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Development of Manufacturing Features with Advanced Parameterization Possibilities

Dr Alexander Sharmazanashvili

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CA Engineering Modeling

CA Product Modeling

CA Process Modeling

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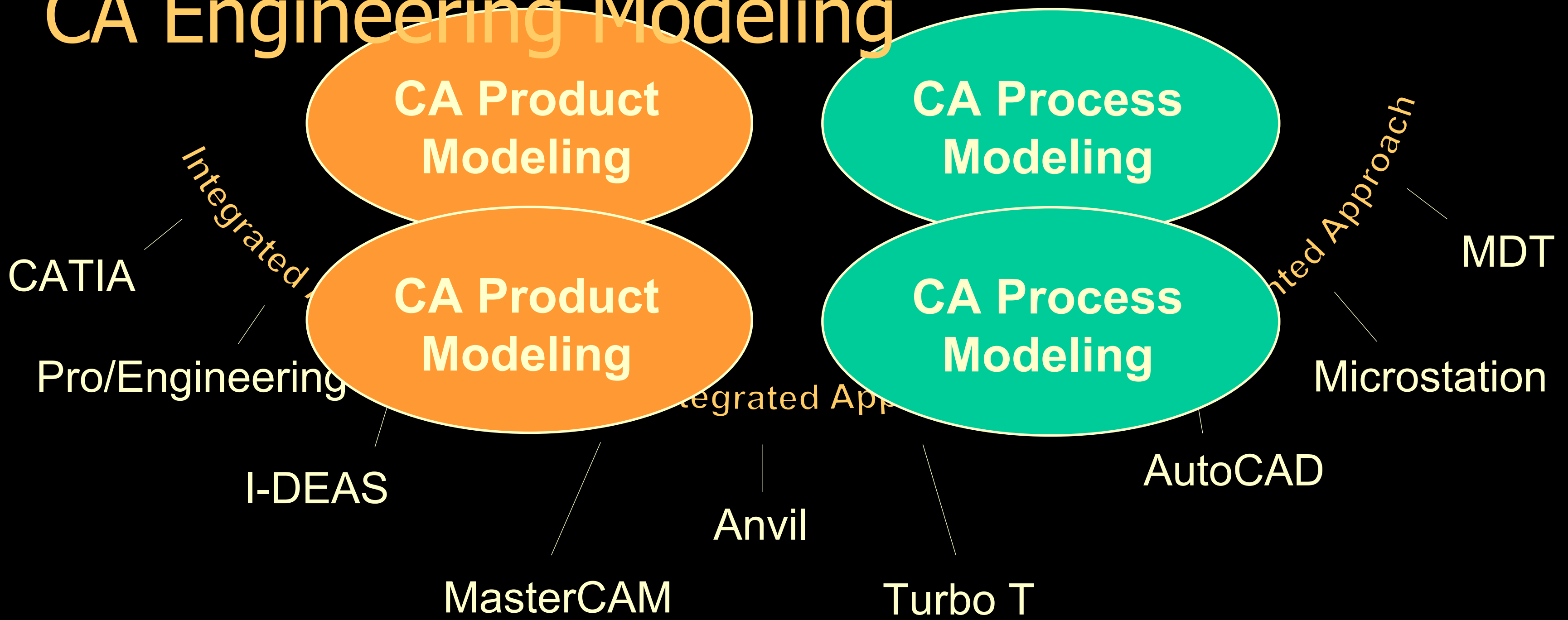
CA Engineering Modeling



Question: What is the final result of CAEM ?

Answer: This is NC Data

Manufacturers Expressions:

The Japanese: 6 iterations needed

US: Expensive

The Germans: Time consuming

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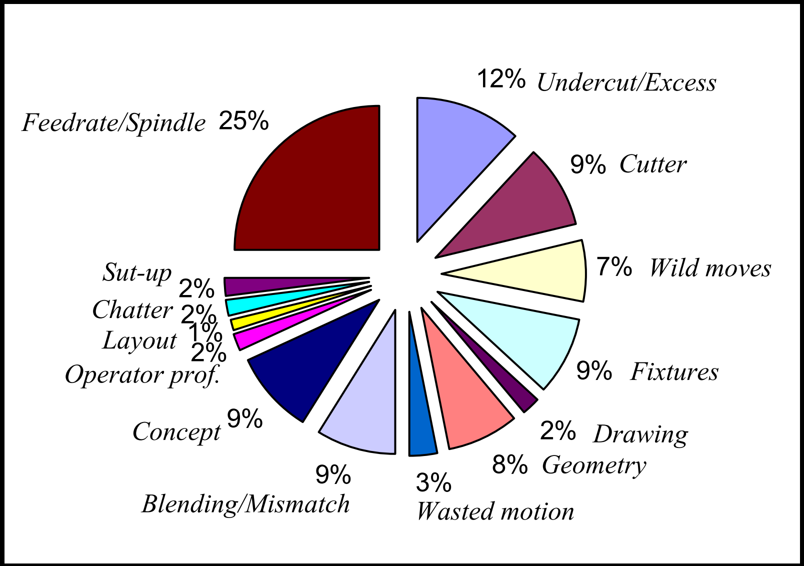
Statistical issue produced by Dun&Breadstreet



$$\Delta_{\Sigma} = \Delta_1 + \Delta_2$$

43% 57%

Δ_1 – "Expected" errors conditioned by inaccuracy of Decision Making Models, inaccuracy of input data, operator faults

Δ_2 – "Unexpected" errors conditioned by difference between projected and actual values of machine tools, fixtures, cutting tools and workpiece

Δ_1 – can be expressed through the determinate models and will be identified and corrected by special models and corresponding software

Δ_2 – can be expressed through the stochastic models while influence of technological disturbances is considerable

Investigation of Dimensional fluctuation of workpiece geometry and fluctuation of workpiece Hardness

1. Reviewing of engineering hand-books
2. Reviewing of manufacturing experience
3. Reviewing of literature sources

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Engineering hand-books survey

Types	$(R_z)_1$ (mm)	h_1 (mm)	$(\Delta_\Sigma)_1$ (mm)			$(Td)_1$ (mm)	ε_1 (mm)
CASTING	0.2	0.1	0.28			4	2.6
PUNCHING	0.2	0.25	$\Delta_к$: 0.084	$\Delta_б$: 1	1.1	5	4
ROLLING	0.32	0.4	2.1			3	4.32
WELDING	1.5	-	$\Delta_к$: 0.06	$\Delta_б$: 1	1.06	5.5	5.3

Manufacturing experience survey

Types	$(R_z)_1$ (mm)	h_1 (mm)	$(\Delta\Sigma)_1$ (mm)	$(Td)_1$ (mm)	ε_1 (mm)
CASTING	$(R_z)_1$	h_1	$(\Delta\Sigma)_1$	4	2.6
PUNCHING	$(R_z)_1$	h_1	$(\Delta\Sigma)_1$	4.2	3.7
ROLLING	-	-	-	–	–
WELDING	$(R_z)_1$	h_1	$(\Delta\Sigma)_1$	11	8.1

Survey of literature sources

Types	$(R_z)_1$ (mm)	h_1 (mm)	$(\Delta_\Sigma)_1$ (mm)	$(Td)_1$ (mm)	ε_1 (mm)
CASTING	$(R_z)_1$	h_1	0.21	2.6	1.8
PUNCHING	0.2	1	$(\Delta_\Sigma)_1$	2.4	3.5
ROLLING	$(R_z)_1$	0.75	$(\Delta_\Sigma)_1$	$(Td)_1$	4.7
WELDING	–	3.5	5.6	15.3	16.8

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Combined results of dimensional fluctuations

	Hand-Books ε_1 (mm)	Experience ε_2 (mm)	Sources ε_3 (mm)
CASTING	2.6	2.6	1.8
PUNCHING	4	3.7	3.5
ROLLING	4.32	-	4.7
WELDING	5.3	8.1	16.8

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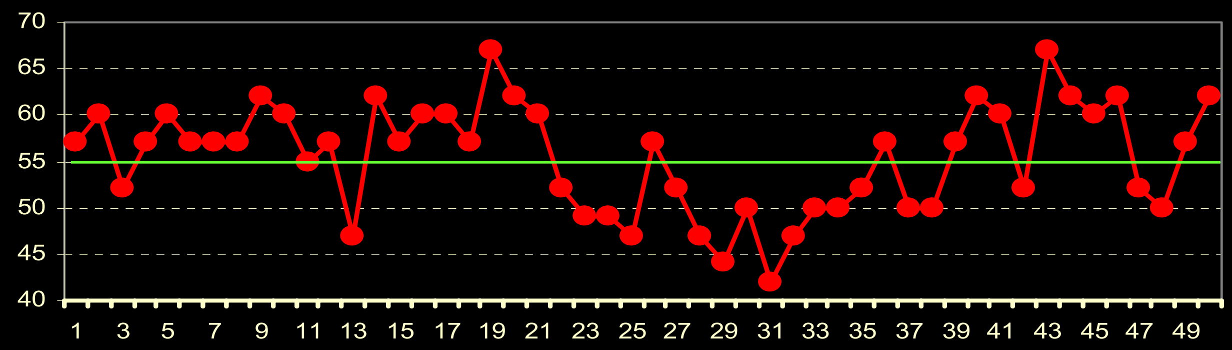
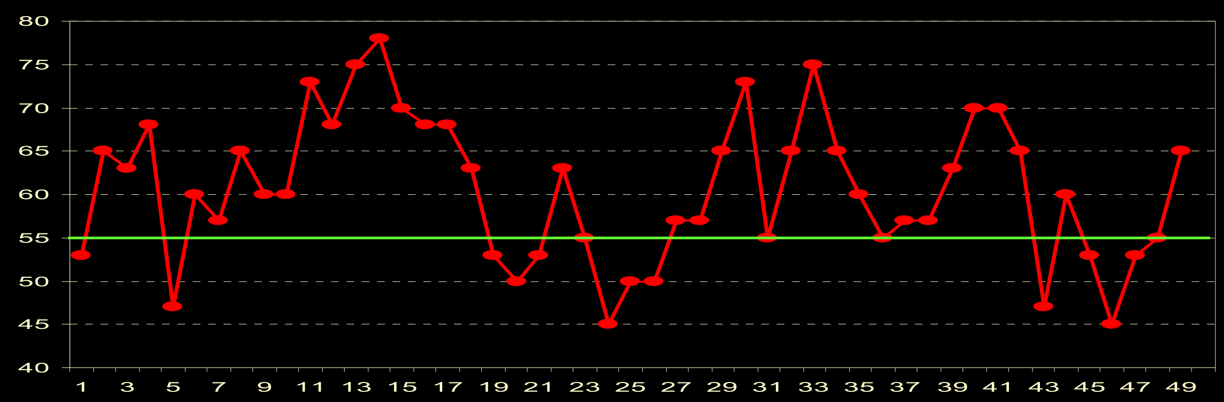
Fluctuation of workpiece hardness

In one smelt



In different smelt



Consideration of standard process of thermal strain-hardening

Iron Alloys

№	Thermal Conditions	Actual values of Hardnes (HB)		
		Average Value	Stray Field	Standard Deviation
1	Отжиг$810^0 – 840^0$C	154.1	12.3	8.00%
2	Нормализация 860^0 – 880^0C, выдержка 20 мин.	169.5	6.2	3.60%
3	Закалка $840^0 – 860^0$C, вода отпуск 630^0C	190.6	25.8	13.50%
4	Закалка $840^0 – 860^0$C, вода отпуск 630^0C	216.3	41.3	19.10%
5	Закалка $840^0 – 860^0$C, вода отпуск 600^0C	233.5	53.5	23.00%
6	Закалка $840^0 – 860^0$C, вода отпуск 500^0C	265.7	82	30.90%
7	Закалка $840^0 – 860^0$C, вода отпуск 440^0C	329.1	148.3	45.10%

Aluminum Alloys

№	Thermal Conditions	Actual values of Hardnes (HB)		
		Average Value	Stray Field	Standard Deviation
1	Отжиг$810^0 – 840^0$C	147.2	12.5	8.50%
2	Нормализация 860^0 – 880^0C, выдержка 20 мин.	158.5	9.5	6.00%
3	Закалка $840^0 – 860^0$C, вода отпуск 630^0C	182.4	27.3	15.00%
4	Закалка $840^0 – 860^0$C, вода отпуск 630^0C	218.1	51.1	23.40%
5	Закалка $840^0 – 860^0$C, вода отпуск 600^0C	-	-	-
6	Закалка $840^0 – 860^0$C, вода отпуск 500^0C	253.8	116.5	46.00%
7	Закалка $840^0 – 860^0$C, вода отпуск 440^0C	248.4	121	48.70%

Main Question of Research:

How reduce the Δ_2 component of error in NC data conditioned by above mentioned disturbances ?

Ways of problem solution

I. Implementation of preliminary inspected high-precision workpieces

Advantage: Decrease dispersion of hardness and geometry and as a result Δ_2 component of error

Disadvantage: Final cost will undesirable especially for small batch sizes

$$C_\Sigma = C_1\downarrow + C_2\uparrow + \ldots + C_n$$

Ways of problem solution

II. Premeditated diminution of design parameters

Advantage: Ensure the quality of part surfaces, remove the risk of process violation

Disadvantage: Low profitability of using of CNC machine tools

Ways of problem solution

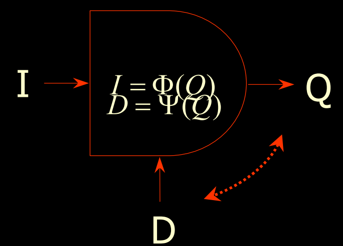
III. Implementation of real-time Adaptive Control Systems

Advantage: Compensate disturbances by real-time control according to preliminary adjusted rules – P_z=Const, M=Const, V=Const, etc.

Disadvantage: Fixed rules enables to compensate disturbances in small range of dispersion

Implementation of Adaptable Decision Making Models (ADMM) on CAEM

ADMM is determinate model which in addition contains constraint equation between output parameter and disturbances



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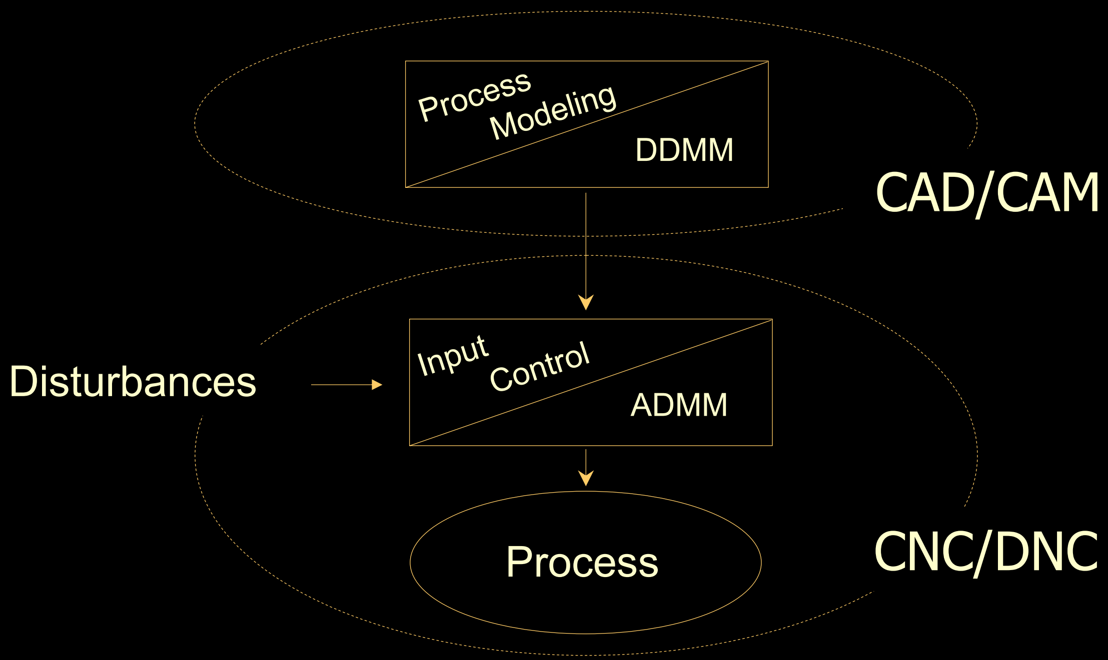
Place of ADMM implementation

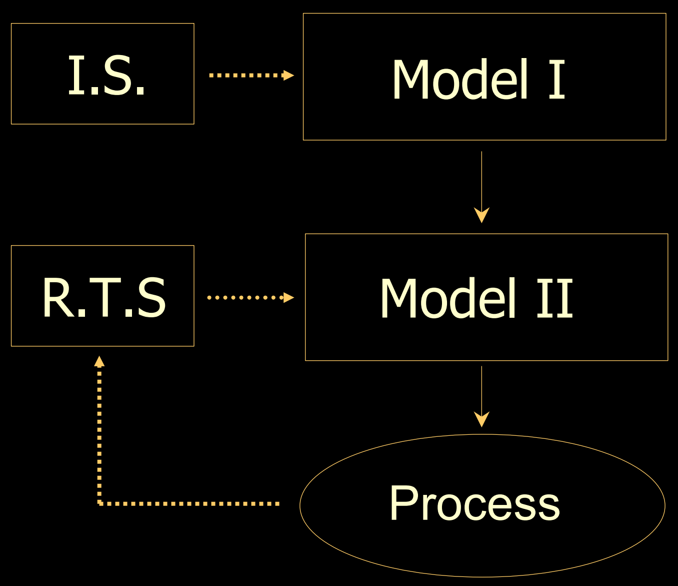


ADMM joins two types of models:

I. Models for re-calculation of depth of cut and tool path geometry according to actual dimensions of workpiece.

II. Models for re-determination of cutting conditions according to actual values of depth of cut and workpiece hardness.

Models activity



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Model I

For separation of depth of cut and tool path calculation models it is necessary to formalize typical

- Shapes
- Tools
- Schemes

Model I

Shape Formalization

Two main geometrical structures have been formed:

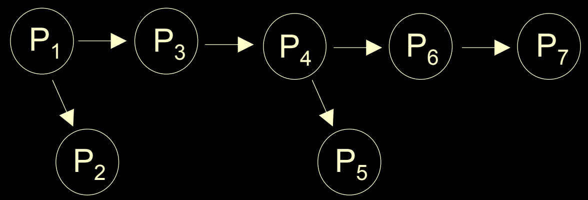
STHO - the half-open “STAIR”

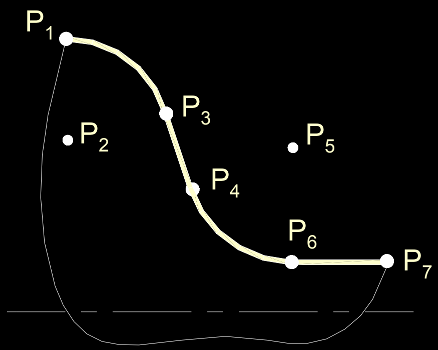
STCL - the closed “STAIR”

Model I

STHO structure is built on the base of typical constraints of 5 geometrical elements:

$$P_1 \rightarrow C_1 \rightarrow L_1 \rightarrow C_2 \rightarrow L_2$$

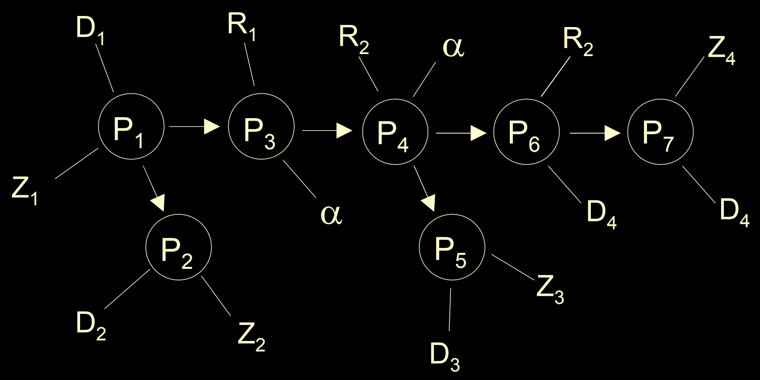


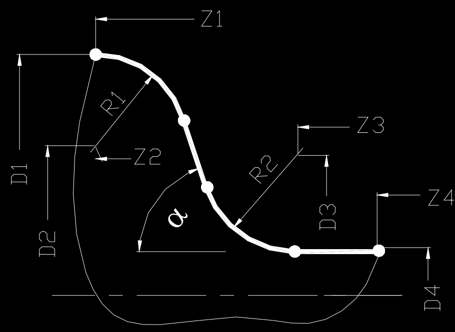


$$STHO = \{P_1 \wedge (C_1 \vee L_1 \vee C_2) \vee L_2\}$$

Model I

Parameterization scheme of STHO





Model I

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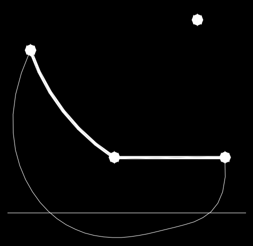
Typical structures of STHO

$STHO_{4-1}$

$$\Pi^{0}_{4-1} = \{D_1, Z_1, D_3, Z_3, D_4, Z_4\}$$

$$\Pi^{K}_{4-1} = \{R_2 = 0\}$$

$$\Pi^{H}_{4-1} = \{D_2, Z_2, R_1, \alpha\}$$

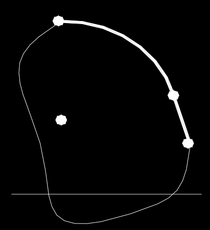


$STHO_{5-6}$

$$\Pi^{0}_{5-6} = \{D_1, Z_1, R_1, \alpha, D_4\}$$

$$\Pi^{K}_{5-6} = \{D_2 = 0, Z_2 = 0, Z_4 = 0\}$$

$$\Pi^{H}_{5-6} = \{D_3, Z_3, R_2\}$$

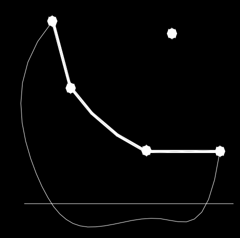


$STHO_{7-1}$

$$\Pi^{0}_{7-1} = \{D_1, Z_1, \alpha, R_2, D_3, Z_3, D_4, Z_4\}$$

$$\Pi^{K}_{7-1} = \{\ \}$$

$$\Pi^{H}_{7-1} = \{D_2, Z_2, R_1\}$$



58 typical structures can be generated

Model I

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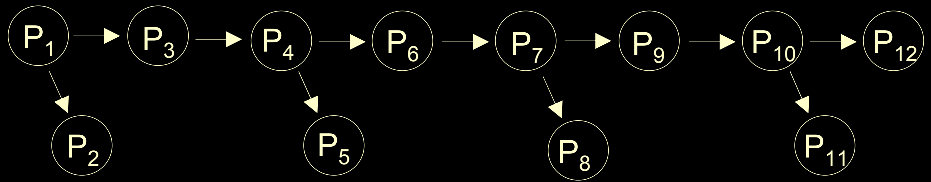
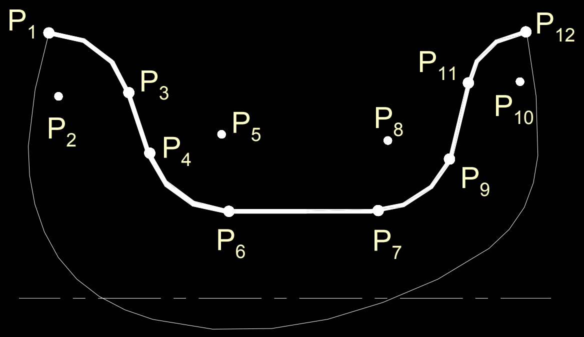
STCL structure is built on the base of composition of half-open stair STHO with its mirror structure





$$STCL = \{P_1 \wedge (C_1 \vee L_1 \vee C_2) \vee L_2 \wedge (C_3 \vee L_3 \vee C_4)\}$$

Model I

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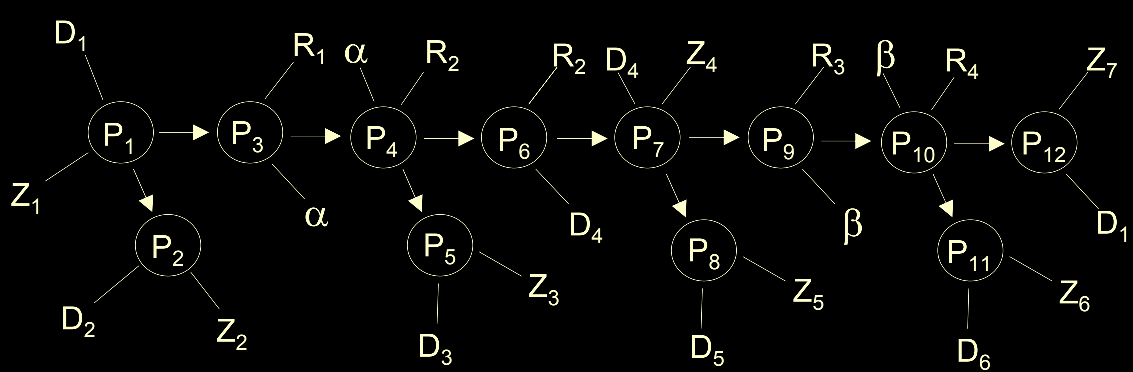
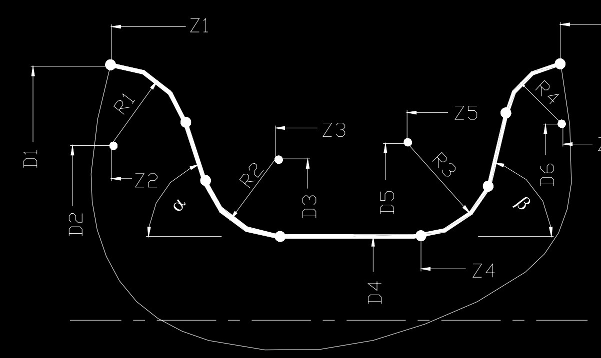
Parameterization scheme of STCL





1798 typical structures can be generated

Model I

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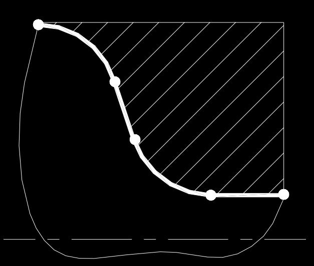
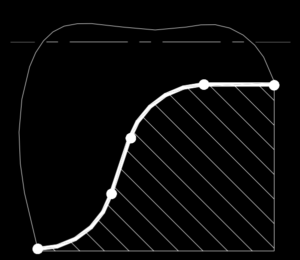
On the base of STHO and STCL structures 8 manufacturing shapes for turning was developed

$$Z_{HO}^{E} = \psi(STHO)$$



$$Z_{HO}^{I} = \psi(|STHO|_{180^o})$$



Model I

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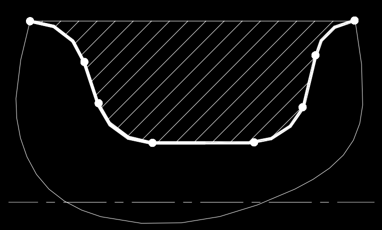
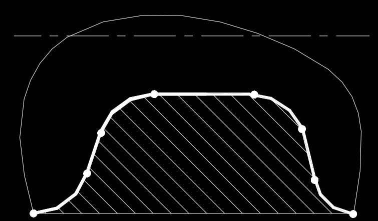
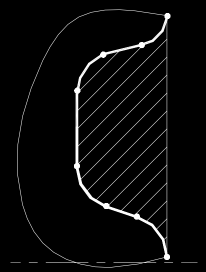
$Z_{CL}^{E} = \psi(STCL)$



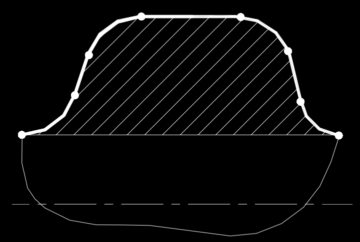
$Z_{CL}^{I} = \psi(|STCL|_{180^o})$



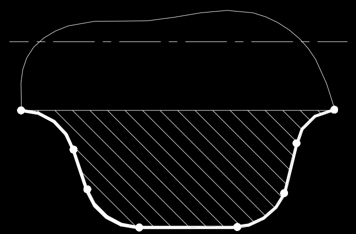
$Z_{CL}^{P} = \psi(|STCL|_{90^o})$



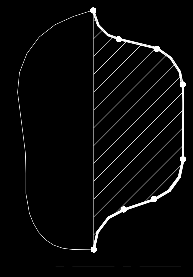
$Z_{OP}^{E} = \psi(|STCL|_{180^o})$



$Z_{OP}^{I} = \psi(STCL)$



$Z_{OP}^{E} = \psi(|STCL|_{90^o})$



Model I

Each parametric shape {Z} is associated with cutting tools {T} and corresponding tool movement scheme {P}

Each typical combination of {Z} -> {T} -> {P} brings formalism for development of models of depth of cut and tool path geometry re-calculation (Model I)

Model II

By joining the formalism {Z} -> {T} -> {P} with models {M} for re-calculation of cutting conditions according to real-time sensor-based control, final formalism of ADMM will be formulated.

Model II

[S_0N] rule

{M} models are distributed in two groups:

- Rough cutting group

  [V_0S_0] [S_0N] [S_0F] [S_0T] [V_0T]

- Finish cutting group

  [V_0S_0] [V_0Q] [V_0R_z]

Model II

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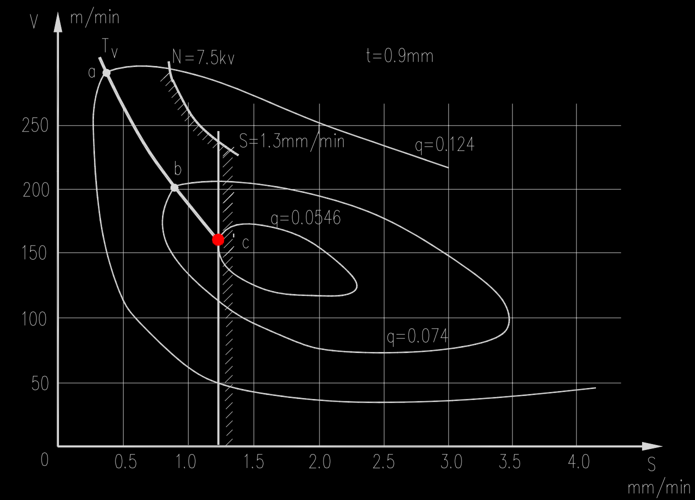
$[S_0N]$ rule

Make real-time recalculations of cutting speed V in order to ensure constant value of feedrate – S_0 and cutting power - N



Model I + Model II = ADMM

ADMM Formalism: {Z} -> {T} -> {P} -> {M}

↓

For each typical case of turning corresponding manufacturing feature can be formed

Manufacturing Features

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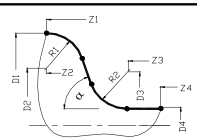
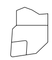
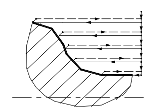
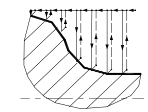
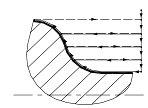
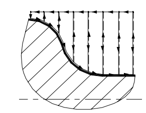
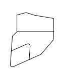
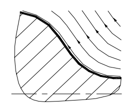
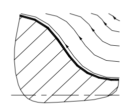
Shape	Tool	Scheme	Rules
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$

Manufacturing Features

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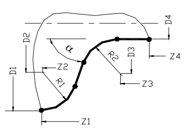
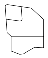
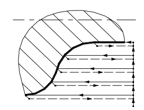
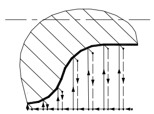
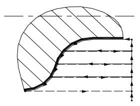
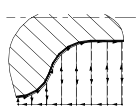
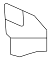
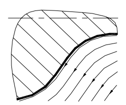
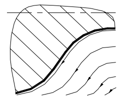
	Shape	Tool	Scheme	Rules
				$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
				$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
				$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
				$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
				$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$
				$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$

Manufacturing Features

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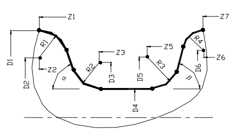
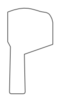
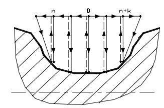
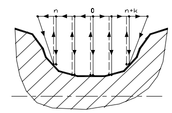
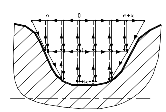
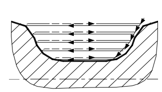
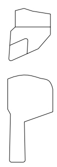
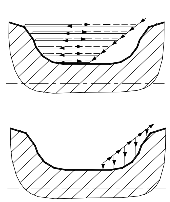
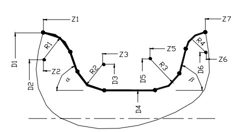
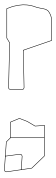
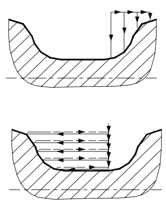
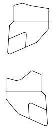
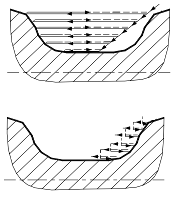
Shape	Tool	Scheme	Rules
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$

Shape	Tool	Scheme	Rules
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$

Manufacturing Features

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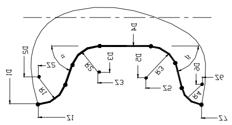
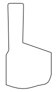
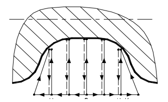
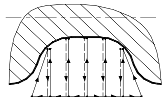
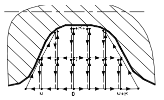
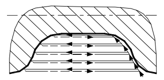
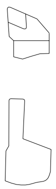
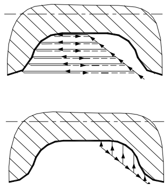
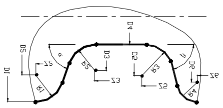
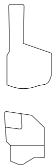
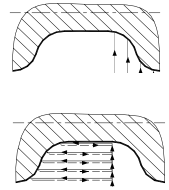
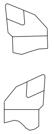
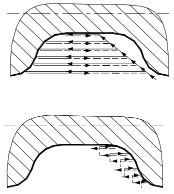
Shape	Tool	Scheme	Rules
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$

Shape	Tool	Scheme	Rules
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$

Manufacturing Features

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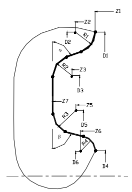
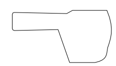
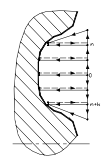
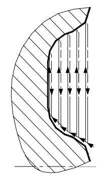
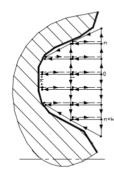
Shape	Tool	Scheme	Rules
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$

Manufacturing Features

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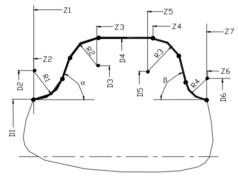
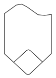
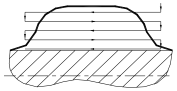
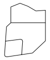
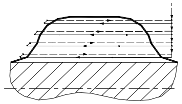
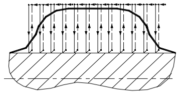
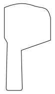
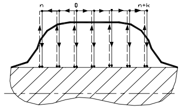
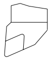
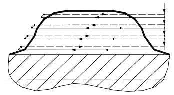
Shape	Tool	Scheme	Rules
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$

Manufacturing Features

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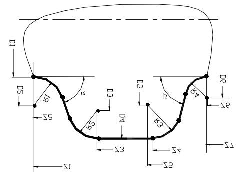
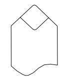
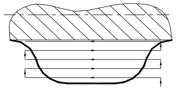
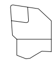
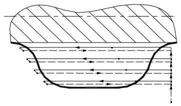
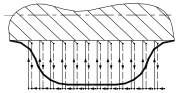
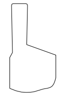
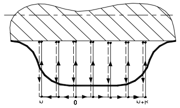
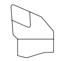
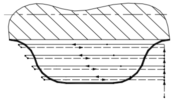
Shape	Tool	Scheme	Rules
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
			$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$

Manufacturing Features

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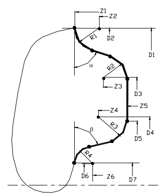
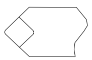
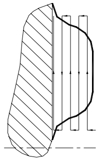
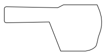
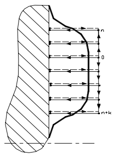
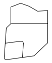
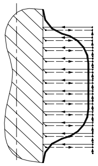
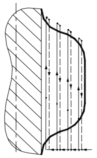
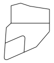
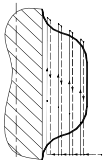
	Shape	Tool	Scheme	Rules
				$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
				$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
				$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
				$[V_0S_0]$ $[S_0N]$ $[S_0F]$ $[S_0T]$
				$[V_0S_0]$ $[V_0Q]$ $[V_0R_Z]$ $[V_0T]$

What we receive finally ?

↓

Collection of manufacturing features which **enables :**

enables :

- To built models for re-calculation of depth of cut, tool path geometry and cutting conditions for CNC
- To realize CA process modeling activity adaptable to actual manufacturing conditions
- To organize CA process modeling software architecture and develop the corresponding software tools

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Process Modeling Adaptive Engineering (PMAE)

Manufacturing Features

AutoCAD/CATIA

Architecture
- Classes
- ARX Objects

CAD/CAM

CA Applications
- Feature recognition
- Parametric optimization
- Structural optimization

CNC

Control Models
- Depth calculation
- Path calculation
- Cutting conditions definition

Conclusions

1. Process Modeling Adaptive Engineering enables to ensure high reliability of output of CAEM
2. Through the ADMM it is possible to enlarge range of disturbances compensation of real-time adaptive control system
3. Suggested collection of manufacturing features can be modified by expending the collection of tool or movement scheme, but not by modifying parametric shapes or cutting rules, while they express absolute majority of turning cases.

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Thank You for attention