37th AIM Conference in Vienna "Human Centered Production in Cyber-Physical Production Systems"

Variety Induced Complexity in Mass Customization

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Technical University of Košice, Slovakia

Agenda of Presentation

1. *Brief introduction of TUKE*
2. *Recent related research works*
3. *The main topic of the presentation:*

   Variety Induced Complexity in Mass Customization

   3.1 Human-Centered Production and Mass Customization

   3.2 Introduction to Mass Customization

   3.4 Complexity issues of Mass customization

   3.5 Conclussions

Brief Introduction of TUKE

The Technical University of Košice was founded in **1952**,

Faculty of Metallurgy
Faculty of Mechanical Engineering
Faculty of Electrical Engineering and Informatics
Faculty of Civil Engineering
Faculty of Economics,
Faculty of Manufacturing Technologies
Faculty of Arts
Faculty of Aeronautics
Faculty of Mining, Ecology, Process Control and Geo-technology

Slovakia 2015

ranking	World Rank	University	Det.	Presence Rank*	Impact Rank*	Openness Rank*	Excellence Rank*
1	634	Comenius University in Bratislava / Univerzita Komenského v Bratislave	»	345	1390	534	666
2	675	Slovak University of Technology in Bratislava / Slovenská technická univerzita v Bratislave	»	352	824	557	1117
3	768	Technical University of Košice / Technická univerzita v Košiciach	»	1045	843	776	1222
4	1495	Pavol Jozef Šafárik University in Košice / Univerzita Pavla Jozefa Šafárika v Košiciach	»	2138	3288	876	1473
5	1752	University of Žilina / Žilinská univerzita v Žiline	»	1498	3224	1265	2086

Brief Introduction of TUKE

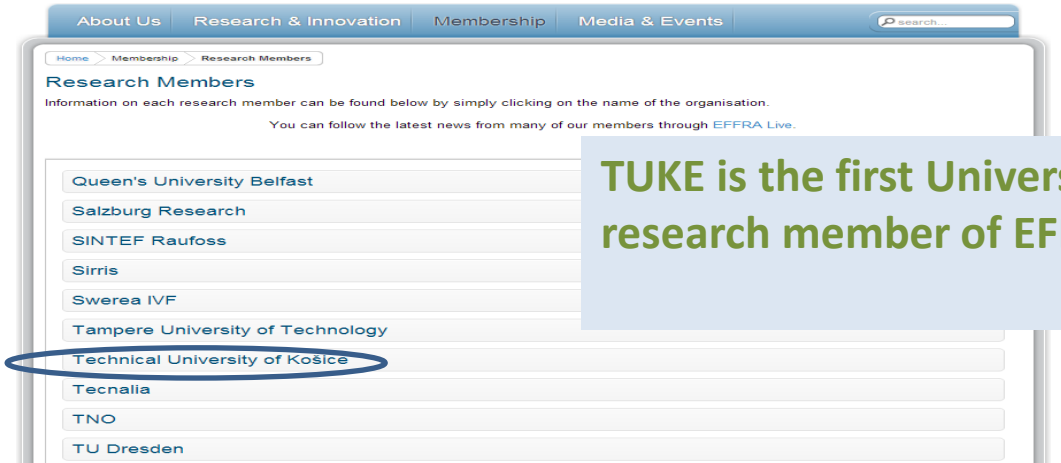
TUKE is member of the RawMatTERS – winner of [EIT Raw Materials]

EIT's 2014 Call for KICs Proposals

EIT Raw Materials is a consortium of more than 100 partners from leading businesses, research centres and universities from 20 EU Member States. EIT Raw Materials was designated as an EIT Knowledge and Innovation Community (KIC) by the EIT Governing Board on 09 December 2014.

TUKE is the first university from Slovakia involved in Knowledge and Innovation Community (KIC)

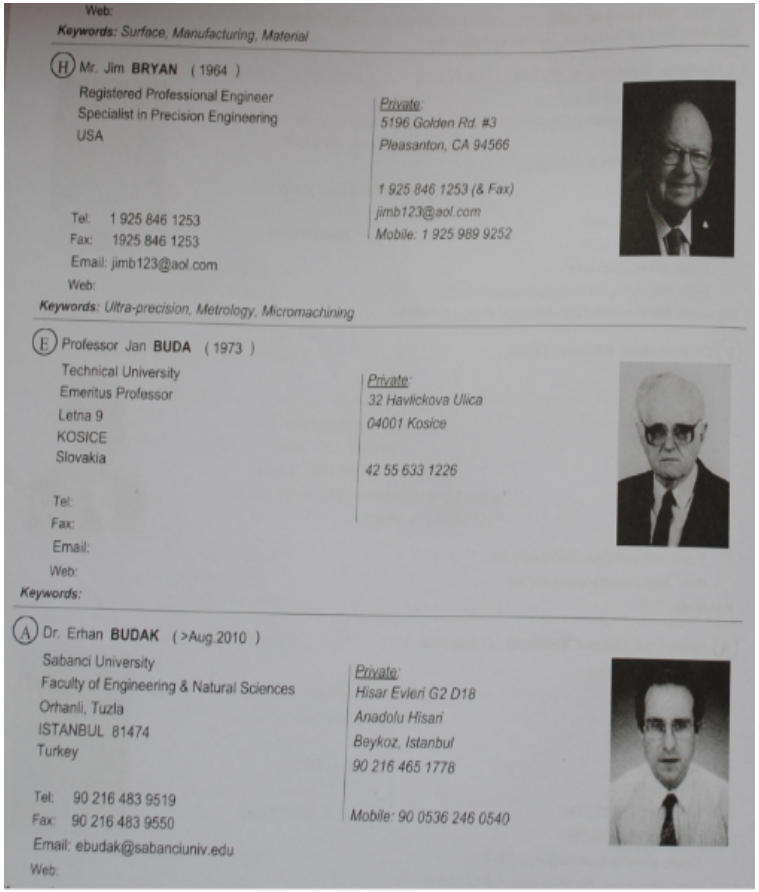
TUKE is research member of EFFRA -**European Factories of the Future Research Association**



TUKE is the first University from Slovakia who is a research member of EFFRA

Brief Introduction of TUKE

The first fellow of CIRP in Slovakia became Prof. Ján Buda from TUKE (1973)
Presently, he is **fellow emeritus of The CIRP.**



Web:
Keywords: *Surface, Manufacturing, Material*

(H) Mr. Jim **BRYAN** (1964)
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Keywords: *Ultra-precision, Metrology, Micromachining*

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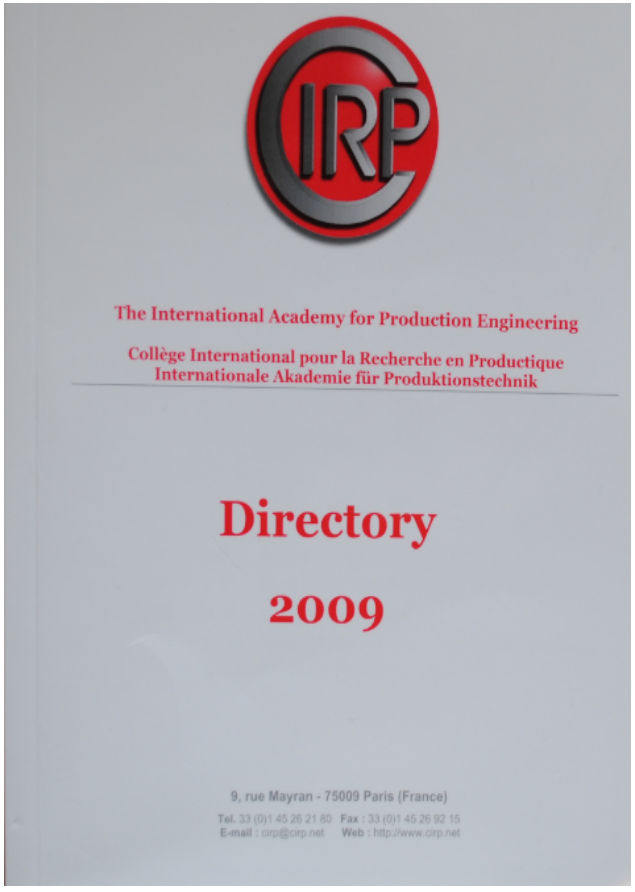

CIRP

The International Academy for Production Engineering

Collège International pour la Recherche en Productique
Internationale Akademie für Produktionstechnik

Directory

2009

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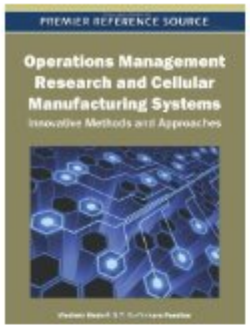
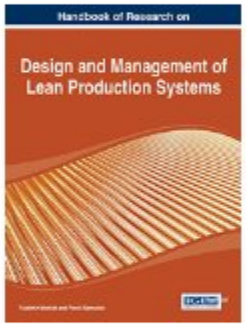
Recent related research works: International book projects



Operations Management Research and Cellular Manufacturing Systems: Innovative Methods and Approaches 2011

by Vladimir Modrak and R. Sudhakara Pandian

Hardcover



Design and Management of Lean Production Systems 24 Jan 2014

by Vladimír Modrák and Pavol Semano

Hardcover

Mass Customized Manufacturing: Theoretical Concepts and Practical Approaches

by Modrak; Vladimir

Edition:	1st
ISBN13:	9781498755450
ISBN10:	1498755453
Pub. Date:	3/15/2017
Publisher(s):	CRC Press

3.1 Human-Centered Production and Mass Customization

The lesson learned from the CIM crisis: Human work in factories can never be entirely replaced by computers and artificial int. (Zuehlke, 2009).

Arguments:

1) **full automation is inflexible, error-prone and expensive to keep running**
2) **According to concept Indutry 4.0 educated and skilled workers will integral part of the Cyber-physical production systems**

Further development of mass customized production will follow paradigm of HCP.

Zühlke, Detlef. "SmartFactory Â–a Vision Becomes Reality.„ *Information Control Problems in Manufacturing*. Vol. 13. No. 1. 2009.

Variety Induced Complexity in Mass Customization

The main impacting factors on Human-centered production (Gorecky, 2013):

-***Globalisation***

- ***Rapid technological developments***

- ***Changing customer demands*** – Firms tend to produce a wide variety of products and product variants to satisfy a broad customer spectrum.

- ***Demographic changes***

-**Knowledge-based Economy**

Mass customization strategy is influencing *Human-centered production.*

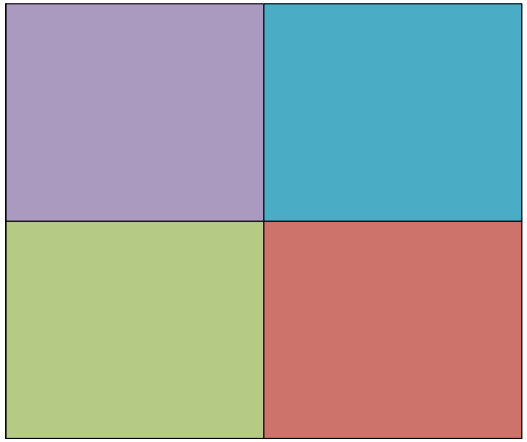
Gorecky, D., Mura, K., & Arlt, F. (2013, August). A Vision on Training and Knowledge Sharing Applications in Future Factories. In *Analysis, Design, and Evaluation of Human-Machine Systems* (Vol. 12, No. 1, pp. 90-97).

3.2 Introduction to Mass Customization

Anderson (2004): **Mass customization means manufacturing custom products in large quantity (not just assembly modules) quickly and efficiently to achieve higher customer satisfaction**.

THE FOUR APPROACHES TO MASS CUSTOMIZED MANUFACTURING (Gilmore and Pine**):**

Gilmore J, Pine B. The four faces of mass customization. Harv Bus Rev, 1997; 75(1):91-101.



3.3 Complexity issues of Mass customization

In the context of increasing complexity of mass customized operation, product variant management gains importance.

Source : ElMaraghy W, ElMaraghy H, TomiyamaT, Monostori L. Complexity in engineering design and manufacturing. CIRP Ann Manuf Technol, 2012; 61(2):793–814

There are more methodological approaches to a quantification of **product variety induced complexity**:

1. **Combinatorial Based Approach** to determine all of the possible product configurations (PCs)
2. **Axiomatic Design and Entropy Based Approach**

Combinatorial Based Approach / proposed methodological framework defines:

1) entry assembly components as basic elements for the calculation of PCs
2) Procedures for the calculations in individul assembly nodes
3) Procedure to calcuate PCs of entire SC.

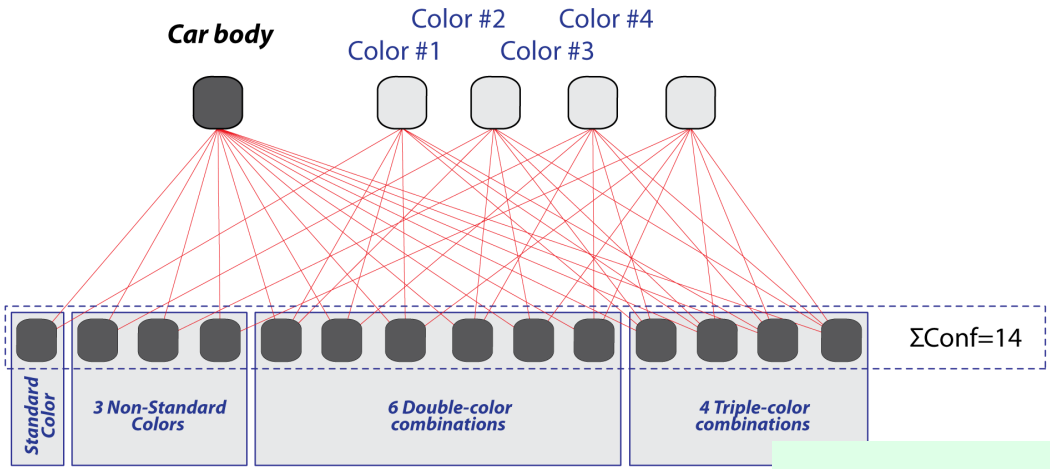
Note: A component, in this context can be understood as a part, module, and group of products, property or other characteristic of the module/product.

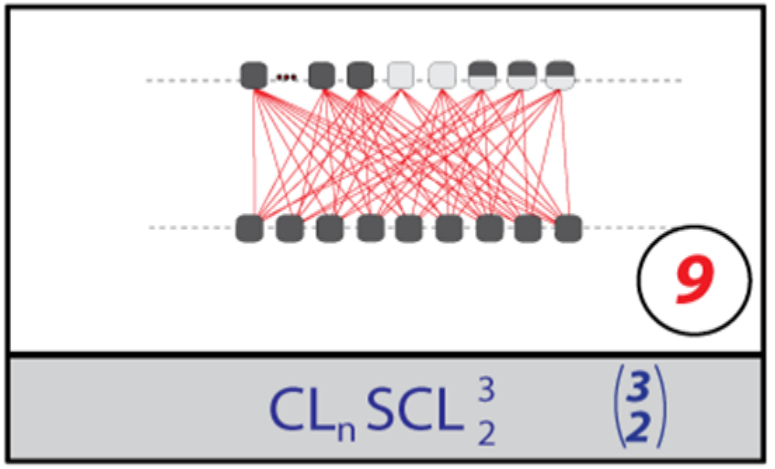
Practically, three types of entry assembly components has to be identified:

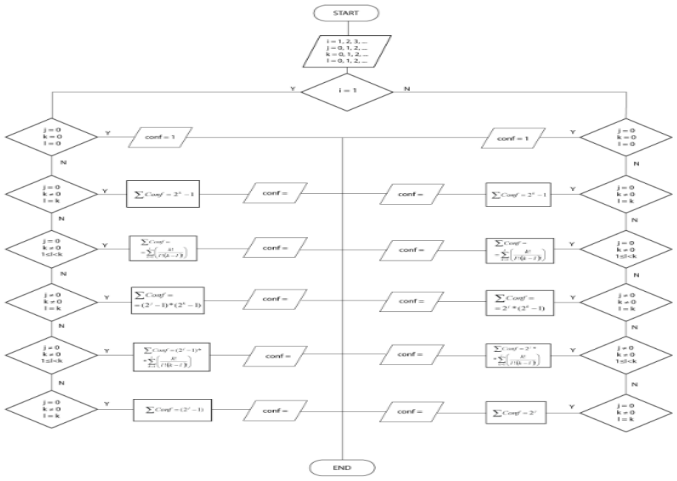
- **stable components,**
- **voluntary components,**
- **compulsory optional components.**

3.3 Complexity issues of Mass customization

Combinatorial Based Approach







Config. Calculator

$$\sum Konf_{CL_1 SCL_5^{10}} = \left((2^j)-1\right) * \sum_{k=1}^{j} \left(\frac{k!}{l!\,(k-l)!}\right)$$

$$= (2^5 - 1)$$

$$* \left(\left(\frac{10!}{1!\,(10-1)!}\right) + \left(\frac{10!}{2!\,(10-2)!}\right) + \left(\frac{10!}{3!\,(10-3)!}\right) + \left(\frac{10!}{4!\,(10-4)!}\right)\right.$$

$$+ \left(\frac{10!}{5!\,(10-5)!}\right) + \left(\frac{10!}{6!\,(10-6)!}\right) + \left(\frac{10!}{7!\,(10-7)!}\right) + \left(\frac{10!}{8!\,(10-8)!}\right)$$

$$\left. + \left(\frac{10!}{9!\,(10-9)!}\right)\right)$$

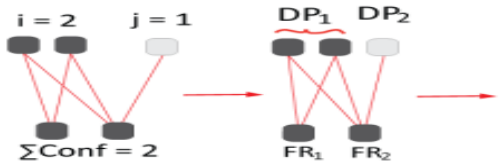
$$= (32-1) * (10 + 45 + 120 + 210 + 252 + 210 + 120 + 45 + 10)$$

$$= 31 * 1022 = 31\,682$$

3.3 Complexity issues of Mass customization

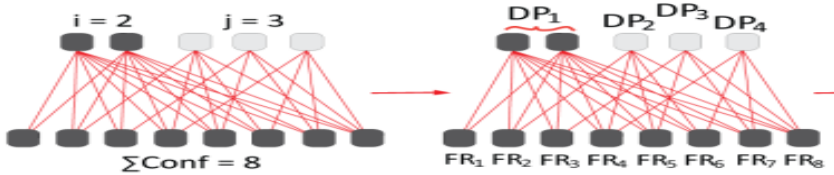
Axiomatic Design and Entropy Based Approach

1 Step: *Transforming nodes of MCA into axiomatic design matrices*



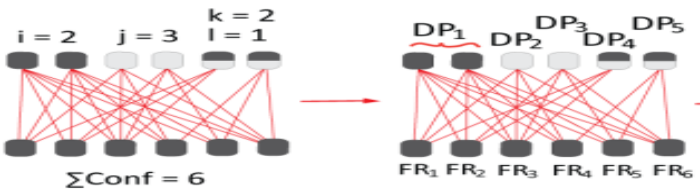
a)

	DP_1	DP_2
FR_1	X	O
FR_2	X	X



b)

	DP_1	DP_2	DP_3	DP_4
FR_1	X	O	O	O
FR_2	X	X	O	O
FR_3	X	O	X	O
FR_4	X	O	O	X
FR_5	X	X	X	O
FR_6	X	X	O	X
FR_7	X	O	X	X
FR_8	X	X	X	X



c)

	DP_1	DP_2	DP_3	DP_4	DP_5
FR_1	X	X	O	X	O
FR_2	X	O	X	X	O
FR_3	X	X	X	X	O
FR_4	X	X	O	O	X
FR_5	X	O	X	O	X
FR_6	X	X	X	O	X

3.3 Complexity issues of Mass customization

Axiomatic Design and Entropy Based Approach

2 step: *Application the concepts of Entropy and Degree of Disorder* *to quantify product variety induced complexity through complexity indicator presented by Guenov*

The first one, denoted as Systems Design Complexity (SDC),

$SDC = \sum N_j \ln N_j$,

where 'N_j' is interpreted as number of interactions per single DP of measured designed matrix.

The second measure is Degree of disorder:

$$\Omega = C_N^{N_1} * C_{N-N_1}^{N_2} * C_{N-N_1-N_2}^{N_3} \dots * \dots C_{N-N_1-\dots-N_{K-1}}^{N_K} = \frac{N!}{N_1!N_2!\dots N_K!},$$

$$C_N^{N_1} = \frac{N!}{(N-N_1)!N_1!},$$

Where 'N' is number of interactions within a measured design matrix, and N_1, N_2, …, N_K are number of interactions per each DP of the same matrix.

Third indicator ***Ln Ω*** was proposed in order to obtain less exponential and more tangible values of Ω . Calculated values of the , Ln and *SDC* for all product classes and sub-classes have been determined for both, FS1 and FS2.

Guenov, Marin D. "Complexity and cost effectiveness measures for systems design." (2002).

3.3 Complexity issues of Mass customization

Axiomatic Design and Entropy Based Approach

Fragment values of complexity indicators for classes CL_1 to CL_6. ***Scenario #1***

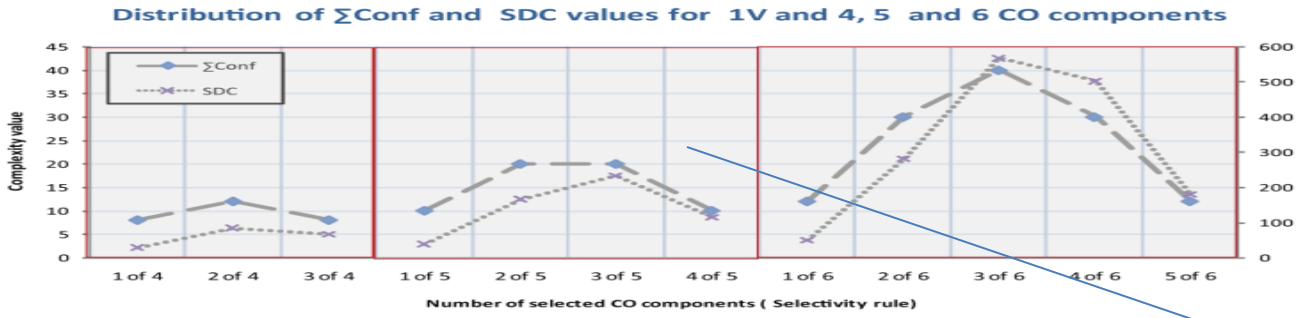
Component Class	Component Sub-class		∑Conf	N	DPs	Ω	ln[Ω]	SDC
	S	VO						
CL1	1	1	1	2	2	2	0,69	1,39
	1	2	3	7	3	210	5,3	6,1
	1	3	7	19	4	1,7E+09	21,3	30,3
	1	4	15	47	5	7,5E+28	66,5	107,2
	1	5	31	111	6	5,3E+79	183,6	328,3
	1	6	63	255	7			926,4
	1	7	127	573	8			2478,4
	1	8	255	1266	9			6334,7
CL2+	2	1	2	3	2	3	1,1	4,7
	2	2	4	8	3	420	6,0	8,3
	2	3	8	20	4	4,4E+09	22,2	33,3
	2	4	16	48	5	2,2E+29	67,6	110,9
	2	5	32	112	6	1,9E+80	184,8	332,7
	2	6	64	256	7			931,6
	2	7	128	574	8			2484,2
	2	8	256	1267	9			6341,3

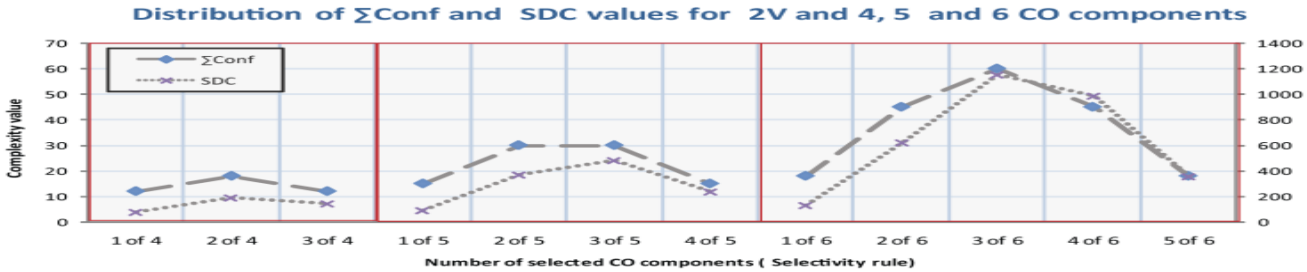
Fragment values of complexity indicators for classes $CL_{1-\infty}$. ***Scenario #2***

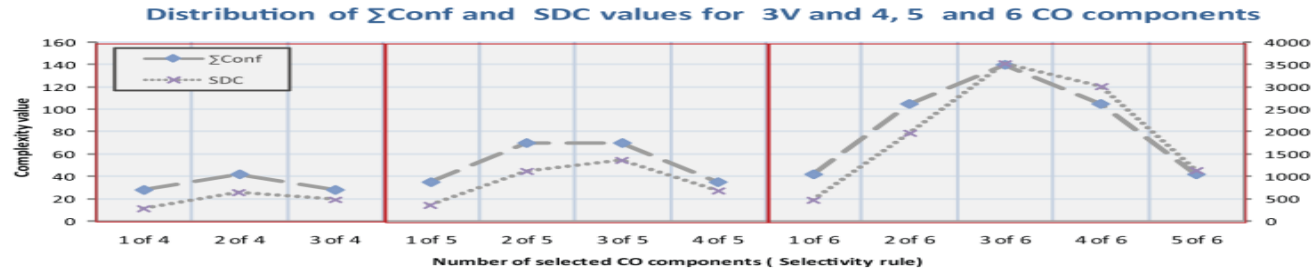
S	VO	CO	Condition for CO	∑Conf	N	DPs	Ω	ln[Ω]	SDC
CL1-∞	1	0	0	2	3	2	3	1,1	1,4
		2	1 of 2	4	10	4	18900	9,8	9,7
		3	1 of 3	6	15	5	37837800	17,4	18,2
			2 of 3	6	21	5	8,55513E+11	27,5	30,7
		4	1 of 4	8	20	6	1,57135E+11	25,8	27,7
			2 of 4	12	42	6	1,51593E+28	64,9	83,6
			3 of 4	8	36	6	1,43045E+24	55,6	65,2
		5	1 of 5	10	25	7	1,11314E+15	34,6	38,0
			2 of 5	20	70	7	1,27325E+52	120,0	166,1
			3 of 5	20	90	7	6,67365E+69	160,8	232,0
			4 of 5	10	50	7	6,55433E+32	75,6	114,3
		6	1 of 6	12	30	8	1,20174E+19	43,9	48,9
			2 of 6	30	105	8	1,36536E+84	193,7	280,8
			3 of 6	40	180	8			567,0
			4 of 6	30	165	8	7,5406E+140	324,4	502,1
			5 of 6	12	78	8	1,43801E+64	147,7	178,7
		o	I of k	–	–	–	–	–	–
	2	0	0	3	7	3	210	5,3	6,1
		2	1 of 2	6	20	5	1,62955E+11	25,8	28,4
		3	1 of 3	9	30	6	6,52797E+18	43,3	51,2
			2 of 3	9	39	6	2,90509E+26	60,9	73,5
		4	1 of 4	12	40	7	8,08467E+26	62,0	76,3
			2 of 4	18	78	7	4,44573E+59	137,3	190,8
			3 of 4	12	64	7	9,39695E+48	112,8	142,2
		5	1 of 5	15	50	8	1,83983E+39	90,4	90,4
			2 of 5	30	130	8	1,1909E+172	396,2	371,0
			3 of 5	30	160	8	2,7915E+136	314,2	482,0
			4 of 5	15	95	8	2,37897E+79	182,8	235,8
		6	1 of 6	18	60	9	1,21409E+44	101,5	131,4
			2 of 6	45	195	9			619,1
			3 of 6	60	320	9			1153,0
			4 of 6	45	285	9			987,6
			5 of 6	18	132	9	1,5224E+118	272,1	355,4
		o	I of k	–	–	–	–	–	–
	3	0	0	7	19	4	1745944200	21,3	30,3
		2	1 of 2	14	52	6	5,55671E+35	82,3	114,1
		3	1 of 3	21	78	7	1,5753E+58	134,0	194,3
			2 of 3	21	99	7	3,51198E+78	180,9	260,6
		4	1 of 4	28	104	8	5,71576E+81	188,3	280,9
			2 of 4	42	198	8			641,5
			3 of 4	28	160	8	2,4779E+136	314,1	482,1
		5	1 of 5	35	130	9	6,7354E+109	252,9	358,7
			2 of 5	70	330	9			1113,3
			3 of 5	70	400	9			1368,0
			4 of 5	35	235	9			677,4
		6	1 of 6	42	156	10	2,6951E+127	293,4	467,5
			2 of 6	105	494	10			1972,3
			3 of 6	140	799	10			3527,9
			4 of 6	105	704	10			3010,0
			5 of 6	42	324	10			1132,4
		o	I of k	–	–	–	–	–	–

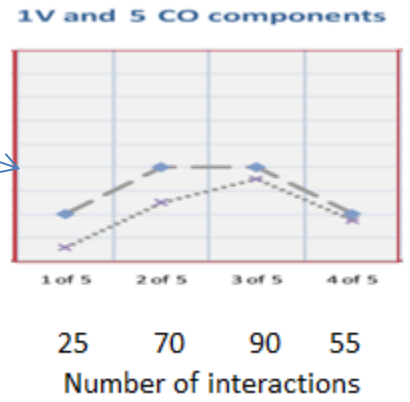
3.3 Complexity issues of Mass customization

Comparison of two different approaches



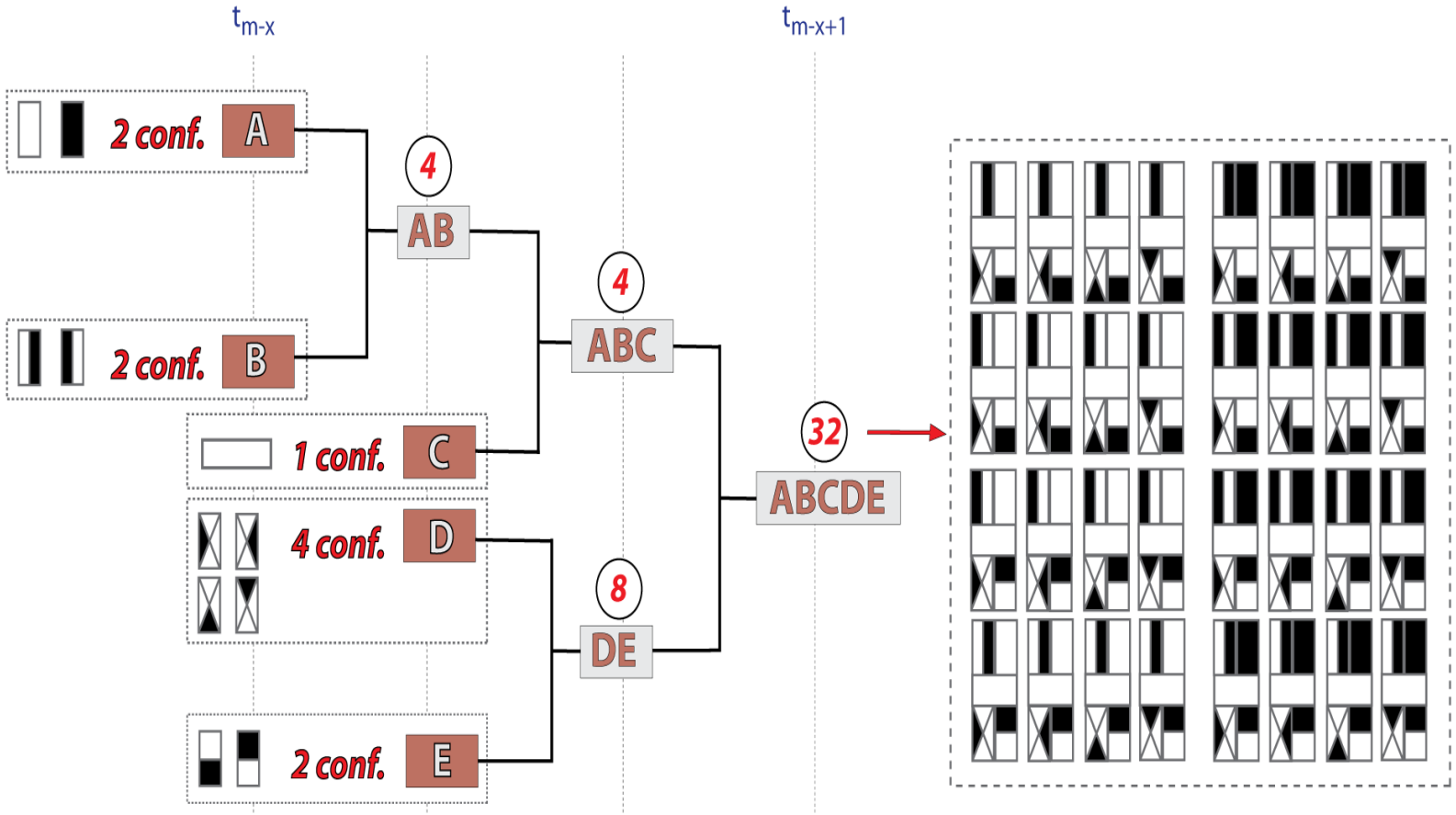






3.3 Complexity issues of Mass customization

Procedure to calcuate PCs of entire SCs :



3.4 Conclussions

Comparison of two different approaches showed:

1) Both, PCs and SDC measures can be desribed by more or less a **concave** complexity functions.

2) SDC indicator applies results of PCs

3) **SDC indicator brings more realistic complexity values** than values of all of possible product configurations (PCs).

Thank you!