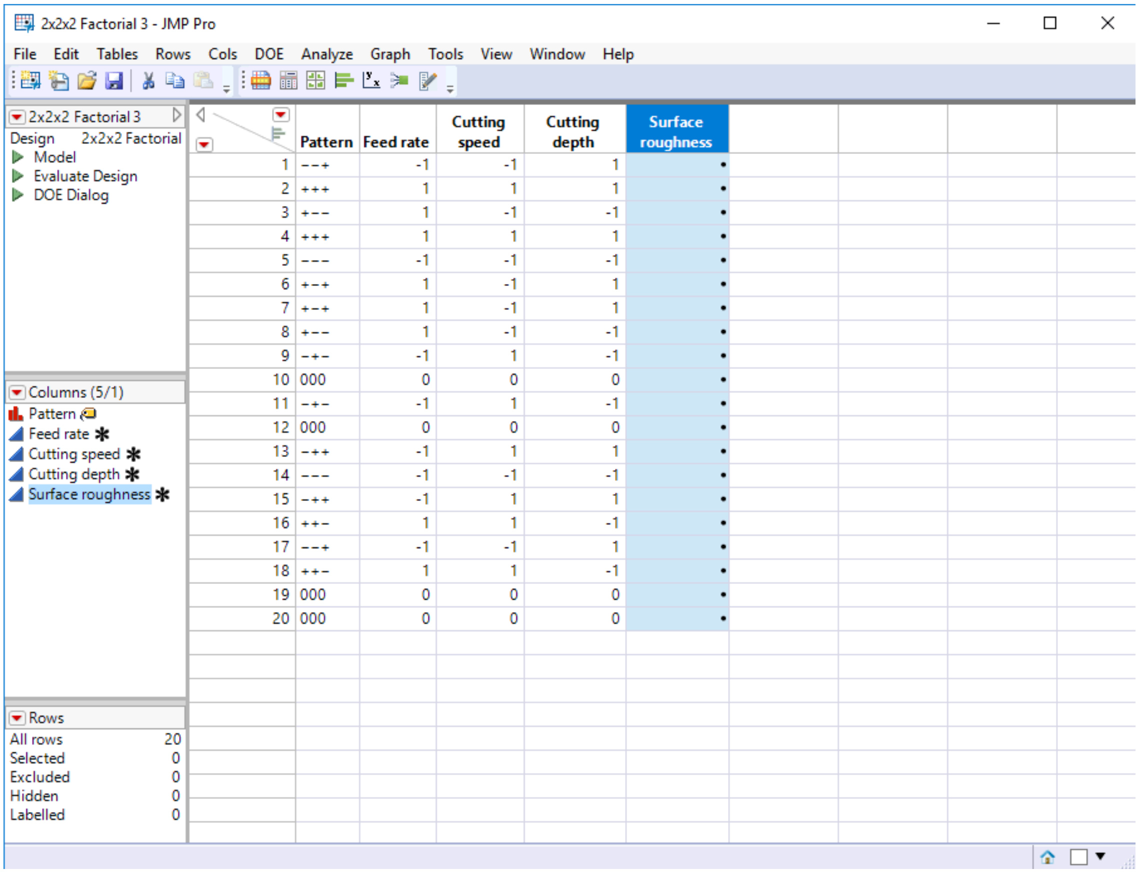
Experimental identification of parameters influencing surface roughness

1. The quality of turned machine parts is mainly determinined by the quality of the surface and therefore by their surface roughness. To avoid subsequent processes for optimizing the roughness, the turning parameters should be optimized to reach the necessary surface quality.
2.
    a. The factors studied in the experiment are:
        i. Feed rate (mm/rev), range: 0.2-0.3 mm/rev, 2 levels
        ii. Cutting speed (m/min), range : 60-120 m/min, 2 levels
        iii. Cutting depth (mm), range: 0.5-1.5 mm, 2 levels
    b. The factors that are held constant are:
        i. Material of tool
        ii. Material of material
        iii. Type of cooling
        iv. Flow rate of coolant
    c. Factors that are allowed to vary:
        i. Tool condition
        ii. Temperature of coolant
        iii. Temperature of material
3. The response variable is the surface roughness of the machined material, which can be measured individually for every part after it has been threatend. The roughness is measured with a tool called contact-type roughness meter by tracing the probe across the surface of the target. The measuring technique is calibrated by its manufacturer. So there is no need to calibrate it during the experiment.

Experimental Design:

- The experiment considers three different factors at two levels each
- Because of the uncomplicated and cost-efficient opportunity to replicate runs a full factorial design is chosen to examine the influence of each main effect and the different two-factor interactions as well as the influence of the three-factor interaction
- The unreplicated 2^3-design has a low power of round about 17.6%
- For that reason the 2^3-design is repeated once
- Furthermore center points are used to identify possible non-linear dependencies
- The center points are equivalent to the actual used parameter configuration
- The randomized design is shown in the following illustration:



2x2x2 Factorial 3 - JMP Pro

	Pattern	Feed rate	Cutting speed	Cutting depth	Surface roughness
1	−−+	-1	-1	1	•
2	+++	1	1	1	•
3	+−−	1	-1	-1	•
4	+++	1	1	1	•
5	−−−	-1	-1	-1	•
6	+−+	1	-1	1	•
7	+−+	1	-1	1	•
8	+−−	1	-1	-1	•
9	−+−	-1	1	-1	•
10	000	0	0	0	•
11	−+−	-1	1	-1	•
12	000	0	0	0	•
13	−++	-1	1	1	•
14	−−−	-1	-1	-1	•
15	−++	-1	1	1	•
16	++−	1	1	-1	•
17	−−+	-1	-1	1	•
18	++−	1	1	-1	•
19	000	0	0	0	•
20	000	0	0	0	•

- By replicating the runs once a increase of power up to 95.8 % was reached

Power Analysis

Significance Level 0.05

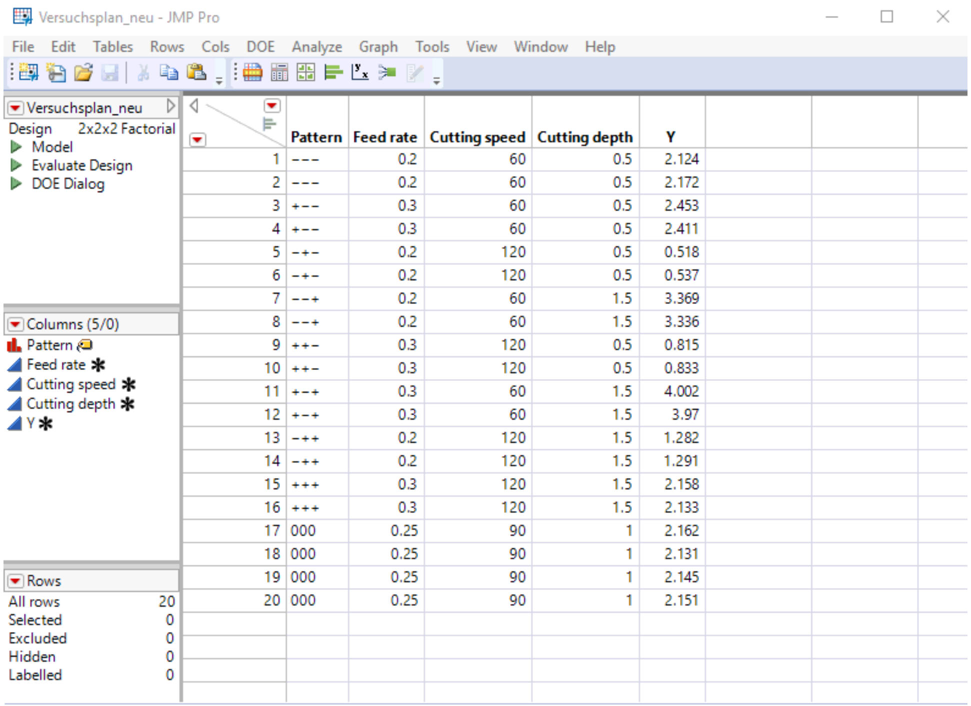
Anticipated RMSE 1

Term	Anticipated Coefficient	Power
Intercept	1	0.985
X1	1	0.958
X2	1	0.958
X3	1	0.958
X1*X2	1	0.958
X1*X3	1	0.958
X2*X3	1	0.958

Experimental procedure:

- The 20 runs shown in the design above were run using a CNC turning machine
- The surface roughness of those 20 workpieces was measured afterwards

- Responses to the different factor levels are shown in following graphic (ordered design, though the experiment was conducted in random order):



	Pattern	Feed rate	Cutting speed	Cutting depth	Y
1	---	0.2	60	0.5	2.124
2	---	0.2	60	0.5	2.172
3	+--	0.3	60	0.5	2.453
4	+--	0.3	60	0.5	2.411
5	-+-	0.2	120	0.5	0.518
6	-+-	0.2	120	0.5	0.537
7	--+	0.2	60	1.5	3.369
8	--+	0.2	60	1.5	3.336
9	++-	0.3	120	0.5	0.815
10	++-	0.3	120	0.5	0.833
11	+-+	0.3	60	1.5	4.002
12	+-+	0.3	60	1.5	3.97
13	-++	0.2	120	1.5	1.282
14	-++	0.2	120	1.5	1.291
15	+++	0.3	120	1.5	2.158
16	+++	0.3	120	1.5	2.133
17	000	0.25	90	1	2.162
18	000	0.25	90	1	2.131
19	000	0.25	90	1	2.145
20	000	0.25	90	1	2.151

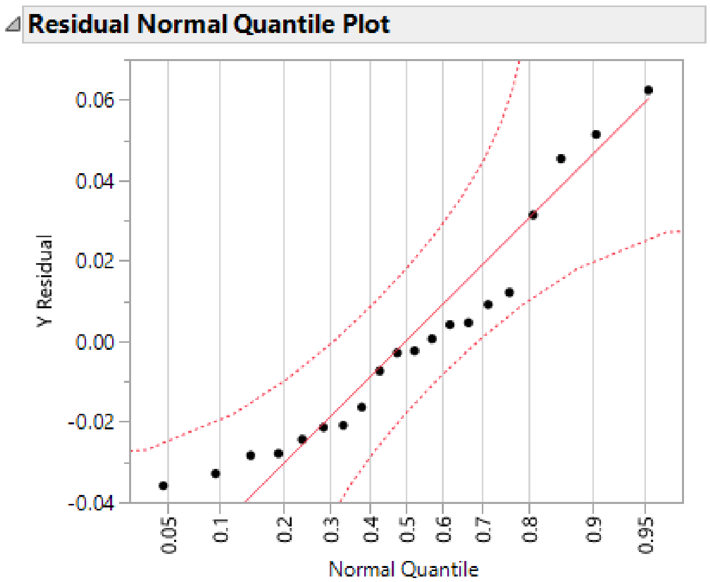
Results:

- Analysis shows that all factors, all two factor interactions and the three factor interaction are highly significant
- For that reason no terms can be removed and the model can't be refined

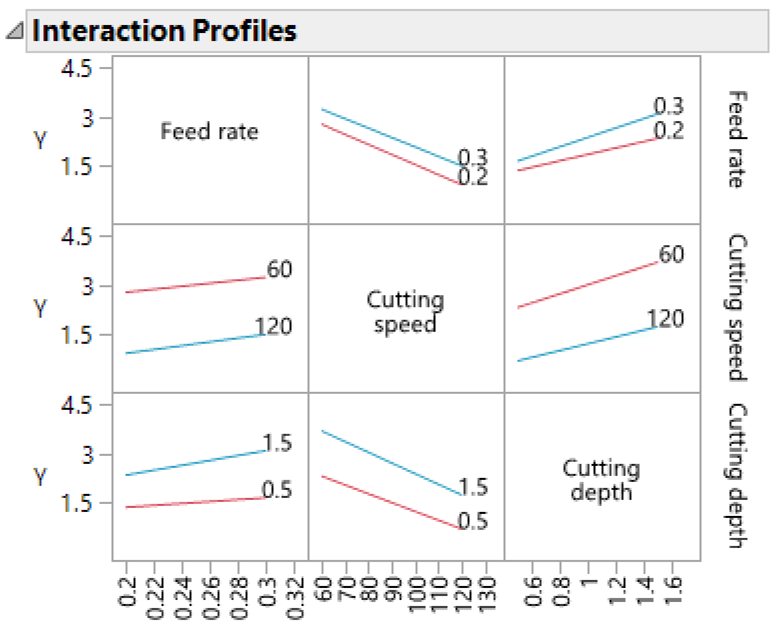
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Feed rate(0.2,0.3)	1	1	1.074332	825.5865	<.0001*
Cutting speed(60,120)	1	1	12.727056	9780.294	<.0001*
Feed rate*Cutting speed	1	1	0.014161	10.8822	0.0064*
Cutting depth(0.5,1.5)	1	1	5.853980	4498.578	<.0001*
Feed rate*Cutting depth	1	1	0.207936	159.7915	<.0001*
Cutting speed*Cutting depth	1	1	0.114921	88.3127	<.0001*
Feed rate*Cutting speed*Cutting depth	1	1	0.011342	8.7161	0.0121*

- The residual analysis shows no anomalies; using a normal-quantile plot all values are close to the diagonal -> no transformation is needed

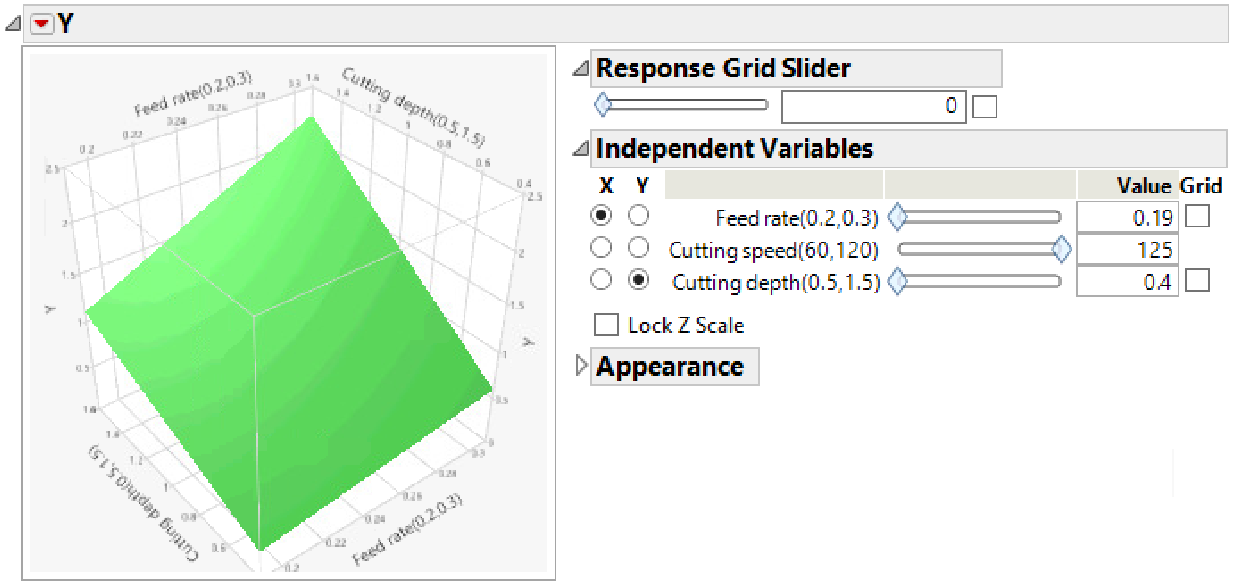


- As mentioned all factors and all interactions are significant
- For increasing cutting speed the surface roughness diminishes
- An increase of cutting depth or feed rate increases the surface roughness



- The lowest surface roughness within the experiment could be reached by using cutting speed at high level and feed rate and cutting depth at low level
- This interrelation is visualized at the following graphic (cutting speed is set at high level)

  -> the lowest point is at the front left corner, where the feed rate and the cutting depth are both at low level



- The predicted surface roughness at this specific point is 0.5394 µm
- The confidence in that prediction is pretty high, because the correlations identified within the examination are physically comprehensible and plausible. A higher feed rate and cutting depth result in higher forces on the tool so that there could be more vibration and with that a worse surface condition. Opposite to that, a higher cutting speed reduces the cutting forces (if steel is used as the workpiece material) so that the surface is much smoother.

- The next steps are:
    - Validate that the results are reliable by conducting validation runs
    - Set the parameters to the best levels identified within the experiment
    - Examine if further improvement is possible (e.g. by increasing the cutting speed even more -> where is the limit of the improvement?)
    - Check if other properties of the workpiece are influenced by the new parameter set

- The results of the Experiment were validated by running 5 more runs at the optimal parameter setting
- Those runs confirmed the results (surface roughness was in the same magnitude as in the initial experiment)