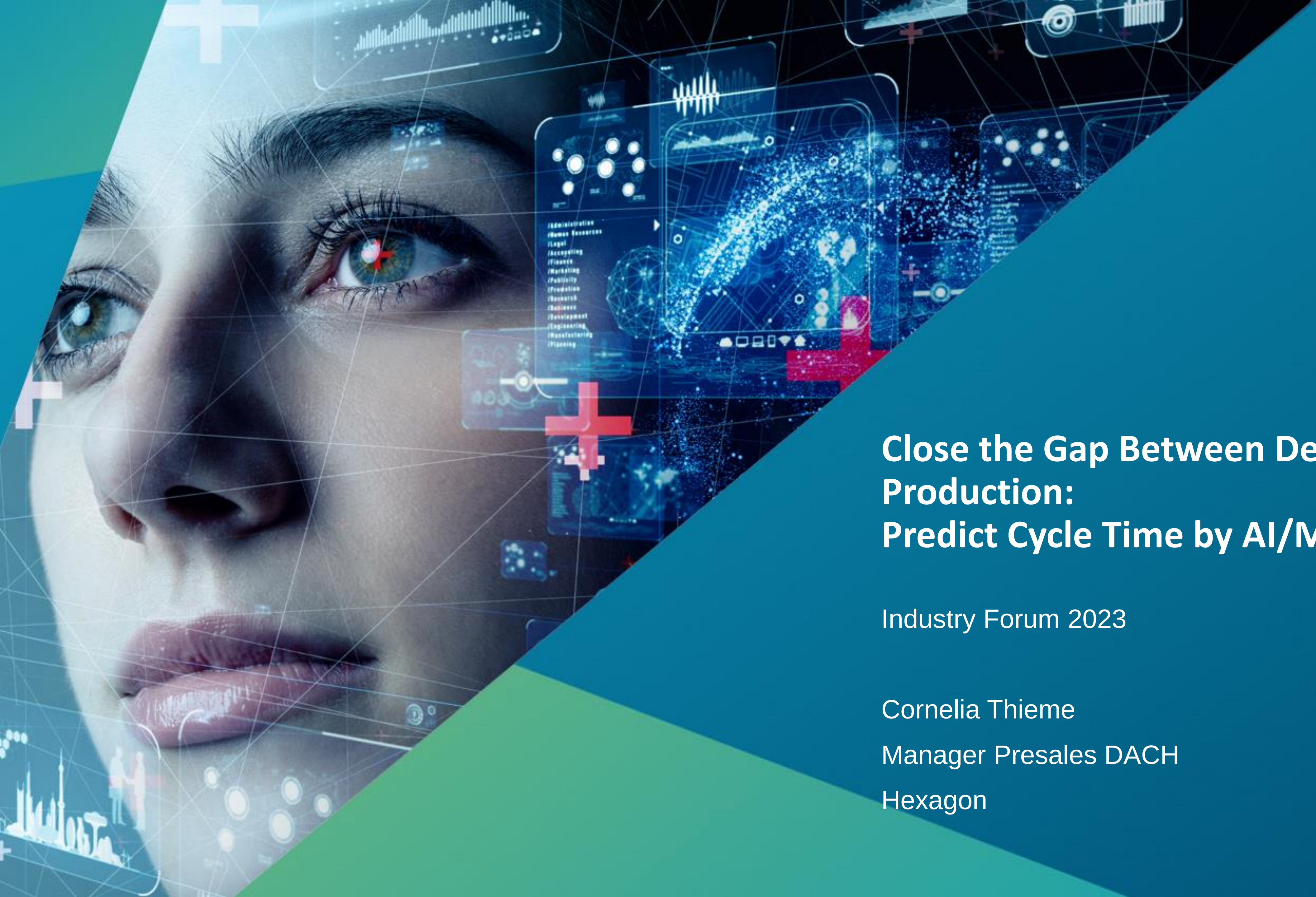

Close the Gap Between Design and Production: Predict Cycle Time by AI/ML

Industry Forum 2023

Cornelia Thieme
Manager Presales DACH
Hexagon

HEXAGON

Hexagon: Innovation in our DNA

We are a global leader in sensor, software and autonomous solutions committed to empowering a sustainable autonomous future.

We are committed to

Delivering
innovation

Empowering
autonomy

Advancing
technology

Accelerating
sustainability

Here to stay

- **50 countries**
- **23,000 employees**
- **3,700+ patents**
- **85%**
- **90%**
- **95%**

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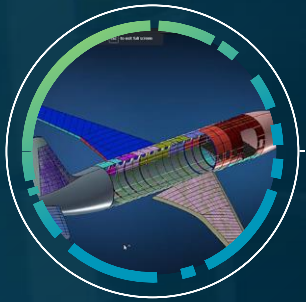
Hexagon: Putting Data to Work from Concept to Operation

Aerospace example

Design and engineering



Structural concept and dynamics simulation

Prototype distortion monitoring

Production

Manufacturing process simulation

Metrology assisted manufacturing

Inspection

In-process inspection and data analytics

Maintenance / Repair

Fuselage defect analysis and repairs

Process monitoring and corrections

Guidance for design optimisation

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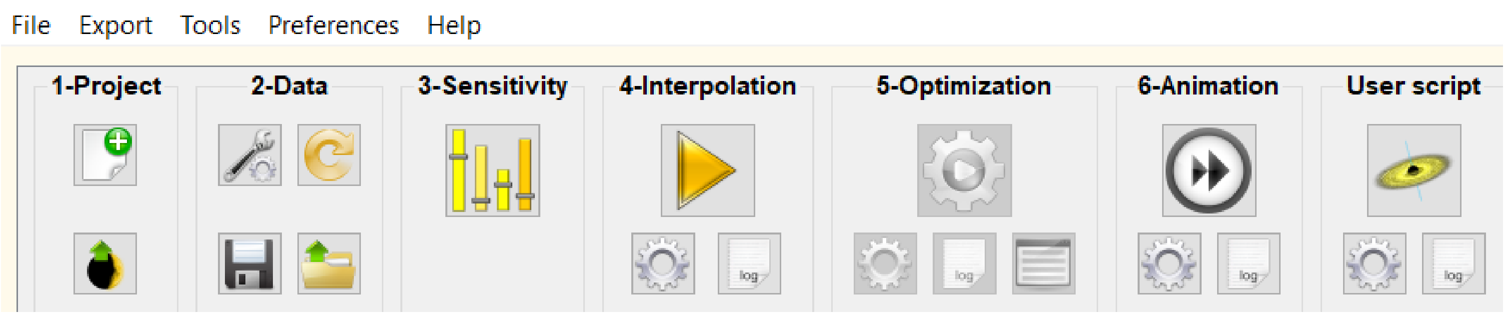
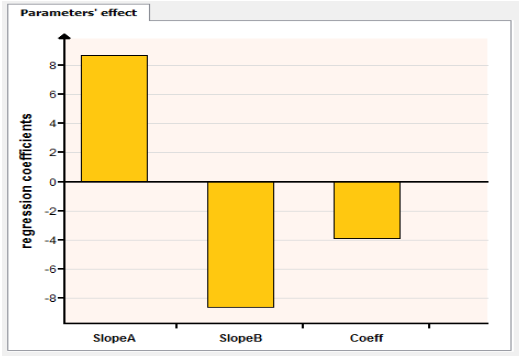
ODYSSEE Machine Learning



- From available analysis, test results or measurements, predict responses for further data points
- ODYSSEE delivers the response in seconds
- Predict results values, curves and animations
- Improve parameters of manufacturing processes
- Input: csv files
- Can use images or step files instead of parameters
- Easy-to-use GUI
- Scripting possible
- Create and improve DOE
- Plot tool for correlation, PCA, heat map, etc.
- Optimization



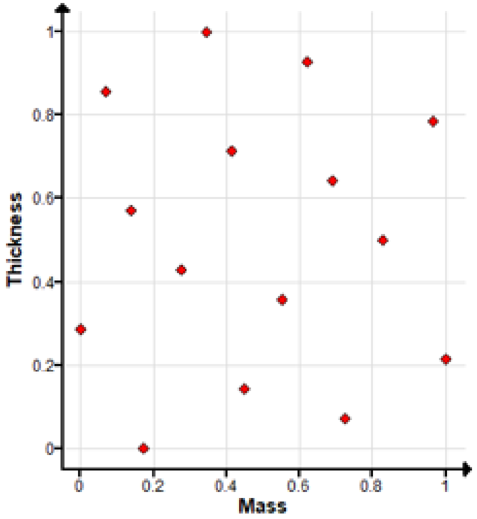


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Image and Step File Based Machine Learning

Use of Past Experience to Predict New Outcomes

1 Learning Phase

Images, 3D files,
Curves data, Signals, etc.

Inputs / Features (X)

Outcomes, Time-Dependent Responses etc…

Associated Results (Y)

2 Predictions

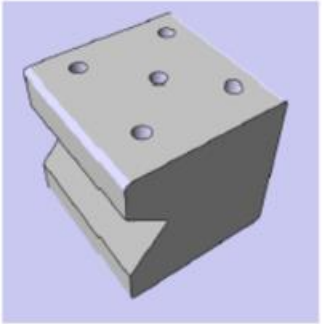
New Images, 3D files, Curves data, Signals, etc.

Predicted data in **real time**

Predict Machining Time from Geometry, Material and Surface Roughness

CNC QUOTE allows to predict a machining time using an existing learning database composed of :

- 3D models (File(step) type) where **Complex indicators** (λ) are calculated automatically
- **Material** tag (Tags type)
- **Tapped holes number** estimation per 3D part analyzed
- **percent (%)** of 3D part with a surface roughness **Ra<=0.8**
- **percent (%)** of 3D part with a surface roughness **Ra at 1.6**
- **percent (%)** of 3D part with a great accuracy machining (**small tolerance**)
- And the **associated machining time**.



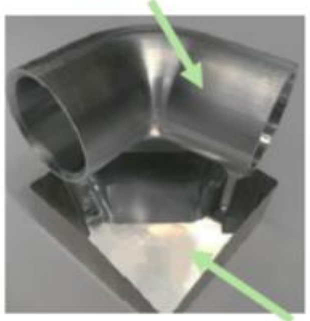
Tapped holes number	0	1	2	3	4	5	10	...	15	20	25	30

Materials
Alu2017
S235
2024T351
Titane

% Ra <=0.8
0
25
50
75
100

% Ra 1.6
0
25
50
75
100

25% Rough effect = Ra1.6



% Great accuracy machining
0
25
50
75
100

75% high precision machining

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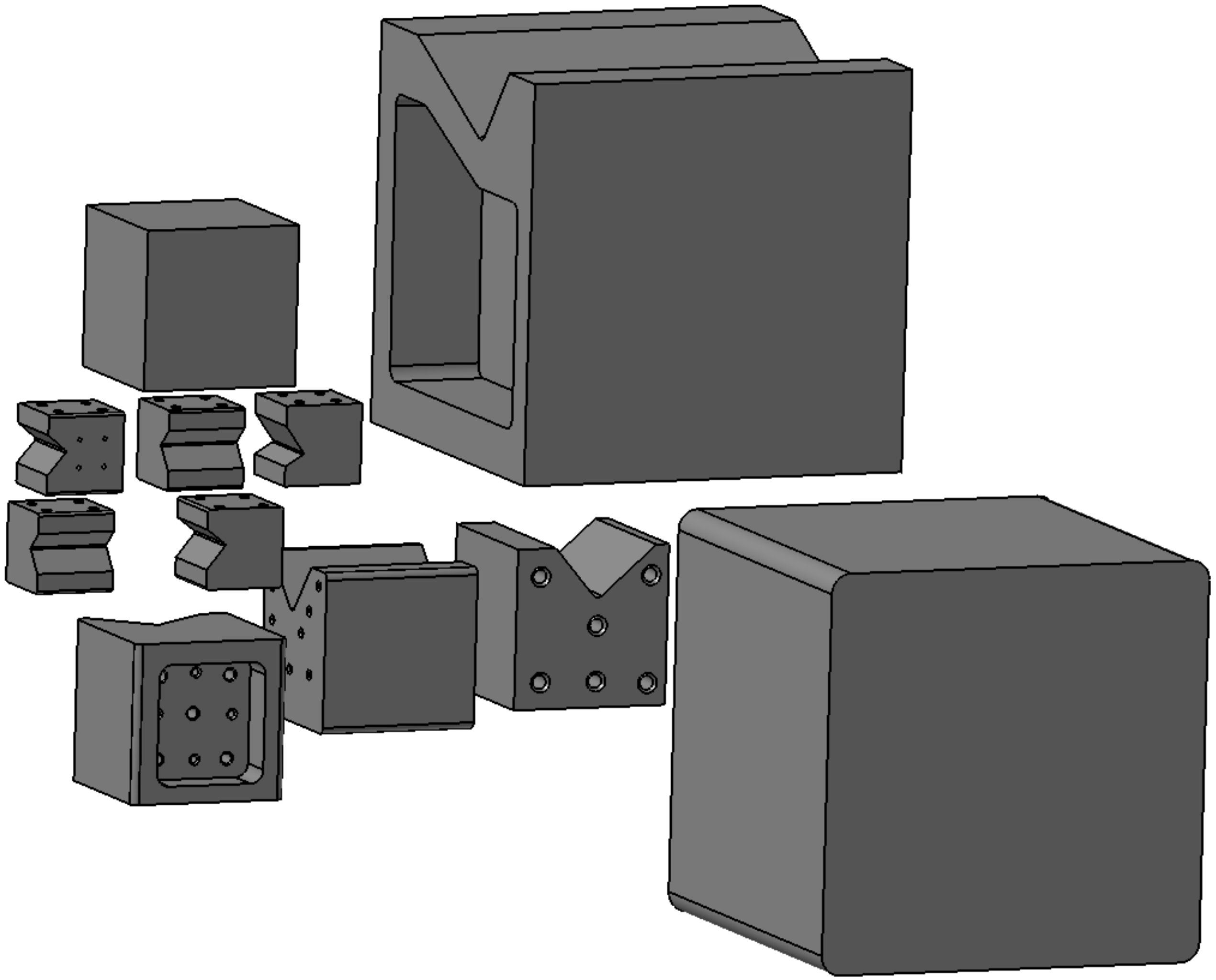
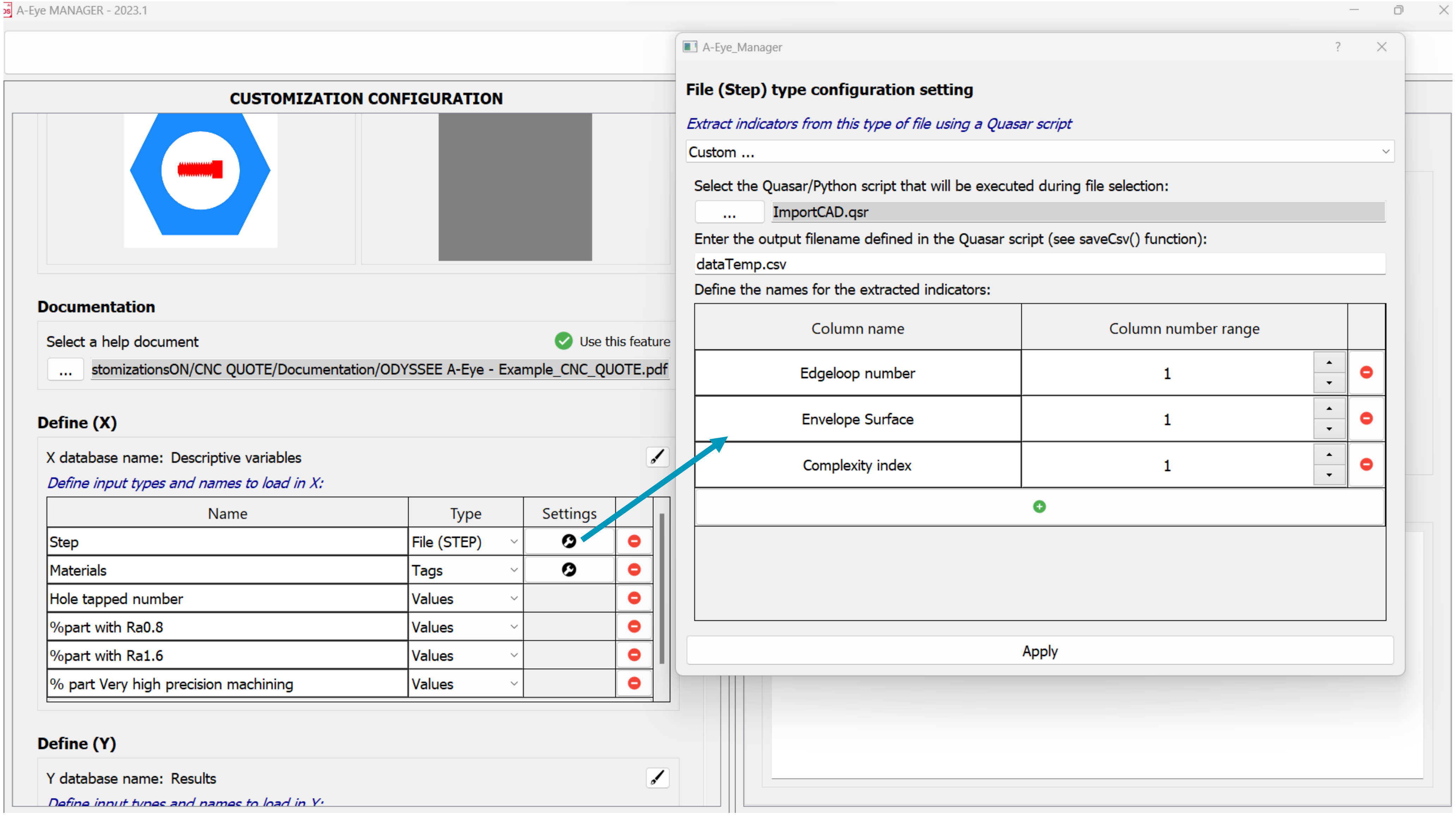
Predict Machining Time from Geometry, Material and Surface Roughness



Some of the geometries, available as 3d step files

Predict Machining Time from Geometry, Material and Surface Roughness

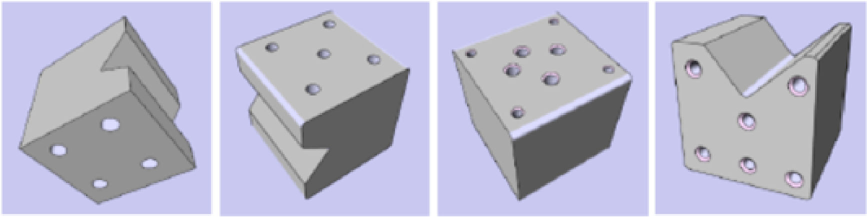


Define a customization:

- Define the parameter format as files, images (not in this case), tags, or values
- Define how to interpret the step file

Predict Machining Time from Geometry, Material and Surface Roughness

47 cases in database



CASE	Step	Materials	Number of Tapped Holes	%part wth Ra0.8	%part wth Ra1.6	%part very high precision machining	Machining time (r
CASE 1. case1	3D	AlloyAlu2024T351_430MPa	4	70	10	10	2.21
CASE 2. case2	3D	SteelS235_360MPa	6	20	80	20	1.99
CASE 3. case3	3D	Alu2027_225MPa	1	20	20	90	3.63
CASE 4. case4	3D	AlloyAlu2024T351_430MPa	5	30	40	30	4.99
CASE 5. case5	3D	SteelS235_360MPa	7	80	20	20	5.69
CASE 6. case6	3D	SteelS235_360MPa	6	10	60	90	6.57
CASE 7. case7	3D	SteelS235_360MPa	10	50	50	40	5.33
CASE 8. case8	3D	Alu2027_225MPa	9	80	10	60	3.51
CASE 9. case9	3D	AlloyAlu2024T351_430MPa	1	0	40	20	4.16

X Y

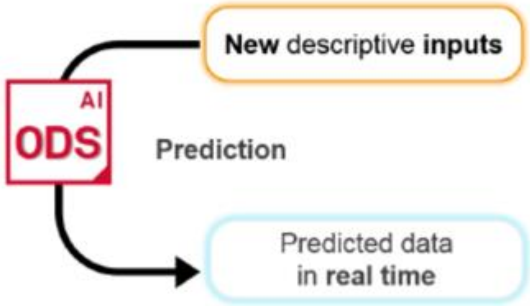
***Note**: The X database is constituted of: 3D file, material tag, number of tapped holes, % part at Ra0.8, % part at Ra1.6, % part at high precision machining.*

Predict Machining Time from Geometry, Material and Surface Roughness

	Name	Edgeloop number	Envelope Surface	Complexity index	Materials:Alu2027_225MPa	Materials:SteelS235_360MPa	Materials:AlloyAlu2024T351_430	Number of Tapped Holes	%part with Ra0.8	%part with Ra1.6	%part very high precision machining	Machining time (minutes)
1	case1	34	23500	0.293	0	0	1	4	70	10	10	2.21
2	case2	38	23300	0.295	0	1	0	6	20	80	20	1.99
3	case3	39	24700	0.537	1	0	0	1	20	20	90	3.63
4	case4	38	22700	0.596	0	0	1	5	30	40	30	4.99
5	case5	59	26200	0.508	0	1	0	7	80	20	20	5.69
6	case6	44	22700	0.586	0	1	0	6	10	60	90	6.57
7	case7	89	27000	0.436	0	1	0	10	50	50	40	5.33
8	case8	98	25000	0.712	1	0	0	9	80	10	60	3.51
9	case9	18	84900	0.744	0	0	1	1	0	40	20	4.16
10	case11	68	95300	0.444	0	1	0	8	0	100	70	14.84
11	case12	42	93300	0.518	1	0	0	3	80	0	30	4.44
12	case13	50	92100	0.687	1	0	0	0	60	10	50	2.1
13	case14	68	97500	0.529	0	0	1	6	0	100	30	8.34
14	case15	60	93900	0.79	0	1	0	3	10	80	0	6.2
15	case16	90	86100	0.655	0	1	0	8	10	40	20	6.13
16	case17	96	95800	0.665	1	0	0	4	20	80	10	3.01
17	case18	14	89200	0.824	0	1	0	1	30	30	70	4.08
18	case19	78	112000	0.762	1	0	0	7	60	20	0	4.27
19	case20	78	93700	0.626	0	1	0	10	20	60	10	7.53

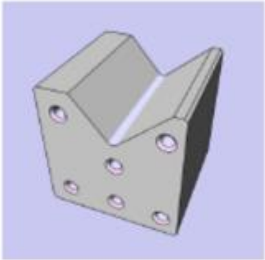
Odyssee transforms step files, images and tags to a matrix

Predict Machining Time from Geometry, Material and Surface Roughness



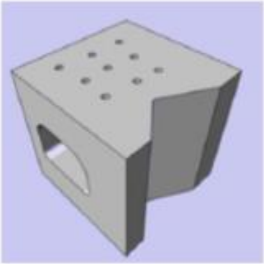
3 cases to predict

Expected time (empirical formula)



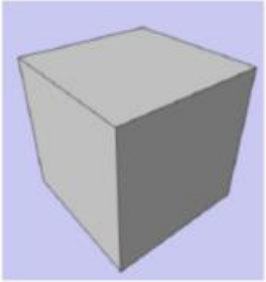
Material : Steel (σ_f =225MPa)
Surface: 91403mm2 (L=120mm)
7 tapped holes
100% 3D part with Ra0.8
40% 3D part with high accuracy machining

→ 7.8 min



Material : Steel (σ_f =225MPa)
Surface: 618935 mm2 (L=300mm)
4 tapped holes
90% 3D part with Ra1.6
80% 3D part with high accuracy machining

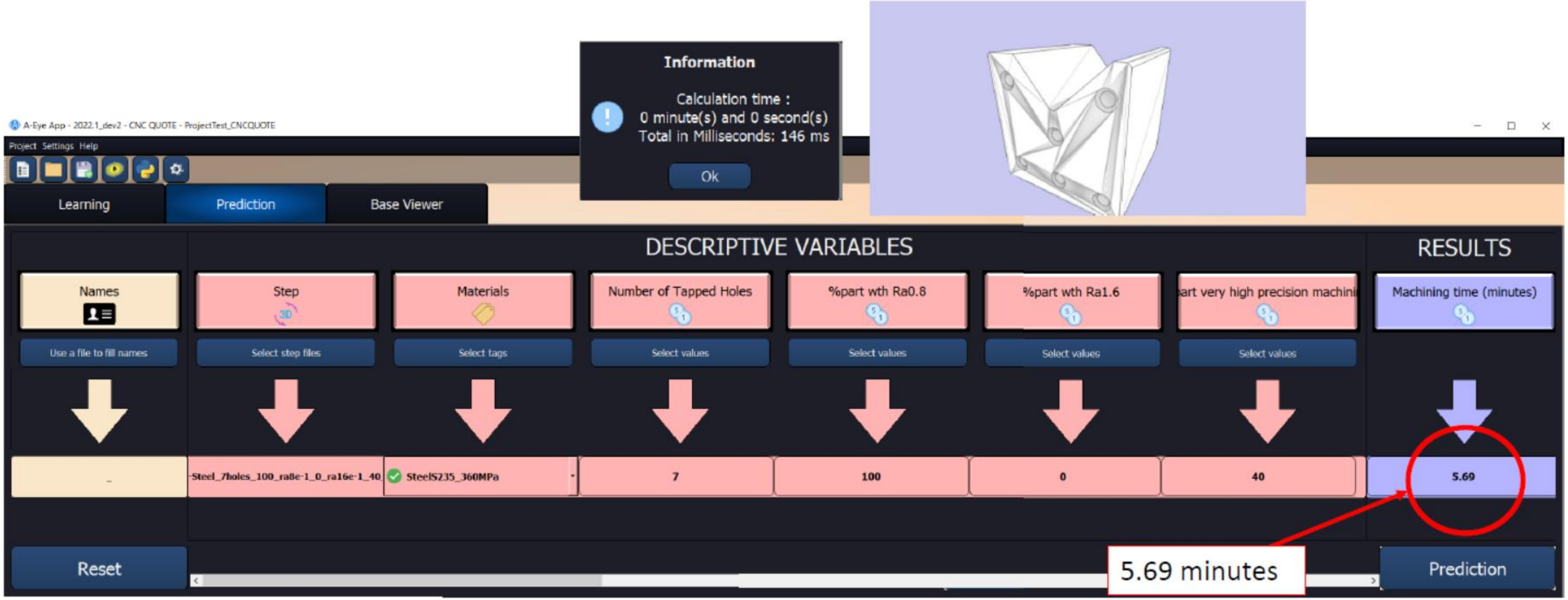
→ 17 min



Material : Aluminum Alloy (σ_f =420MPa)
Surface: 540000mm2 (L=300mm)
0 tapped holes
100% 3D part with Ra3.2
100% 3D part with traditional accuracy

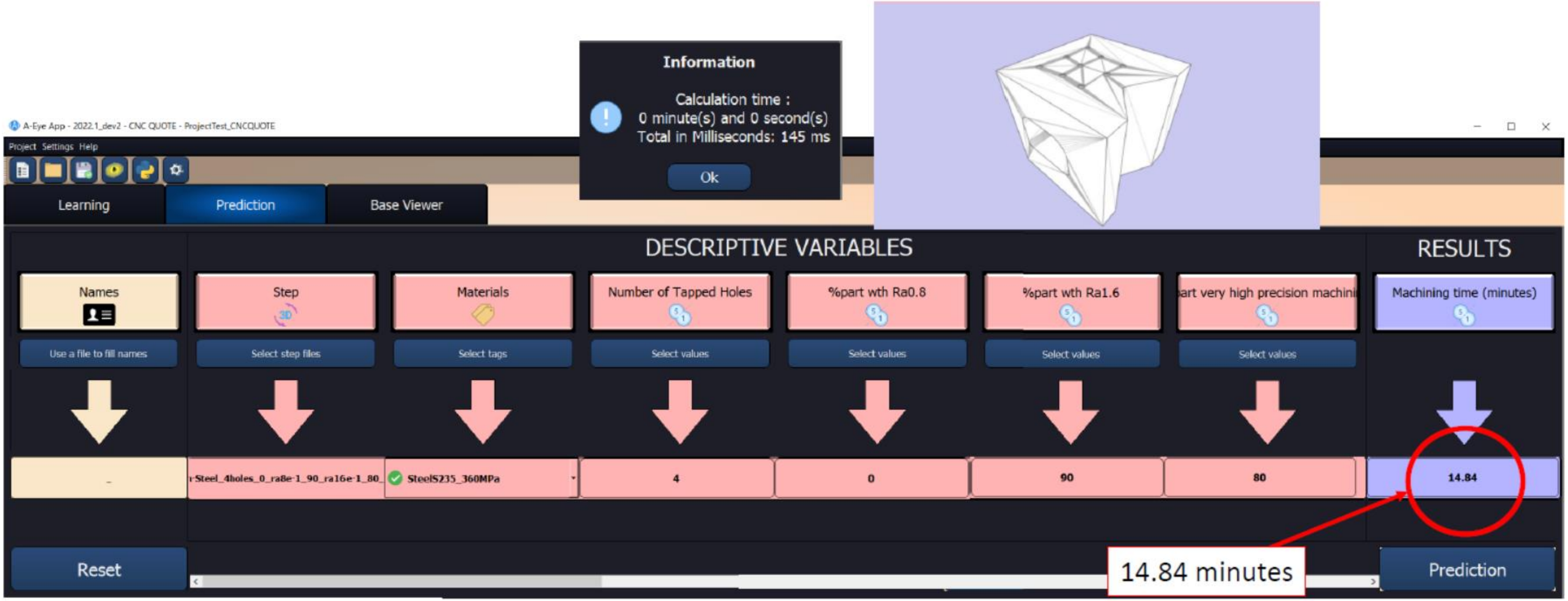
→ 3.8 min

Predict Machining Time from Geometry, Material and Surface Roughness



vs 7.8 min

Predict Machining Time from Geometry, Material and Surface Roughness



vs 17 min

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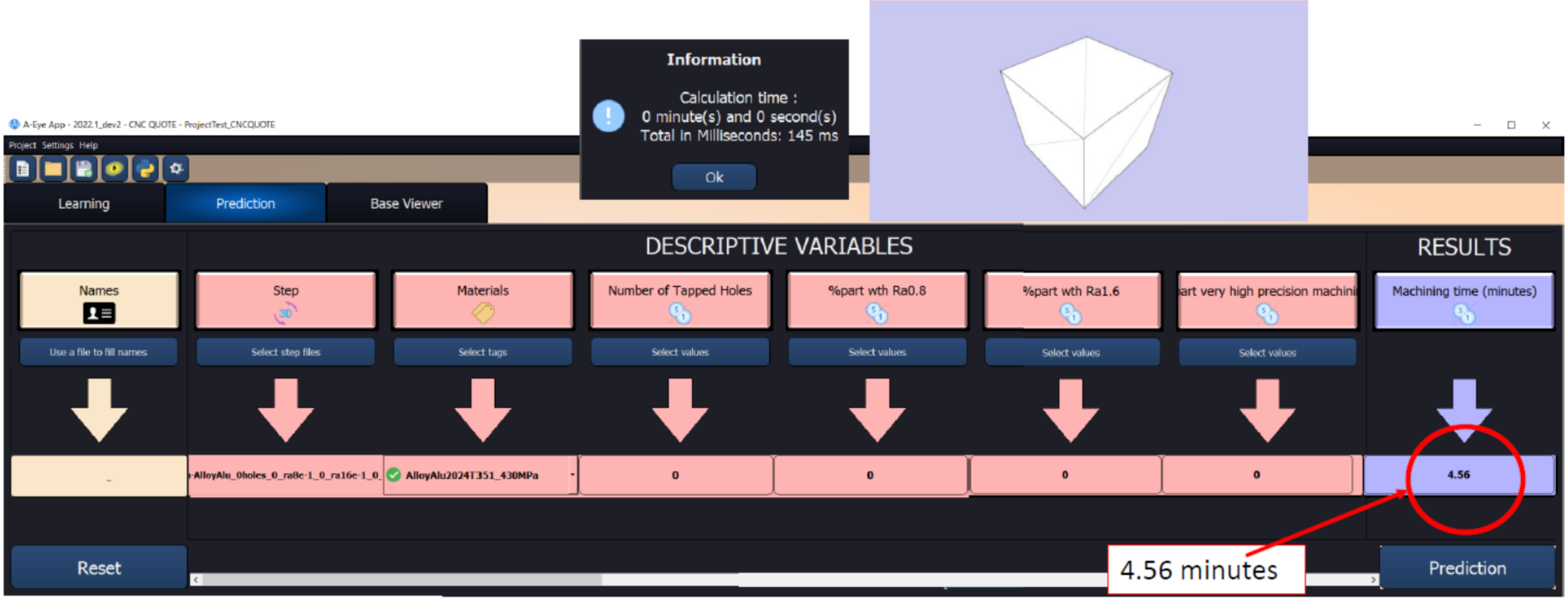
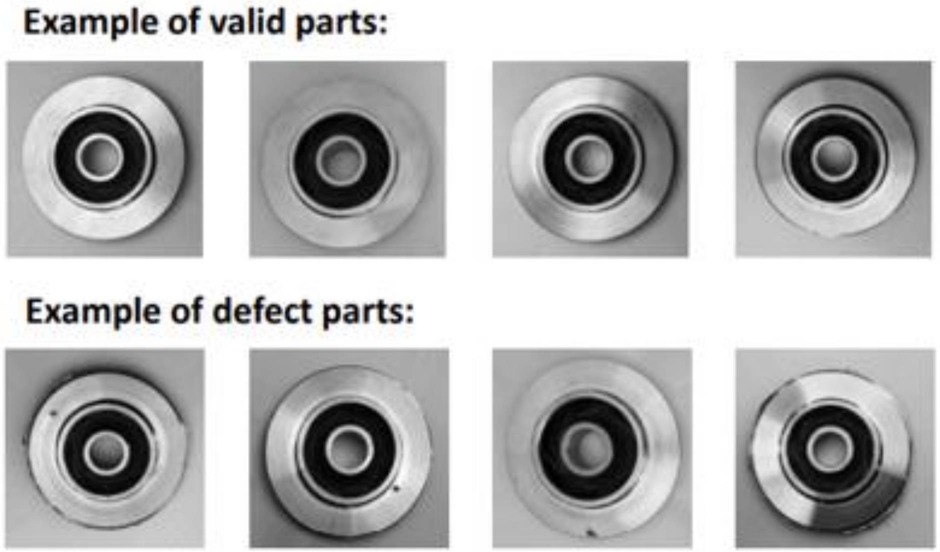
Predict Machining Time from Geometry, Material and Surface Roughness

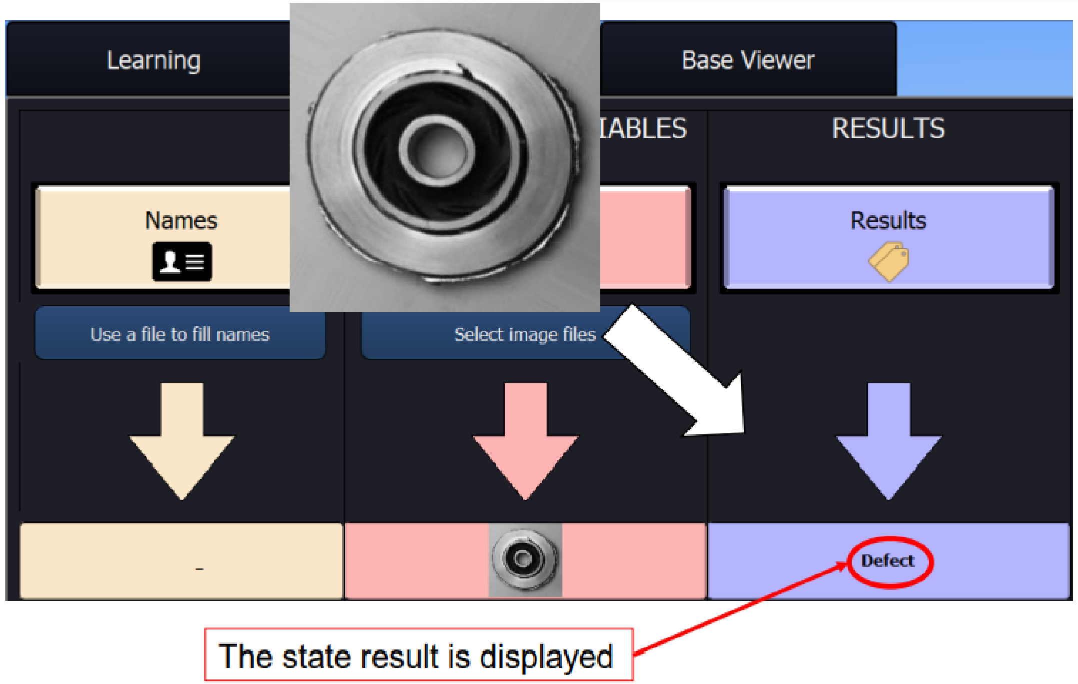


vs 3.8 min

Real-Time Product Quality Inspection

Classify „valid“ or „defect“





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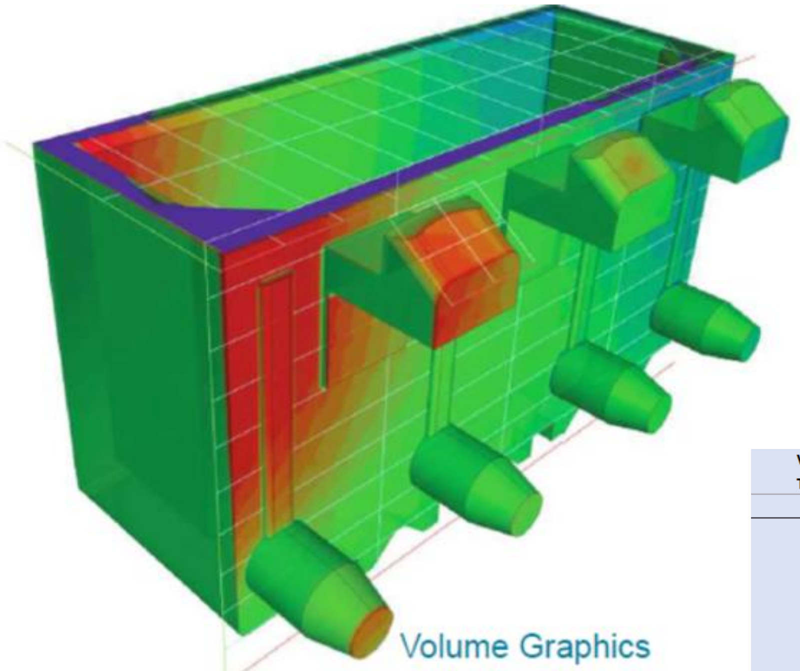
Optimize Manufacturing Process: Minimize Deviations in Injection Molding



Color-coded visualization of deviations of the manufactured part from the target

Find optimum values of the process parameters (blue) to reach optimum measurement results (green).
Ideally, these parameters are later used in the injection molding process and then get comparable measurement results.

Variable 1: Tool Temp	Variable 2: Pressure	Variable 3: Cooling	Variable 4: Temp	Variable 5: Filling	Variable 6: Switch	Variable 7: Post Pressure	Dim 1 Diameter	Dim 2 Diameter	Dim 3 Diameter	Dim 4 Diameter	Dim 5 Flatness	Dim 6 Perpendicularity	Dim 7 Parallelism	Dim 8 Perpendicularity	Dim 9 Coaxiality	Dim 10 Distance
°C	Normiert	s	°C	s	%	Normiert	**5.00**	**5.00**	**5.00**	**3.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**68.00**
20	-1	15	230	0.3	96	-1	4.90	4.90	4.90	2.89	0.12	0.05	0.54	0.26	1.94	67.80
20	-1	25	230	0.7	100	1	4.88	4.88	4.88	2.88	0.44	0.52	0.39	0.19	4.28	67.15
20	1	15	270	0.3	100	1	4.90	4.89	4.92	2.90	0.59	0.93	0.90	0.45	3.93	66.86
20	1	25	270	0.7	96	-1	4.90	4.90	4.91	2.90	0.60	0.90	0.78	0.38	2.85	67.02
60	-1	15	270	0.7	96	1	4.90	4.90	4.90	2.89	0.07	0.08	0.32	0.15	1.08	67.72
60	-1	25	270	0.3	100	-1	4.89	4.89	4.90	2.89	0.60	0.46	0.81	0.45	2.30	66.74
60	1	15	230	0.7	100	-1	4.89	4.89	4.90	2.89	0.49	0.55	0.44	0.24	3.80	67.13
60	1	25	230	0.3	96	1	4.89	4.89	4.91	2.89	0.60	0.72	0.79	0.38	7.00	66.91
20	-1	20	230	0.5	98	0	4.88	4.88	4.88	2.88	0.18	0.27	0.22	0.12	0.30	67.66
60	-1	20	230	0.5	98	0	4.90	4.89	4.90	2.89	0.16	0.05	0.18	0.08	0.78	67.60
20	1	20	230	0.5	98	0	4.90	4.89	4.92	2.90	0.59	0.93	0.90	0.45	3.93	66.86
60	1	20	230	0.5	98	0	4.89	4.89	4.91	2.89	0.56	0.63	0.62	0.30	3.01	67.06
20	-1	20	270	0.5	98	0	4.91	4.90	4.91	2.89	0.14	0.11	0.36	0.18	0.94	67.81
60	-1	20	270	0.5	98	0	4.90	4.89	4.90	2.89	0.36	0.08	0.15	0.08	1.36	67.36
20	1	20	270	0.5	98	0	4.89	4.89	4.90	2.89	0.49	0.55	0.44	0.24	3.80	67.13
60	1	20	270	0.5	98	0	4.89	4.89	4.91	2.89	0.52	0.54	0.42	0.23	2.06	67.19
40	0	20	230	0.5	98	0	4.90	4.89	4.91	2.89	0.47	0.39	0.22	0.11	1.66	67.38
40	0	20	270	0.5	98	0	4.90	4.90	4.91	2.89	0.45	0.34	0.16	0.08	1.43	67.45
40	-1	20	250	0.5	98	0	4.90	4.90	4.90	2.89	0.12	0.04	0.38	0.19	1.03	67.80
40	1	20	250	0.5	98	0	4.90	4.89	4.91	2.89	0.60	0.84	0.83	0.40	6.89	66.92
20	0	20	250	0.5	98	0	4.90	4.90	4.91	2.89	0.52	0.55	0.32	0.16	2.05	67.34
60	0	20	250	0.5	98	0	4.89	4.89	4.90	2.89	0.42	0.26	0.20	0.11	1.69	67.35
40	0	20	250	0.5	98	0	4.90	4.90	4.90	2.89	0.12	0.05	0.54	0.26	1.94	67.80

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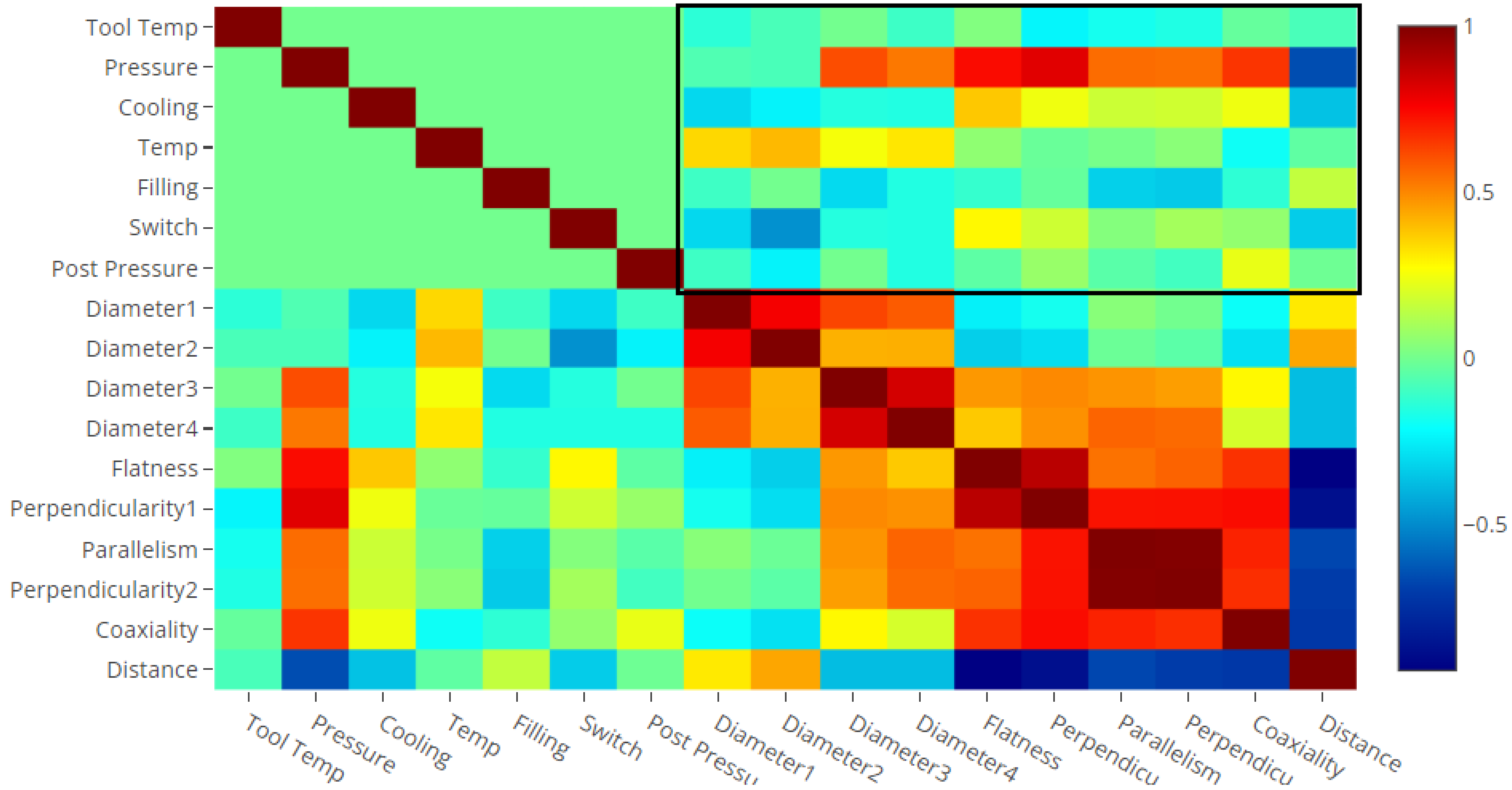
Optimize Manufacturing Process: Correlation Plot



Influence of the parameters on the results. Tool temp, filling, switch and post pressure have a low correlation with most results.

1: 100% correlated

0: not correlated

-1: 100% negative correlation

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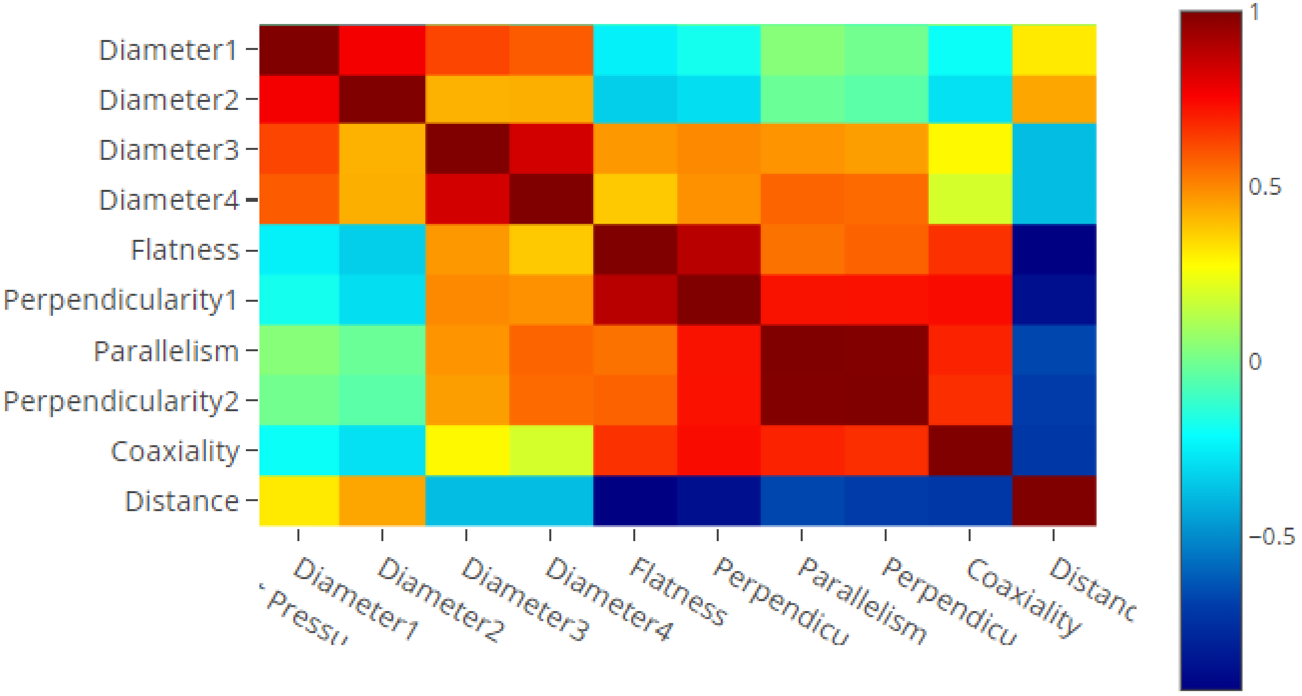
Optimize Manufacturing Process:
Optimization – Objective

Try to get close to the target values; or maximize / minimize values. Both methods perform very similar.

Dim 1 Diameter	Dim 2 Diameter	Dim 3 Diameter	Dim 4 Diameter	Dim 5 Flatness	Dim 6 Perpendicularity	Dim 7 Parallelism	Dim 8 Perpendicularity	Dim 9 Coaxiality	Dim 10 Distance
5.00	5.00	5.00	3.00	0.00	0.00	0.00	0.00	0.00	68.00
max.	max.	max.	max.	min.	min.	min.	min.	min.	max.



Tradeoff:
Flatness, Perpendicularity, Parallelism, Coaxiality increase with Diameter 3 and 4 (go in the same direction)
But Flatness, Perpendicularity, Parallelism, Coaxiality should be minimized, while Diameter 3 and 4 should be maximized

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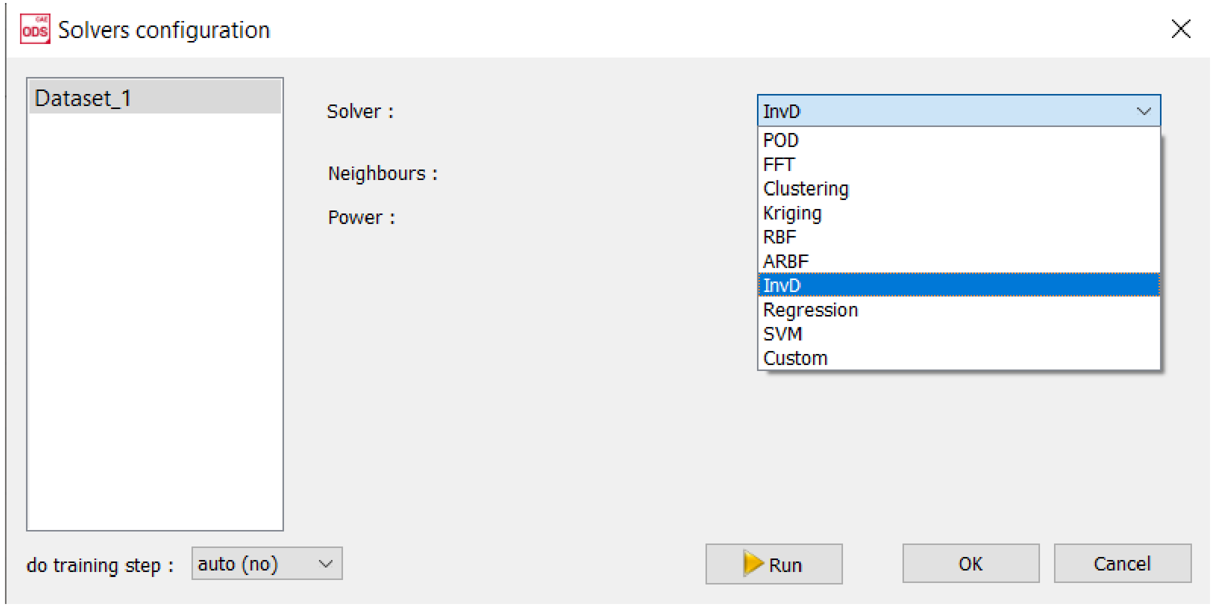
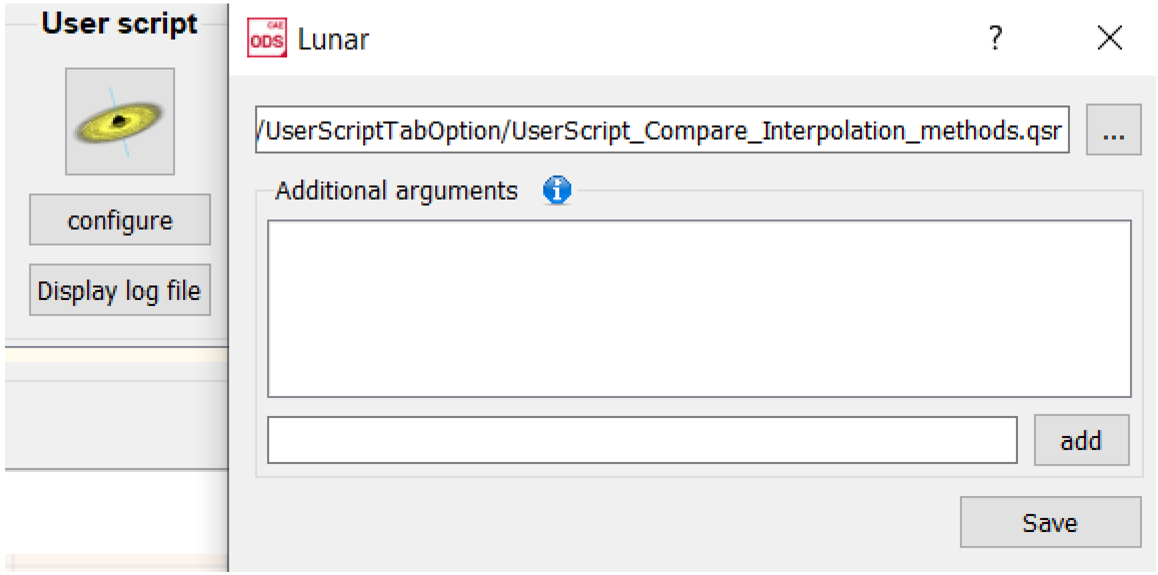
Optimize Manufacturing Process:
Find the Best Interpolation Method

Omitted some data points (7, 23) from the learning base and predicted them

A script runs all methods automatically and finds the one with the best accuracy. Here:

```
The best method found for Dataset_1 CLUSTER_1 is:
InvD 3neighbours power=1.5, with a L2norm= 0.154009.
```





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Optimize Manufacturing Process: Reduce Parameters

Pressure	Cooling	Temp
-1	15	230
-1	25	230
1	15	270
1	25	270
-1	15	270
-1	25	270
1	15	230
1	25	230
-1	20	230
-1	20	230
1	20	230
1	20	230
-1	20	270
-1	20	270
1	20	270
1	20	270
0	20	230
0	20	270
-1	20	250
1	20	250
0	20	250
0	20	250
0	20	250

→

Pressure	Cooling	Temp										
-1	15	230	4.9	4.9	4.9	2.89	0.12	0.05	0.54	0.26	1.94	67.8
-1	25	230	4.88	4.88	4.88	2.88	0.44	0.52	0.39	0.19	4.28	67.15
1	15	270	4.9	4.89	4.92	2.9	0.59	0.93	0.9	0.45	3.93	66.86
1	25	270	4.9	4.9	4.91	2.9	0.6	0.9	0.78	0.38	2.85	67.02
-1	15	270	4.9	4.9	4.9	2.89	0.07	0.08	0.32	0.15	1.08	67.72
-1	25	270	4.89	4.89	4.9	2.89	0.6	0.46	0.81	0.45	2.3	66.74
1	15	230	4.89	4.89	4.9	2.89	0.49	0.55	0.44	0.24	3.8	67.13
1	25	230	4.89	4.89	4.91	2.89	0.6	0.72	0.79	0.38	7	66.91
-1	20	230	4.89	4.885	4.89	2.885	0.17	0.16	0.2	0.1	0.54	67.63
1	20	230	4.895	4.89	4.915	2.895	0.575	0.78	0.76	0.375	3.47	66.96
-1	20	270	4.905	4.895	4.905	2.89	0.25	0.095	0.255	0.13	1.15	67.585
1	20	270	4.89	4.89	4.905	2.89	0.505	0.545	0.43	0.235	2.93	67.16
0	20	230	4.9	4.89	4.91	2.89	0.47	0.39	0.22	0.11	1.66	67.38
0	20	270	4.9	4.9	4.91	2.89	0.45	0.34	0.16	0.08	1.43	67.45
-1	20	250	4.9	4.9	4.9	2.89	0.12	0.04	0.38	0.19	1.03	67.8
1	20	250	4.9	4.89	4.91	2.89	0.6	0.84	0.83	0.4	6.89	66.92
0	20	250	4.896667	4.896667	4.903333	2.89	0.353333	0.286667	0.353333	0.176667	1.893333	67.49667

Kept only the 3 parametes with the highest influence.

Then there are duplicate parameter sets with different results for same parameter combination. These results are averaged.

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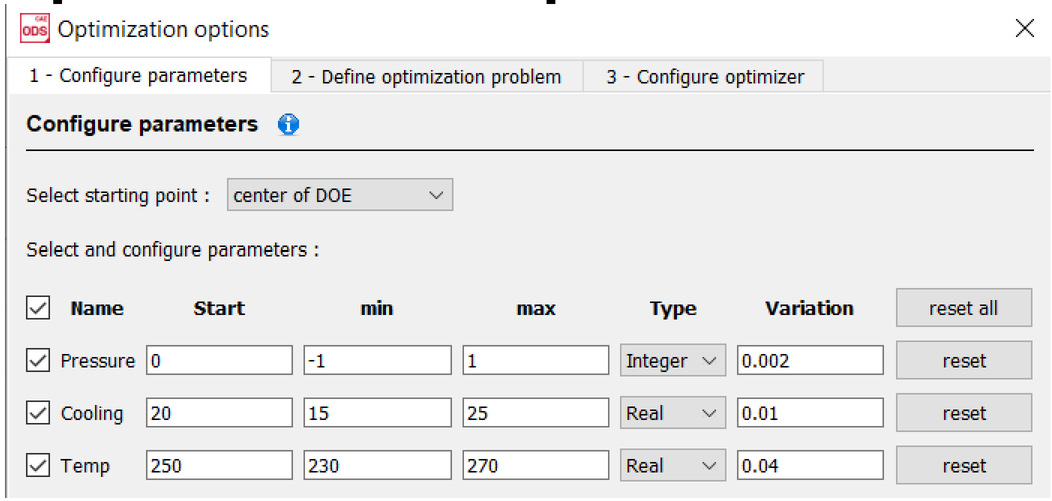
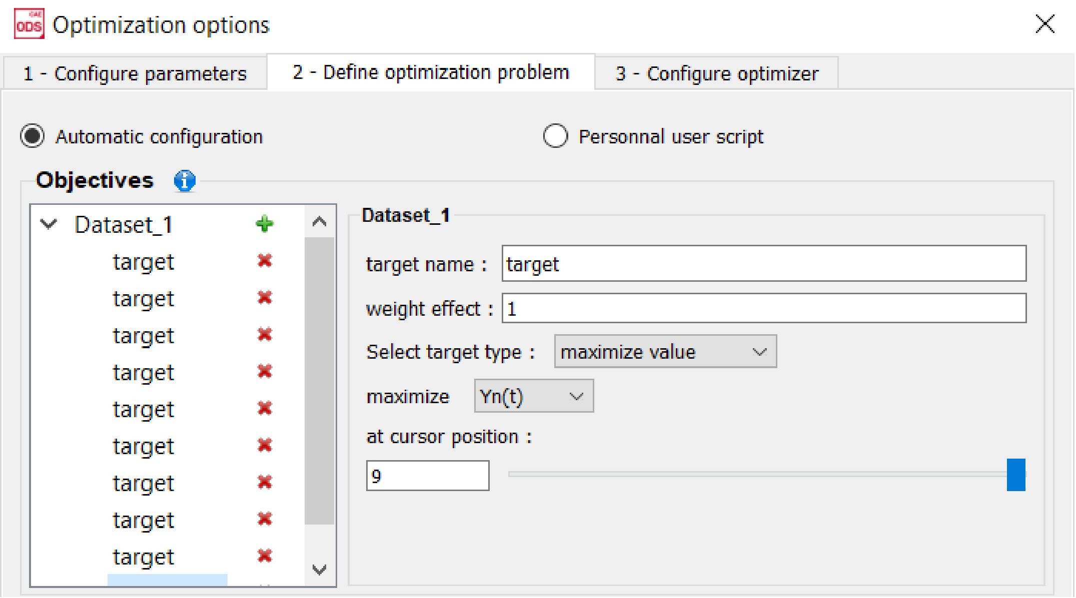
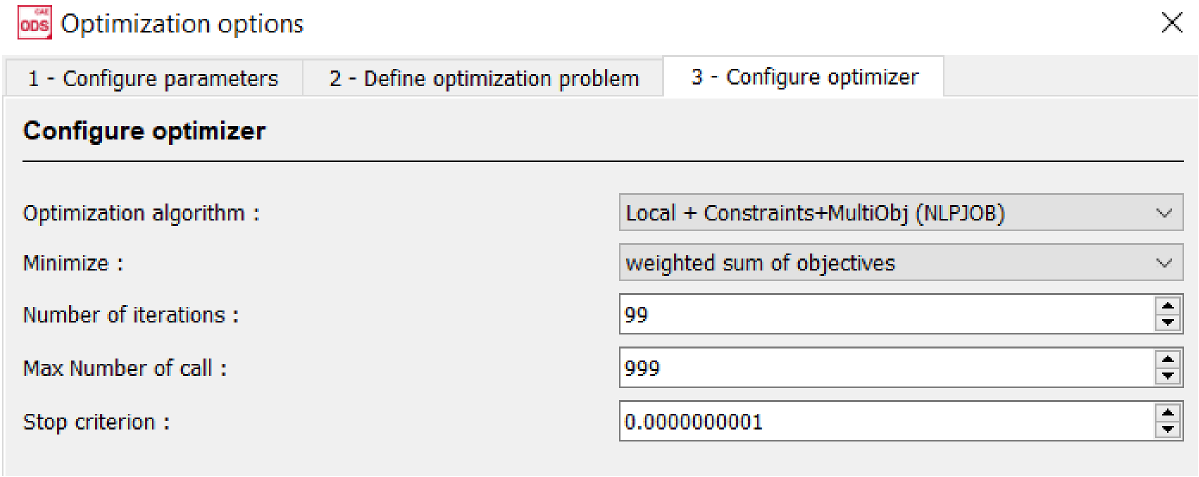
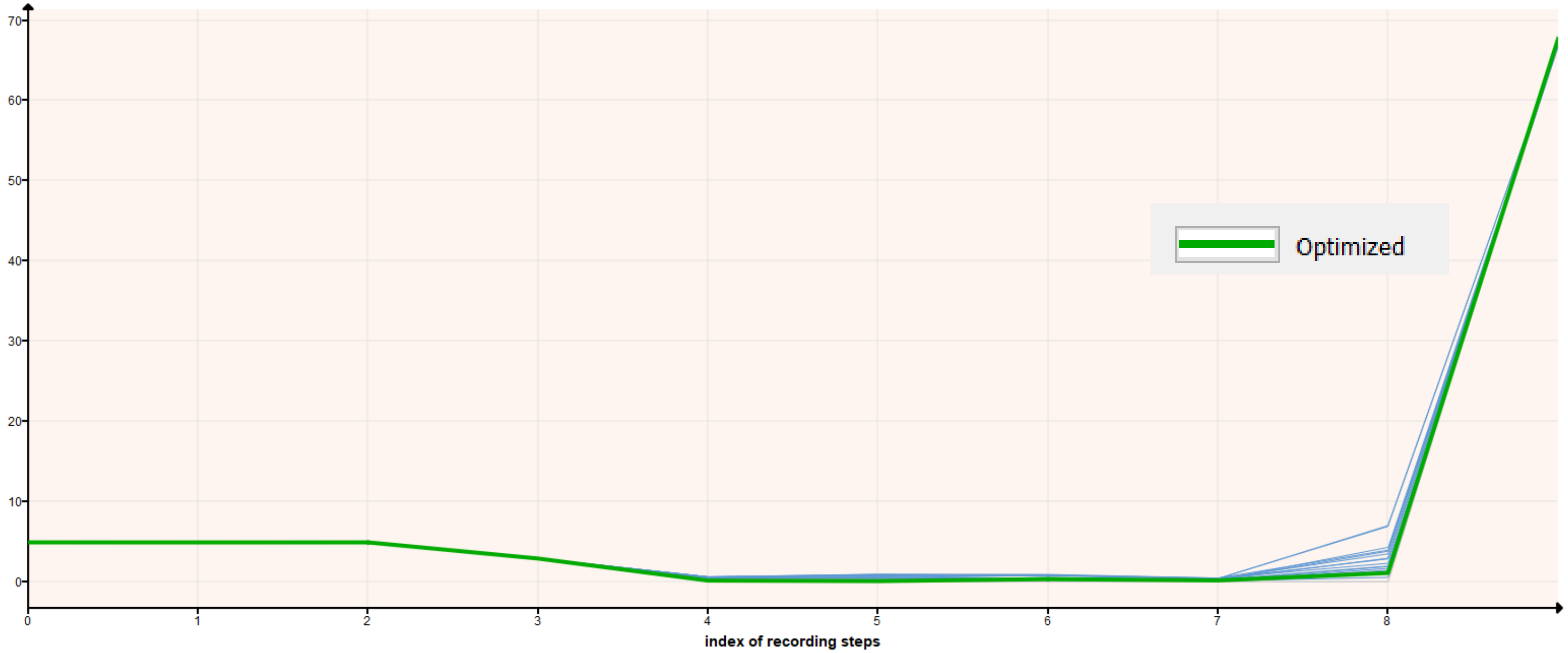
Optimize Manufacturing Process: Optimization Setup







Optimize Manufacturing Process: Optimization Result



Optimized parameters

Pressure: -1
Cooling: 15
Temp: 255

(For the other parameters, maybe use an average value)

Target #1	5	5	5	3	0	0	0	0	0	68
Odyssee	4.90147	4.89853	4.90147	2.89	0.139338	0.07137	0.320426	0.157158	1.08431	67.7063

Questions?

HEXAGON