

# Product and Production Configuration Method – enhancing the customer driven value chain by the cognitive dimension

Noëlle Jufer<sup>1</sup>, Jens Bathelt<sup>1</sup>, Matthias Dürst<sup>2</sup>, Andreas Kunz<sup>2</sup>

<sup>1</sup>*inspire AG, Tannenstrasse 3, 8092 Zurich, Switzerland, {jufer,bathelt}@inspire.ethz.ch*

<sup>2</sup>*Swiss Federal Institute of Technology Zurich, Tannenstrasse 3, 8092 Zurich, Switzerland, duerstm@student.ethz.ch, kunz@iwf.mavt.ethz.ch*

## Abstract

Concurrent product and production design in conjunction with mass customisation is in the focus of the work presented in this paper. The novel Product and Production Configuration Method (PPCM) is embedded in two dimensions: the value chain dimension and the cognitive dimension. The value chain dimension includes the synchronisation of product and production design considering all variants implied by the customer. The cognitive dimension captures the knowledge generation and exploitation within an organization. Relations and dependencies between the variants demanded by the customer and the corresponding product- and production-properties can be tracked and documented by the PPCM. The knowledge about these dependencies is crucial when synchronising product and production data. A case study demonstrating the capabilities of the PPCM concludes this work.

## Keywords

Value Chain Dimension, Knowledge based manufacturing considering the Cognitive Dimension, Customer Driven Design and Production, Crossing-Life Cycles Point, Factory as Product

## 1 Introduction

Increased competitive pressure, globalized markets, and ever shorter product life cycles force manufacturing enterprises, in the following called factories, to gain more flexibility and to master faster reaction to respond to changing markets. In addition, customers expect more and more individualized and innovative products at favourable prices, short delivery time, and high delivery reliability. Customers nowadays prefer quality, style, and uniqueness to homogeneous products [Jiao, Tseng, 2004]. This augments the internal product complexity, which causes an increasing number of exceptions in existing product structures [Bongulielmi, et al. 2001]. In addition, the resulting ever more complex product design, in the sense of an increasing amount of variants and shorter development cycles, also strongly affects the planning, development and operative phase of the corresponding production processes and facilities. The planning and design processes of product and factory development have to be coordinated and parallelized in order to get more agile and to swiftly respond to the fast changing conditions [Weimer, et al. 2008].

The value chain dimension, described in section 2, covers the product and factory life cycle and the synchronisation of the product and production design considering the influence by the customer. The cognitive dimension is discussed in the following section defining the terms ‘data’, ‘information’ and ‘knowledge’. These definitions are completed with the description of the process of gaining cognisance and insight on the one hand and the process of value creation on the other hand; as a foundation for the simultaneous design within the value chain dimension. Section 4 describes the novel Product and Production Configuration Method (PPCM) connecting the customer’s point of view with the product and production properties. Finally, a customer driven shoe scenario exemplifies the PPCM in section 5.

## 2 Value Chain Dimension

The new and innovative industrial paradigm ‘Factory as Product’ supports the fusion of a factory and its products within a unique and integrated scope by regarding the factory as a new and complex type of product [Jovane, et al. 2008]. One of the envisioned benefits of this approach is represented by the advantage of applying the life cycle paradigm to the factory. The life cycle approach helps reducing the required resources and improving the technical and social performance in various stages of a factory’s and product’s life. By implementing the life cycle management capability, considerable benefits such as faster time to market, lower cost, reduction of rework and rejection dates, and a higher reuse of components and technologies are achieved [Aldinger, et al. 2006].

In addition, the ‘Factory as Product’ paradigm implies the usage of methods and tools from product design in the new field of production, in which there is a lack of methods and tools. Thus, proven methods and tools are adapted to this new application field, focusing in particular on synchronising product and production, as well as on integrating the customers’ requirements more closely. This includes both design and redesign of products and factories. Figure 1 shows the life cycles of the factory and of the products to be produced.

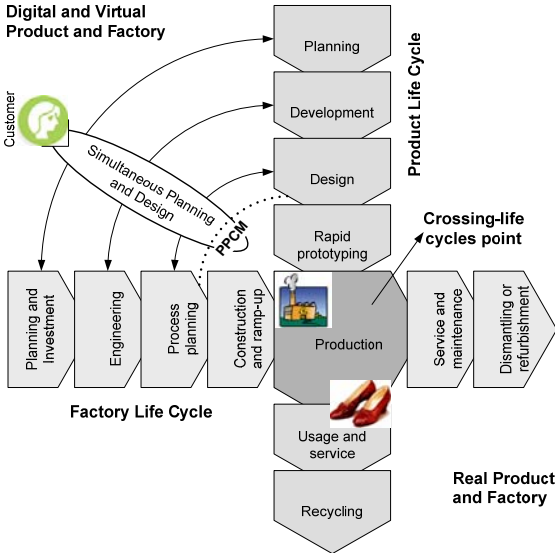


Figure 1: Crossing-Life Cycles Point, based on [Pedrazzoli, et al. 2007]

The central part of Figure 1 is the overlap of factory operation and maintenance and the manufacturing of products in the so-called production phase. This overlap represents the critical point, called ‘Crossing-Life Cycles Point’. Here, digital products and factories become reality. The real product is built in the real factory. In this phase, the production processes are implemented by using the most suitable technologies. Then, all the engineering activities and efforts performed so far will be proved and verified [Pedrazzoli, et al. 2007].

Within the life cycle stages prior to the intersection point, i.e. the planning-, design- and realization stages, the product as well as the factory exist only digitally. This particular form of existence allows realizing adaptations and modifications much easier and faster compared to all stages after the intersection point, at which the product as well as the factory are physically present.

Based on experiences gathered at the running production or from products being already on the market, optimization potential can be recognized within the life cycle stages after the intersection point. This triggers further adaptations in the digital and physical product and/or factory representation. Such a procedure corresponds to a cycle of continuous improvement and further design which aims at a sustainable and successful performance of a factory within a global and individualized market.

### 3 Cognitive Dimension

Figure 2 defines the terms ‘data’, ‘information’, and ‘knowledge’ of the ‘cognitive dimension’.

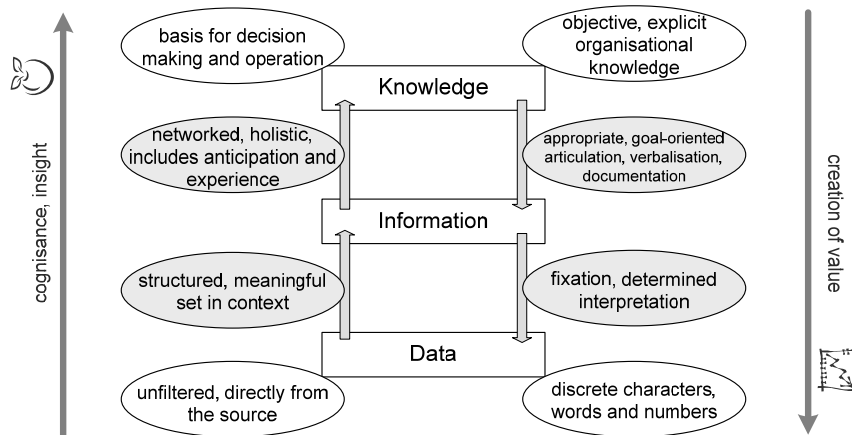


Figure 2: Cycle of organisational learning and value creating in the cognitive dimension

In this dimension, *data* is considered to be mere values, such as discrete characters, words and numbers, which are unfiltered and are taken directly from the source. On the direction of gaining cognisance and insight, which is considered a process of organisational learning, *data* can be transformed into *information* by setting the mere values into a context and/or meaningful structure. One step further on the way to cognisance and insight, *information* can be transformed into *knowledge* by bringing together *information* and its underlying *data* in an integrated and networked point of view, which relies on individual experience and anticipation. Therefore, *knowledge* is person-specific. In a factory, the organisational *knowledge* is composed by consolidation of the factory members’ person-specific *knowledge*. The *cognitive dimension* only considers the objective and explicit [Nonaka, Takeuchi, 1995] part of the organisational *knowledge*, which is based on verified *data* and *information*. This *knowledge* forms the basis for decision making and factory operations.

In the inverse direction, from *knowledge* to *information* and finally to *data*, organisational value is created. The organisational *knowledge* must be articulated, verbalised and documented in an appropriated and goal-oriented way by the specific persons who hold the *knowledge*, in order to keep it in the factory and being able to use and reuse it. These articulations, verbalisations and documentations will represent *information* to other persons since it is not based on their individual experiences. But they can exploit *information* to enlarge their own *knowledge* by connecting *information* with their personal experiences. This newly created *knowledge* again serves as the basis for decision making and factory operation and has again to be articulated in an appropriate way.

The transformation from *knowledge* to *information* and from *information* to new *knowledge* describes one possible cycle of continuous organisational learning and value creation in the *cognitive dimension*. There exists another possible cycle, which is based on *data*. *Information* itself consists of *data*, which is fixed by the value creation process in an information specific medium and which follows rules that determine the *data*’s interpretation. By picking required *data* from the appropriate medium and setting it into a new context and/or meaningful structure, new *information* will be generated. This newly generated *information* again will be the base for *knowledge* creation. Thus, the individual and by this the organisational *knowledge* grows continuously.

The cycle of organisational learning and value creating, based on *data*, *information* and *knowledge*, enables the factory to perform successfully in the market through continuous learning and improvement.

## 4 Product & Production Configuration Method (PPCM)

During the last years, factories have reacted to the individualisation by offering an increasing product-variety. The product-configuration process has become more and more complex for vendors and customers. Although the product configuration is an issue in many companies, it is usually not treated in a methodical way [Bongulielmi, et al. 2001]. The K- & V-Matrix Method deals with the challenges concerning the configuration of variant products. The PPCM exploits and extends the K- & V-Matrix Method including the factory view. It integrates the product, factory and customer view. In the following section 4.1, a short introduction of the K- & V-Matrix Method is provided, followed by the presentation of the PPCM in section 4.2.

### 4.1 The K- & V-Matrix Method

Figure 3 shows the basic design of the K- & V-Matrix Method, which originates from the product engineering world.

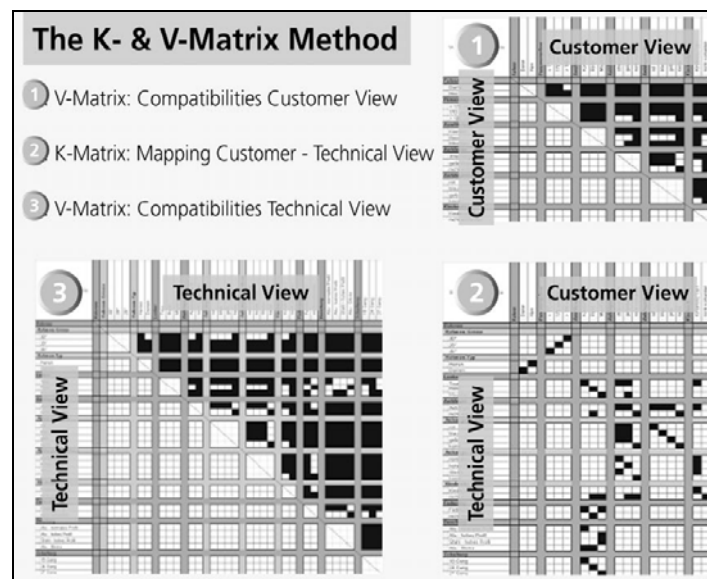


Figure 3: The structure of the K- & V-Matrix Method.

It is based on two kinds of matrices: the symmetric Compatibility (V) and the Configuration (K) Matrix. The method consists of two Compatibility (V) Matrices; one shows the technical and the other one the customer oriented view of the product. The customer view describes product features or requirements which are essential for the customer to configure his favoured product. The technical view contains all product modules which have variants and it is derived from the hierarchical product structure. The matrix fields describe the compatibilities of the feature's properties with each other. Whenever a field is shaded, the combination of the properties of the corresponding line and column is possible.

The Configuration (K) Matrix lines up the characteristics of the two different views mapped in the Compatibility Matrices. The fields of this matrix represent the mapping of the customer's options to the technical modules. In this matrix, all possible combinations are identified. The three matrices together identify and mark all properties that are compatible. A detailed description of the method can be found in [Bongulielmi, et al. 2001] and [Puls, et al. 2002].

### 4.2 PPCM extending the K- & V-Matrix Method by integrating the factory view

Figure 4 shows the expansion of the PPCM in order to integrate the factory into a holistic knowledge base, which considers the product's and the factory's representation. The white area shows the K- & V-Matrix Method whereas the 'Customer View' describes the customer features and the 'Technical View' describes the product features. The newly added light-grey Configuration (T/F) and Compatibility (F) Matrices describe the factory constraints.

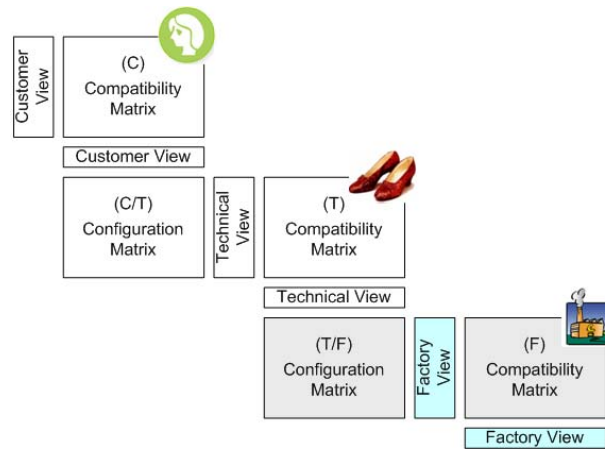


Figure 4: PPCM extending the K- & V-Matrix Method by integrating the factory view

The novel Configuration Matrix (T/F) confronts the properties of the product features with the ones from the factory; the novel Compatibility Matrix (F) shows the compatibility among the factory properties. All the Compatibility Matrices (C, T, and F) are symmetric. In the PPCM, the factory's view is represented by the features of the elements of the production processes. The production processes are divided into manufacturing-, assembly- and logistic processes.

The technical view bridges the customer and the factory view. Thus, relations and dependencies between the variants demanded by the customer and the corresponding product- and production-properties can be tracked and documented by the PPCM.

#### 4.2.1 PPCM in the context of the Value Chain Dimension

In the context of the value chain dimension, the PPCM represents a novel method, which synchronizes the life cycles of product and factory in the design phase (Figure 1) and thus supports the simultaneous product and factory design. When linked with the digital product and the factory, the PPCM supports the virtual evaluation of different variants and their impact on the corresponding product- and production properties.

#### 4.2.2 PPCM in the context of the Cognitive Dimension

Figure 5 shows a detail of the Configuration Matrix (C/T) of the PPCM.

C/T	customer features	option 1		option 2		option 3						
	properties	1.1	1.2	2.1	2.2	3.1	3.2	3.3	3.4	3.5	3.6	3.7
technical features	module 1	1.1	1.2									
	module 2	2.1										
module 3	3.1											
	3.2											

Figure 5: PPCM in the context of the Cognitive Dimension

In the PPCM, all the properties noted such as '1.1, 1.2, ..., 3.7' in the customer's and in the technical view is *data*. The structure of the properties can be regarded as *information*. For example: 'property 2.1' and 'property 2.2' belong to 'option 2' of the customer's features in the customer's view, while 'property 1.1' and 'property 1.2' belong to 'module 1' of the technical features in the technical view. *Knowledge* is presented in the matrices; 'property 1.1' of 'option 1' in the customer's view will be provided by 'property 1.1' and 'property 1.2' of 'module 1', 'property 2.1' of 'module 2' and 'property 3.1' of 'module 3' in the technical view. In the PPCM, *knowledge* is the networked and holistic view of all the possible variants of the customer-driven product and production. The PPCM Method allows the representation of the configuration knowledge in a structured way and represents the rule-based expertise for customer's product and production configuration.

## 5 PPCM exemplified by customer-driven shoe production

For a better understanding of the cooperation of the five matrices (Figure 4), an example of an imaginary shoe-collection will be shown in this paragraph. To make this example more understandable, one feature of the customer's view and its influences through all the matrices is discussed. Figure 6 shows the simplified first Configuration Matrix (C/T), which only shows the influences of the customer's feature: 'Shoe Colour'.

C/T	customer features	Shoe Colour		
	properties	black	red	blue
Upper-Colour	black			
	red			
	blue			X
Upper-Material	synthetic			
	leather			X
	Sweat-EX (permeable to air)			

← A  
← B

Figure 6: Reduced Configuration Matrix (C/T) for the customer's point of view: Shoe Colour

For this example, the customer has chosen the property 'blue'; a blue shoe. This selection refers to the property 'blue' of the feature 'Upper-Colour' in the technical view 'A'. On the other hand, the blue 'Shoe Colour' is not available for 'leather' (Upper-Material) 'B'. Now, these two corresponding technical views have to be examined in the Compatibility Matrix (T) of the technical view and the blue shoe colour in the Compatibility Matrix (C) of the customer's view as shown in Figure 7.

T	technical features	Upper-Colour			Upper-Material		
	properties	black	red	blue	synthetic	leather	Sweat-EX (permeable to air)
Sole	leather-man			X		X	
	leather-woman			X		X	
	rubber black						
	rubber white						
	running black						
	running white						
	running comfort black						
	running comfort white						
Upper-Colour	black						
	red						
	blue			X			
Laces	black						
	white						
	yellow						
	none						X
Upper-Material	synthetic						
	leather					X	
	Sweat-EX (permeable to air)						

C	customer features	Shoe Colour		
	properties	black	red	blue
Gender	male			
	female			
Shoe Type	athletic			
	daily			
	formal			X
Shoe Colour	black			
	red			
	blue			X
Sole Colour	black			
	brown			
	white			X
Laces Colour	black			
	white			
	yellow			
Size	S			
	M			
	L			
	custom			
Foot - Width	normal			
	wide			
	custom			
Shock Absorber	yes			
	no			
Upper-Material	synthetic			
	leather			
	Sweat-EX (permeable to air)			

Figure 7: Reduced Compatibility Matrices; Left: Technical View (T); Right: Customer's View (C)

In these two matrices (Figure 7), more configuration restrictions are the result of the selection of a 'blue shoe'. On the left hand side, the incompatibilities of a blue shoe with leather soles or with a shoe that has no laces are shown at 'A'. 'B' shows the same restrictions as the configuration

matrix above. ‘C’ displays the indirect incompatibilities over the upper material, but in this case they overlap with the discussed ones. On the right hand side, in the compatibility matrix of the customer’s view, the only additional restrictions were that it couldn’t be a formal shoe or a shoe with a brown sole (leather sole), marked with ‘D’.

In the following step, the technical view (rows) is mapped to the factory view (columns) in the second configuration matrix (T/F). In other words, Figure 8 shows the influences of the product modules on the needed process elements.

T/F	factory features	Last Production	Material Inspection	Material Cutting	Upper Inking & Drying	Sole Application	Heel Application	Laces Application	Order	Transfers
technical features	properties	yes none	yes none	standard custom	black red blue	glueing stitching	yes none	black white yellow none	standard with existing customer-last footscan-order	Last Warehouse to Assembly Last Production to Assembly Laces Warehouse to Assembly Heel Warehouse to Assembly Material to Inspection Material to Standard-Cutting Material to Custom-Cutting Inspection to Standard-Cutting Inspection to Custom-Cutting Standard-Cutting to Black-inking Standard-Cutting to Red-inking Custom-Cutting to Black-inking Custom-Cutting to Red-inking Black-ink. to Upper-Stitching Red-ink. to Upper-Stitching Blue-ink. to Upper-Stitching Upper-Mounting to Sole Glueing
Sole	leather-man leather-woman rubber black rubber white running black running white running comfort black running comfort white									
Upper-Colour	black red blue									
Laces	black white yellow none									
Upper-Material	synthetic leather Sweat-EX (permeable to air)									

Figure 8: Reduced Configuration Matrix (T/F): Technical View mapped to Factory View

As seen before, the blue-shoe selection in the customer’s view maps to ‘Upper-Colour’ in the technical view. This leads directly to the blue inking and drying process ‘A’, likewise to the appending logistic transfer processes ‘B’. Further, the materials which are selectable with the blue-shoe choice (synthetic and Sweat-EX) exclude the material inspection process and lead to the corresponding transfers ‘C’. The last matrix (F) in Figure 9 maps the compatibilities between the properties of the factory features.

F	factory features	Last Production	Material Inspection	Material Cutting	Upper Inking & Drying	Sole Application	Heel Application	Laces Application	Order	Transfers
factory features	properties	yes none	yes none	standard custom	black red blue	glueing stitching	yes none	black white yellow none	standard with existing customer-last footscan-order	Last Warehouse to Assembly Last Production to Assembly Laces Warehouse to Assembly Heel Warehouse to Assembly Material to Inspection Material to Standard-Cutting Material to Custom-Cutting Inspection to Standard-Cutting Inspection to Custom-Cutting Standard-Cutting to Black-inking Standard-Cutting to Red-inking Standard-Cutting to Blue-inking Custom-Cutting to Black-inking Custom-Cutting to Red-inking Custom-Cutting to Blue-inking Black-inking to Upper-Stitching Red-inking to Upper-Stitching Blue-inking to Upper-Stitching Upper-Mounting to Sole Glueing Upper-Mounting to Sole Stitching Sole Glueing to Heel Application Sole Glueing to Laces Application Sole Stitching to Laces Application Heel Application to Packaging
Material Inspection	yes none									
Upper Inking & Drying	black red blue									
Sole Application	glueing stitching									
Laces Application	black white yellow none									
Order	standard with existing customer-last footscan-order									

Figure 9: Reduced Compatibility Matrix (F) of the Factory View

For example, the blue inking process leads to the fact that the sole will only be glued and not stitched ‘A’, since in this shoe-collection only a formal man shoe (not available in blue) has a sole which is stitched on. In Figure 9, the appending transfers ‘B’ are selected as well.

Essentially, after a customer has defined his desired product variant, all option properties from the customer’s point of view are specified. The specification of these properties implies the

related module properties within the technical view via the Configuration Matrix (C/T). In view of this, the bill of materials – listing the parts treated in production – is identified. As a result, the specified module properties of the technical view lead to the related process properties of the factory view by applying the Configuration Matrix (T/F) locating all elements of the production process sheet. In summary, the compatibility matrices (C, T, and F) ensure consistency within the three views (customer/product/factory) and the configuration matrices (C/T) and (T/F) constrain the consistency between the three views.

## 6 Conclusion and Outlook

PPCM can be exploited to introduce the cognitive dimension in customer driven design and production. The knowledge about relations and dependencies between the variants demanded by the customer and the corresponding product- and production-properties can be visualised and documented by the PPCM. This configuration knowledge is crucial when synchronizing product and production data. The benefit of this synchronisation lies in obtaining the knowledge about the impact of a change in one or more properties in one or more views on the remaining or additional properties and on the whole system.

In the future, performance indicators such as, cost and throughput time, can be assigned to the properties of all three views (factory/technical/customer) within PPCM. This will for instance enable the calculation of the cost and throughput time of each customer option based on the specified customer variant.

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### References

- Aldinger L, Constantinescu C, Hummel V, Kreuzhage R and Westkämper E. (2006) New approaches for advanced Manufacturing Engineering. Scientific Management, Factory Life Cycle, Factory as a Product and advanced Industrial Engineering (aIE). In: wt Werkstattstechnik online, Issue 3, 2006, Springer-VDI-Verlag
- Bongulielmi L, Henseler P, Puls Ch, Meier M. (2001) The K-&V-Matrix Method – an approach in analysis and description of variant products. International Conference on Engineering Design (ICED 2001), Glasgow, August 21-23, 2001, Professional Engineering Publishing Limited, Bury St Edmunds and London, UK.
- DOROTHY: Design Of Customer driven shOes and multi-siTe factorY. WWW page.  
<http://web.ttsnetwork.net/dorothy/>, accessed 6.3.2009.
- DOROTHY-wiki: Design Of Customer driven shOes and multi-siTe factorY. WWW page.  
<http://dorothy.wikidot.com/>, accessed 6.3.2009.
- Jovane F, Westkämper E, Williams D. (2008) The Manufacture Road: Towards Competitive and Sustainable High-Adding-Value Manufacturing. Ed. F. Jovane, E. Westkämper, D. Williams, Springer Verlag, Feb.08
- Nonaka I, Takeuchi H. (1995) The knowledge-creating company: how Japanese companies create the dynamics of innovation. Oxford University Press, New York, 1995
- Pedrazzoli P, Rovere D, Constantinescu C, Bathelt J, Pappas M, Dépincé P, Chryssolouris G, Boër C, Westkämper E. (2007) High Value Adding VR Tools for Networked Customer-Driven Factory. Proceedings of the 4<sup>th</sup> International Conference on Digital Enterprise Technology (DET 2007), Bath, U.K. CIRP-DET, September 2007, pp.347-352.
- Puls Ch, Bongulielmi L, Henseler P, Meier M. (2002) Die K- & V-Matrix: Methodik und System zur Abbildung von Wissen bezüglich Variantenprodukten. VDI Bericht, 1645, VDI Düsseldorf, Deutschland.
- Jiao J, Tseng M. (2004) Customizability analysis in design for mass customization. Computer-Aided Design, Vol. 36, pp. 745-757
- Weimer T, Kapp R, Klemm P, Westkämper E. (2008) Integrated Data Management in Factory Planning and Factory Operation. An Information Model and its Implementation. The 41<sup>st</sup> CIRP Conference on Manufacturing Systems, Tokyo, Japan, May 26-28, 2008.