional coordination works well in our plant (0.84[c])
The functions in our plant work well together (0.88[c])
The functions in our plant cooperate to solve conflicts between them, when they arise (0.81[c])
Our plant's functions work interactively with each other (0.82[c])
(Respondents: plant superintendent, process engineer, plant manager)

Delivery priority (0.70[a]; 77.2%[b])

Please identify the importance of the market goal below. Identify the goal as absolutely crucial only if it helps "win the order" from the customer in the marketplace relative to the competition. (1=least important, 3=neutral, 5=absolutely crucial)

Fast delivery (0.88[c])
On-time delivery (0.88[c])
(Respondents: plant superintendent, process engineer, plant manager)

TBMP use (0.77[a]; 55.0%[b])

Reengineering set-ups (0.79[c])
Cellular manufacturing (0.64[c])
Quality assurance (0.67[c])
Preventive maintenance (0.81[c])
Dependable suppliers (0.78[c])

Reengineering set-ups[1] (0.83[a]; 54.0%[b])

We are aggressively working to lower setup times in our plant (0.78[c])
We have converted most of our setup time to external time, while the machine is running (0.63[c])
We have low setup times of equipment in our plant (0.67[c])
Our crews practice setups, in order to reduce the time required (0.79[c])
Our workers are trained to reduce setup time (0.81[c])
Our setup times seem hopelessly long (0.71[c]) (reverse scale question)
(Respondents: production control manager, inventory manager, supervisor)

Cellular manufacturing[2] (0.76[a]; 54.0%[b])

We have laid out the shop floor so that processes and machines are in close proximity to each other (0.83[c])
We have organized our plant floor into manufacturing cells (0.52[c])
Our machines are grouped according to the product family to which they are dedicated (0.55[c])
The layout of our shop floor facilitates low inventories and fast throughput (0.86[c])
Our processes are located close together, so that material handling and part storage are minimized (0.84[c])
(Respondents: production control manager, inventory manager, supervisor)

Quality assurance[3] (0.88[a]; 68.0%[b])

Processes in our plant are designed to be "foolproof." (0.63[c])
A large percent of the processes on the shop floor are currently under statistical quality control (0.90[c])
We make extensive use of statistical techniques to reduce variance in processes (0.89[c])
We use charts to determine whether our manufacturing processes are in control (0.76[c])
We monitor our processes using statistical process control (0.91[c])
(Respondents: direct labor, process engineer, quality manager)

Preventive maintenance (0.75[a]; 50.6%[b])

We upgrade inferior equipment, in order to prevent equipment problems (0.74[c])
In order to improve equipment performance, we sometimes redesign equipment (0.50[c])
We estimate the lifespan of our equipment, so that repair or replacement can be planned (0.78[c])
We use equipment diagnostic techniques to predict equipment lifespan (0.76[c])
We do not conduct technical analysis of major breakdowns (0.74[c]) (reverse scale question)
(Respondents: process engineer, supervisor, plant, superintendent)

Dependable suppliers (0.68[a]; 48.9%[b])

We seek short lead times in the design of our supply chains (0.76[c])
Our company strives to shorten supplier lead time, in order to avoid inventory and stockouts (0.68[c])
We believe that cooperating with our suppliers is beneficial (0.77[c])
We emphasize openness of communications in collaborating with our suppliers (0.78[c])
(Respondents: inventory manager, supervisor, plant superintendent)
We can depend upon on-time delivery from our suppliers. (0.45[c])
(Respondents: production control manager, inventory manager, supervisor)

[1] adapted from [78]
[2] [79]
[3] [80]

[a] Cronbach's α
[b] Variance explained by 1st factor
[c] Factor Loading

7. REFERENCES

[1] D.M.McCutcheon, A.S.Raturi, J.R.Meredith, "The customization-responsiveness squeeze", *Sloan Management Review,* Vol.35, No. 2, 1994, pp.89-99.

[2] F.Salvador, C.Forza, "Configuring products to address the customization-responsiveness squeeze: a survey of management issues and opportunities", *International Journal of Production Economics*, Vol.91, No.3, 2004, pp.273-91.

[3] J.Meredith, U.Akinc, "Characterizing and structuring a new make-to-forecast production strategy", *Journal of Operations Management,* Vol.25, No.3, 2007, pp.623-42.

[4] V.E.Barker, D.E.O'Connor, "Expert systems for configuration at Digital: XCON and beyond", *Communications of the ACM*, Vol.32, No.3, 1989, pp.298-318.

[5] J.Tiihonen, T.Soininen, T.Männistö, R.Sulonen, "*State of the practice in product configuration-A survey of 10 cases in the Finnish industry*", in: T.Tomiyama, M.Mäntylä, S.Finger, (Eds.), "Knowledge intensive CAD" – Vol.1, London, UK, Chapman & Hall, 1996, pp.95-114.

[6] C.Forza, F.Salvador, "Product configuration and inter-firm co-ordination: an innovative solution from a small manufacturing enterprise", *Computers in Industry*, Vol.49, No.1, 2002, pp.37-46.

[7] L.Hvam, "Mass customisation in the electronics industry: based on modular products and product configuration", *International Journal of Mass Customisation*, Vol.1, No.4, 2006, pp.410-26.

[8] L.Hvam, S.Pape, M.K.Nielsen, "Improving the quotation process with product configuration", *Computers in Industry*, Vol.57, No.7, 2006, pp.607-21.

[9] P.T.Helo, Q.L.Xu, S.J.Kyllönen, R.J.Jiao, "Integrated vehicle configuration system-Connecting the domains of mass customization", *Computers in Industry*, Vol.61, No.1, 2010, pp.44-52.

[10] C.Forza, F.Salvador, "*Product information management for mass customization*", London, UK, Palgrave Macmillan, 2007.

[11] L.Hvam, N.H.Mortensen, J.Riis, "*Product customization*", Berlin, Germany, Springer, 2008.

[12] M.M.Tseng, T.F.Piller, "*The customer centric enterprise: advances in mass customization and personalization*", Berlin, Germany, Springer Verlag, 2003.

[13] D.L.McGuinness, J.R.Wright, "Conceptual modelling for configuration: a description-based approach", *Artificial Intelligence for Engineering, Design, Analysis and Manufacturing*, Vol.12, No.4, 1998, pp.333–44.

[14] T.Soininen, J.Tiihonen, T.Männistö, R.Sulonen, "Towards a general ontology of configuration", *Artificial Intelligence for Engineering, Design, Analysis and Manufacturing*, Vol.12, No.4, 1998, pp.357-72.

[15] A.Felfernig, G.Friedrich, D.Jannach, "Conceptual modeling for configuration of mass-customizable products", *Artificial Intelligence in Engineering*, Vol.15, No.2, 2001, pp.165-76.

[16] A.Felfernig, "Standardized configuration knowledge representations as technological foundation for mass customization", *IEEE Transactions on Engineering Management*, Vol.54, No.1, 2007, pp.41-56.

[17] D.Yang, R.Miao, H.Wu, Y.Zhou, "Product configuration knowledge modeling using ontology web language", *Expert Systems with Applications*, Vol.36, No.3, Part 1, 2009, pp.4399-411.

[18] S.M.Fohn, J.S.Liau, A.R.Greef, R.E.Young, P.J.O'Grady, "Configuring computer systems through constraint-based modeling and interactive constraint satisfaction", *Computers in Industry*, Vol.27, No.1, 1995, pp.3-21.

[19] P.J.P.Slater, "Pconfig: a web-based configuration tool for configure-to-order products", *Knowldge-Based Systems*, Vol.12, No.5-6, 1999, pp.223-30.

[20] H.Xie, P.Henderson, M.Kernahan, "Modelling and solving engineering product configuration problems by constraint satisfaction", *International Journal of Production Research*, Vol.43, No.20, 2005, pp.4455-69.

[21] S.K.Ong, Q.Lin, A.Y.C.Nee, "Web-based configuration design system for product customization", *International Journal of Production Research*, Vol.44, No.2, 2006, pp.351-82.

[22] X.Luo, Y.Tu, J.Tang, C.K.Kwong, "Optimizing customer's selection for configurable product in B2C e-commerce application", *Computers in Industry*, Vol.59, No.8, 2008, pp.767-76.

[23] M.Heiskala, J.Tiihonen, K.-S.Paloheimo, T.Soininen, "*Mass customization with configurable products and configurators: a review of benefits and challenges*", in: T.Blecker, G.Friedrich, (Eds.), "Mass customization information systems in business", London, UK, IGI Global, 2007, pp.1-32.

[24] C.Voss, N.Tsikriktsis, M.Frohlich, "Case research in operations management", *International Journal of Operations and Production Management,* Vol.22, No.2, 2002, pp.195-219.

[25] C.Voss, "Case research in Operations Management", in: C. Karlsson (Ed), "Researching Operations Management". New York, NY, Taylor & Francis, 2009, pp. 162-95.

[26] J.B.Pine II, "*Mass customization: the new frontier in business competition*", Boston, MA, Harvard Business School Press, 1993.

[27] I.P.McCarthy, "Special issue editorial: the what, why and how of mass customization", *Production Planning and Control*, Vol.15, No.4, 2004, pp.347-51.

[28] G.J.Liu, R.Shah, R.G.Schroeder, "Linking work design to mass customization: a sociotechnical systems perspective", *Decision Sciences*, Vol.37, No.4, 2006, pp.519-45.

[29] C.Forza, F.Salvador, "Application support to product variety management", *International Journal of Production Research*, Vol.46, No.3, 2008, pp.817-36.

[30] D.Leonard-Barton, "The case for integrative innovation: an expert system at Digital", *MIT Sloan Management Review*, Vol.29, No.1, 1987, pp.7-19.

[31] J.J.Sviokla, "An examination of the impact of expert systems on the firm: the case of XCON", *MIS Quarterly*, Vol.14, No.2, 1990, pp.127-40.
[32] K.Steger-Jensen, C.Svensson, "Issues of mass customisation and supporting IT-solutions", *Computers in Industry*, Vol.54, No.1, 2004, pp.83-103.
[33] K.Ferdows, A.De Meyer, "Lasting improvements in manufacturing performance: in search of a new theory", *Journal of Operations Management*, Vol.9, No.2, 1990, pp.168-84.
[34] R.D.Klassen, D.C.Whybark, "The impact of environmental technologies on manufacturing performance", *Academy of Management Journal,* Vol.42, No.6, 1999, pp.599-615.
[35] A.De Toni, S.Tonchia, "Performance measurement systems - Models, characteristics and measures", *International Journal of Operations & Production Management,* Vol.21, No.1/2, 2001, pp.46-70.
[36] S.C.Wheelwright, "Manufacturing strategy: defining the missing link", *Strategic Management Journal,* Vol.5, No.1, 1994, pp.77-91.
[37] M.Swink, M.H.Way, "Manufacturing strategy: propositions, current research, renewed directions", *International Journal of Operations & Production Management,* Vol.15, No.7, 1995, pp.4-26.
[38] N.Slack, M.Lewis, "*Operations strategy*", London, UK, Prentice Hall, 2002.
[39] T.E.Vollmann, W.L.Berry, D.C.Whybark, F.R.Jacobs, "*Manufacturing Planning & Control Systems for Supply Chain Management*", New York, NY, McGraw-Hill, 2005.
[40] N.Slack, S.Chambers, R.Johnston, "*Operations Management*", London, UK, Prentice Hall, 2007.
[41] S.Hoekstra, J.Romme, "*Integrated logistics structures: developing customer oriented goods flow*", London, UK, McGraw-Hill, 1992.
[42] A.De Toni, R.Filippini, C.Forza, "Manufacturing strategy in global markets: an operations management model", *International Journal of Operations & Production Management,* Vol.12, No.4, 1992, pp.7-18.
[43] J.Vanwelkenhuysen, "The tender support system", *Knowledge-Based Systems*, Vol.11, No.5-6, 1998, pp.363-72.
[44] C.Forza, F.Salvador, "Managing for variety in the order acquisition and fulfilment process: the contribution of product configuration systems", *International Journal of Production Economics*, Vol.76, No.1, 2002, pp.87-98.
[45] C.J.Teplitz, "*The Learning Curve Deskbook: A Reference Guide to Theory, Calculations and Applications*", Westport, CT, Quorum Books, 1991.
[46] C.Sheu, J.G.Wacker, "The effects of purchased parts commonality on manufacturing lead time", *International Journal of Operations and Production Management*, Vol.17, No.8, 1997, pp.725-45.
[47] L.P.Bucklin, "Postponement, speculation and the structure of distribution channels", *Journal of Marketing Research,* Vol.2, No. 1, 1965, pp. 26-31.
[48] K.Ulrich, "The role of product architecture in the manufacturing firm", *Research Policy,* Vol.24, No. 3, 1995, pp.419-40.
[49] J.R.Wright, E.S.Weixelbaum, G.T.Vesonder, K.E.Brown, S.R.Palmer, J.I.Berman, H.H.Moore, "A knowledge-based configurator that supports sales, engineering, and manufacturing at AT&T network systems", *AI Magazine*, Vol.14, No.3, 1993, pp.69-80.
[50] L.Hvam, M.Malis, B.Hansen, J.Riis, "Reengineering of the quotation process: application of knowledge-based systems", *Business Process Management Journal*, Vol.10, No.2, 2004, pp.200-213.
[51] P.T.Helo, "Product configuration analysis with design structure matrix", *Industrial Management & Data Systems*, Vol.106, No.7, 2006, pp.997-1011.
[52] L.L.Zhang, C.K.M.Lee, Q.Xu, "Towards product customization: an integrated order fulfillment system", *Computers in Industry,* (In press).
[53] C.Forza, A.Trentin, F.Salvador, "Supporting product configuration and form postponement by groupig components into kits: the case of MarelliMotori", *International Journal of Mass Customisation,* Vol.1, No. 4, 2006, pp.427-44.
[54] E.Bonehill, P.Slee-Smith, "Product configurator", *IEE Digest No. 1998/213*, pp. 9/1-9/4.
[55] X.Koufteros, M.A.Vonderembse, W.J.Doll, "Developing measures of time-based manufacturing", *Journal of Operations Management,* Vol.16, No. 1, 1998, pp.21-41.
[56] J.Blackburn, "*Time-based competition*", Homewood, IL, Business One Irwin, 1991.
[57] K.B.Kahn, J.T. Mentzer, "Marketing's integration with other departments", *Journal of Business Research*, Vol. 42, No.1, pp.53-62.
[58] S.Brown, K.Eisenhardt, "Product development: past research, present findings, and future directions", *Academy of Management Review,* Vol.22, No. 2, 1995, pp.343-78.
[59] E.D.Rosenzweig, A.V.Roth, J.W.Dean Jr, "The influence of an integration strategy on competitive capabilities and business performance: an exploratory study of consumer products manufacturers", *Journal of Operations Management,* Vol.21, No. 4, 2003, pp.437-56.
[60] T.Hill, "*Manufacturing strategy—Text and cases*" (2nd edition), Houndmills, UK, Palgrave, 2000.
[61] R.G.Schroeder, B.B.Flynn, "High *performance manufacturing*", New York, NY, John Wiley & Sons, 2001.
[62] B.B.Flynn, S.Sakakibara, R.G.Schroeder, K.A.Bates, E.J.Flynn, "Empirical research methods in operations management", *Journal of Operations Management*, Vol.9, No.2, 1990, pp.250-84.
[63] S.W.O'Leary-Kelly, R.J.Vokurka, "The empirical assessment of construct validity", *Journal of Operations Management*, Vol.16, No.4, 1998, pp.387-405.
[64] J.C.Nunnally, "*Psychometric theory*", New York, NY, McGraw-Hill, 1978.
[65] Q.Tu, M.A.Vonderembse, T.S.Ragu-Nathan, "Manufacturing practices: antecedents to mass customization", *Production Planning and Control,* Vol.15, No. 4, 2004, pp.373-80.

[66] A.Y.Nahm, M.A.Vonderembse, S.Subba Rao, T.S.Ragu-Nathan, "Time-based manufacturing improves business performance—results from a survey", *International Journal of Production Economics*, Vol.101, No.2, June 2006, pp.213-229.
[67] J.F.Hair, R.E.Anderson, R.L.Tatham, W.C.Black, *"Multivariate data analysis with readings"* (3rd edition), New York, NY, Macmillan, 1992.
[68] J.S.Kim, P.Arnold, "Operationalizing manufacturing strategy", *International Journal of Operations & Production Mangement,* Vol.16, No. 12, 1996, pp.45-73.
[69] R.Myers, *"Classical and modern regression with applications"* (2nd edition), Boston, MA, Duxbury, 1990.
[70] B.L.Bowerman, R.T.O'Connel, *"Linear statistical models: an applied approach"* (2nd edition), Belmont, CA, Duxbury, 1990.
[71] M.K.Malhotra, V.Grover, "An assessment of survey research in POM: from construct to theory", *Journal of Operations Management*, Vol.16, No.4, 1998, pp.407-25.
[72] J.G.Wacker, "A definition of theory: research guidelines for different theory-building research methods in operations management", *Journal of Operations Management*, Vol.16, No.4, 1998, pp.361-85.
[73] J.Mapes, C.New, M.Szwejczewski, "Performance trade-offs in manufacturing plants", *International Journal of Operations and Production Management*, Vol.17, No.10, 1997, pp.1020-33.
[74] P.Ahlström, R.Westbrook, "Implications of mass customization for operations management. An exploratory survey", *International Journal of Operations and Production Management*, Vol.19, No.3-4, 1999, pp.262-74.
[75] B.Squire, S.Brown, J.Readman, J.Bessant, "The impact of mass customisation on manufacturing trade-offs", *Production and Operations Management,* Vol.15, No. 1, 2006, pp.10-21.
[76] J.Warschat, M.Kürümlüoglu, R.Nøstdal, "Enabling IT for mass customisation: the IT architecture to support an extended enterprise offering mass-customised products", *International Journal of Mass Customisation*, Vol.1, No.2/3, 2006, pp.394-401.
[77] T.Blecker, G.Friedrich, "*Mass customization information systems in business*", London, UK, IGI Global, 2007.
[78] B.B.Flynn, E.J.Flynn, "An exploratory study of the nature of cumulative capabilities", *Journal of Operations Management*, Vol.22, No.5, 2004, pp.439-57.
[79] S.Ahmad, R.G.Schroeder, "The impact of electronic data interchange on delivery performance", *Production and Operations Managemen* , Vol.10, No. 1, 2001, pp.16-30.
[80] K.O.Cua, K.E.McKone, R.G.Schroeder, "Relationships between implementation of TQM, JIT, and TPM and manufacturing performance", *Journal of Operations Management*, Vol.19, No.6, 2001, pp.675-94.

CORRESPONDANCE

Dr Alessio Trentin, Res. Ass.
University of Padova
Department of Engineering and Management,
Stradella S. Nicola, 3
36100 Vicenza, Italy
alessio.trentin@unipd.it

Elisa Perin, Phd Student
University of Padova
Department of Engineering and Management,
Stradella S. Nicola, 3
36100 Vicenza, Italy
elisa.perin@studenti.unipd.it

Dr Cipriano Forza, Full Prof.
University of Padova
Department of Engineering and Management,
Stradella S. Nicola, 3
36100 Vicenza, Italy
cipriano.forza@unipd.it