

# Part 2, 3, and 4 (Python and Discussion)

My code for this can be found here as well on this public Github: <https://github.com/Samv6/mece-6397-doe/tree/main/project1>

## Importing Modules

For starters I import pandas, numpy, and combinations which helps generate all possible combos to examine interactions of different factors.

In [ ]:

```
"""
Purpose: Project 1 - Driver script for factorial design and main effects calculation
Author: Syam Evani
"""

# Standard imports
import os

# Additional imports
import pandas as pd
import numpy as np
from itertools import combinations

# Local imports
# None
```

## Creating the design

To create the design I define 2 levels (a low and high) and 5 factors which matches the JMP simulation that we did in the prior section. Notice that for our factors I defined a low and high value similar to that of the jmp simulation.

I generate the experiment design, which at this point is just 0 or 1s indicating low or highs. I save the history of each design into the "pattern" to ultimately display that in the final design output, similar to that of the JMP simulation. I then translate these low and high boolean values into the actual minimum or maximum values specific to the factor itself (for example feed rate low is 10 and high is 15).

I then create a fictional response that we call the "percent reacted" using random number generation.

In [ ]:

```
-----#
# DOE Design Section
#-----
# Define factors and their levels
```

```

levels = [0, 1] # Assuming -1 is low, 0 is medium, and +1 is high
factors={
    'Feed Rate': {"Min": 10, "Max": 15},
    'Catalyst': {"Min": 1, "Max": 2},
    'Stir Rate': {"Min": 100, "Max": 120},
    'Temperature': {"Min": 140, "Max": 180},
    'Concentration': {"Min": 3, "Max": 6}
}

# Generate full factorial design
experiment_design = pd.DataFrame(np.array(np.meshgrid(levels, levels, levels, levels, levels)).T.reshape(-1, 5))

# Capture what pattern was generated
pattern_list = []
for i in range(0,32):
    pattern = []
    for factor in experiment_design.columns:
        pattern.append(experiment_design[factor][i])
    pattern_list.append(pattern)

# Map the levels to their corresponding min and max values
for factor in experiment_design.columns:
    for i in range(0,32):
        if experiment_design[factor][i] == 0:
            experiment_design[factor][i] = factors[factor]["Min"]
        else:
            experiment_design[factor][i] = factors[factor]["Max"]

# Add the pattern and percent reacted to the design
experiment_design['Pattern'] = pattern_list

# Display the design with percent reacted
np.random.seed(42) # For reproducibility
experiment_design['Percent Reacted'] = np.random.rand(len(experiment_design))*100

```

## Main Effects Calculation

Similar to the main effects calculation in the provided code, I simply group the factors and evaluate the mean for percent reacted to see how each factor plays into impacting overall percent reacted.

In [ ]:

```

#-----
# DOE Main Effects Calculation
#-----
main_effects = {}
for factor in factors.keys():
    main_effects[factor] = experiment_design.groupby(factor)[['Percent Reacted']].mean()

```

## Interaction Effects Calculation

To calculate the interactions effects I generate all combinations of the factors (from 2 factors out to 5 factors). I then can similarly group these combinations of factors and evaluate the mean of percent reacted to see the interaction effects.

```
In [ ]: #-----
## DOE Interaction Effects Calculation
#-----
# Calculate interaction effects
interaction_effects = {}
factor_names = list(factors.keys())
for r in range(2, len(factor_names) + 1):
    for combo in combinations(factor_names, r):
        interaction_term = 'x'.join(combo)
        interaction_effects[interaction_term] = experiment_design.groupby(list(combo))
```

## Creating contrast and printing

Similar to the JMP simulation, I want to evaluate the "contrast", which effectively is which direction does it drive the mean of percent reacted. This can be determined by determining the difference between the mean associated with the low and high level of either the main factor or combination of factors.

I then can sort the contrast from most impactful (positively impact percent reacted) to least impactful and output/print this text file to see the full rankings to determine which factors or combinations will be best to increase percent reacted.

```
In [ ]: #-----
# Generate Contrast Output
#-----
contrast_output = pd.DataFrame(columns=['Factor/Interaction', 'Low Level Mean', 'Hi
contrast_rows = []

# Calculate contrast for main effects
for factor in factors.keys():
    low_level_mean = main_effects[factor].iloc[0]
    high_level_mean = main_effects[factor].iloc[1]
    effect = high_level_mean - low_level_mean
    contrast_rows.append({
        'Factor/Interaction': factor,
        'Low Level Mean': low_level_mean,
        'High Level Mean': high_level_mean,
        'Effect': effect
    })

# Calculate contrast for interaction effects
for interaction_term, interaction_data in interaction_effects.items():
    for idx, (level, row) in enumerate(interaction_data.iterrows()):
        low_level_mean = row.iloc[0]
        high_level_mean = row.iloc[1]
        effect = high_level_mean - low_level_mean
        contrast_rows.append({
```

```
'Factor/Interaction': f'{interaction_term} (Level {level})',
'Low Level Mean': low_level_mean,
'High Level Mean': high_level_mean,
'Effect': effect
})

# Save contrast and sort from highest to lowest
contrast_output = pd.DataFrame(contrast_rows)
contrast_output = contrast_output.sort_values(by='Effect', ascending=False)
```

```
In [ ]: #-----
# Print design, main effects contrast, and overall constraint rankings
#-----
# Print design
print("Full Factorial Design and Percent Reacted:")
print(experiment_design)

# Print main effects contrast
print("\nMain Effects:")
for factor, effects in main_effects.items():
    print(f"\n{factor}:")
    print(effects)

# Save contrast to text file for interactions
with open(os.path.join(os.getenv('USERPROFILE'), "repos", "mece-6397-doe", "project1",
                      "file"), "w") as file:
    file.write(contrast_output.to_string(index=False))

# Print overall rankings
with open(os.path.join(os.getenv('USERPROFILE'), "repos", "mece-6397-doe", "project1",
                      "contents"), "r") as file:
    contents = file.read()

print(contents)
```

## Full Factorial Design and Percent Reacted:

	Feed Rate	Catalyst	Stir Rate	Temperature	Concentration	\
0	10	1	100	140	3	
1	10	2	100	140	3	
2	15	1	100	140	3	
3	15	2	100	140	3	
4	10	1	120	140	3	
5	10	2	120	140	3	
6	15	1	120	140	3	
7	15	2	120	140	3	
8	10	1	100	180	3	
9	10	2	100	180	3	
10	15	1	100	180	3	
11	15	2	100	180	3	
12	10	1	120	180	3	
13	10	2	120	180	3	
14	15	1	120	180	3	
15	15	2	120	180	3	
16	10	1	100	140	6	
17	10	2	100	140	6	
18	15	1	100	140	6	
19	15	2	100	140	6	
20	10	1	120	140	6	
21	10	2	120	140	6	
22	15	1	120	140	6	
23	15	2	120	140	6	
24	10	1	100	180	6	
25	10	2	100	180	6	
26	15	1	100	180	6	
27	15	2	100	180	6	
28	10	1	120	180	6	
29	10	2	120	180	6	
30	15	1	120	180	6	
31	15	2	120	180	6	

	Pattern	Percent Reacted
0	[0, 0, 0, 0, 0]	37.454012
1	[0, 1, 0, 0, 0]	95.071431
2	[1, 0, 0, 0, 0]	73.199394
3	[1, 1, 0, 0, 0]	59.865848
4	[0, 0, 1, 0, 0]	15.601864
5	[0, 1, 1, 0, 0]	15.599452
6	[1, 0, 1, 0, 0]	5.808361
7	[1, 1, 1, 0, 0]	86.617615
8	[0, 0, 0, 1, 0]	60.111501
9	[0, 1, 0, 1, 0]	70.807258
10	[1, 0, 0, 1, 0]	2.058449
11	[1, 1, 0, 1, 0]	96.990985
12	[0, 0, 1, 1, 0]	83.244264
13	[0, 1, 1, 1, 0]	21.233911
14	[1, 0, 1, 1, 0]	18.182497
15	[1, 1, 1, 1, 0]	18.340451
16	[0, 0, 0, 0, 1]	30.424224
17	[0, 1, 0, 0, 1]	52.475643
18	[1, 0, 0, 0, 1]	43.194502
19	[1, 1, 0, 0, 1]	29.122914

20	[0, 0, 1, 0, 1]	61.185289
21	[0, 1, 1, 0, 1]	13.949386
22	[1, 0, 1, 0, 1]	29.214465
23	[1, 1, 1, 0, 1]	36.636184
24	[0, 0, 0, 1, 1]	45.606998
25	[0, 1, 0, 1, 1]	78.517596
26	[1, 0, 0, 1, 1]	19.967378
27	[1, 1, 0, 1, 1]	51.423444
28	[0, 0, 1, 1, 1]	59.241457
29	[0, 1, 1, 1, 1]	4.645041
30	[1, 0, 1, 1, 1]	60.754485
31	[1, 1, 1, 1, 1]	17.052412

Main Effects:

Feed Rate:

Feed Rate

10 46.573083

15 40.526837

Name: Percent Reacted, dtype: float64

Catalyst:

Catalyst

1 40.328071

2 46.771848

Name: Percent Reacted, dtype: float64

Stir Rate:

Stir Rate

100 52.893224

120 34.206696

Name: Percent Reacted, dtype: float64

Temperature:

Temperature

140 42.838787

180 44.261133

Name: Percent Reacted, dtype: float64

Concentration:

Concentration

3 47.511706

6 39.588214

Name: Percent Reacted, dtype: float64

Factor/Interaction

Low Level	Mean	High Level	Mean	Effect								
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 120, 1 40))	15.601864	61.185289	45.583425									
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 1, 120, 1 80))	18.182497	60.754485	42.571988									
				Catalyst x Stir Rate x Temperature x Concentration (Level (1, 120, 1 40))								
				10.705113	45.199877	34.494765						
							Feed Rate x Catalyst x Stir Rate x Concentration (Level (15, 1, 1 20))					
							11.995429	44.984475	32.989046			
									Feed Rate x Catalyst x Stir Rate x Temperature (Level (10, 1, 1 20))			
									38.393577	71.242860	32.849284	

		Feed Rate x Catalyst x Temperature x Concentration (Level (15, 1, 1	
80))	10.120473	40.360932	30.240459
		Feed Rate x Catalyst x Stir Rate x Temperature (Level (15, 2, 1	
00))	44.494381	74.207215	29.712833
		Catalyst x Stir Rate x Temperature (Level (1, 1	
20))	27.952495	55.355676	27.403181
		Feed Rate x Catalyst x Temperature (Level (10,	
1))	36.166347	62.051055	25.884708
		Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 1, 120, 1	
40))	5.808361	29.214465	23.406104
		Feed Rate x Stir Rate x Temperature x Concentration (Level (10, 120, 1	
40))	15.600658	37.567338	21.966680
		Feed Rate x Catalyst x Stir Rate x Temperature (Level (15, 1, 1	
20))	17.511413	39.468491	21.957078
		Catalyst x Stir Rate x Concentration (Level (1, 1	
20))	30.709247	52.598924	21.889678
		Feed Rate x Stir Rate x Temperature x Concentration (Level (15, 120, 1	
80))	18.261474	38.903449	20.641975
		Feed Rate x Catalyst x Temperature x Concentration (Level (10, 1, 1	
40))	26.527938	45.804757	19.276819
		Feed Rate x Catalyst x Stir Rate x Temperature (Level (10, 1, 1	
00))	33.939118	52.859250	18.920132
		Feed Rate x Catalyst (Level	
15)	31.547441	49.506232	17.958790
		Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 1, 100, 1	
80))	2.058449	19.967378	17.908929
		Feed Rate x Stir Rate x Temperature (Level (10, 1	
20))	26.583998	42.091168	15.507170
		Catalyst x Stir Rate x Temperature (Level (2, 1	
00))	59.133959	74.434821	15.300862
		Feed Rate x Catalyst x Concentration (Level (15,	
1))	24.812175	38.282708	13.470532
		Feed Rate x Temperature (Level	
10)	40.220163	52.926003	12.705841
		Feed Rate x Catalyst x Stir Rate (Level (10,	
1))	43.399184	54.818219	11.419035
		Feed Rate x Catalyst x Stir Rate x Concentration (Level (10, 1, 1	
20))	49.423064	60.213373	10.790309
		Feed Rate x Stir Rate x Temperature (Level (10, 1	
00))	53.856327	63.760838	9.904511
		Catalyst x Stir Rate x Temperature x Concentration (Level (1, 120, 1	
80))	50.713380	59.997971	9.284591
		Catalyst x Temperature x Concentration (Level (1, 1	
40))	33.015908	41.004620	7.988712
		Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 2, 100, 1	
80))	70.807258	78.517596	7.710338
		Catalyst x Concentration (Leve	
1 1)	36.957543	43.698600	6.741057
		Catalyst x Temperature (Leve	
1 1)	37.010264	43.645879	6.635615
		Cata	
lyst	40.328071	46.771848	6.443777
		Catalyst x Temperature x Concentration (Level (1, 1	
80))	40.899178	46.392580	5.493402
		Stir Rate x Temperature x Concentration (Level (120, 1	
40))	30.906823	35.246331	4.339508

		Feed Rate x Stir Rate x Concentration (Level (15, 1, 1))		
20))	32.237231	35.914387	3.677156	
80))	33.893096	37.299430	3.406334	Feed Rate x Temperature x Concentration (Level (15, 1, 1))
1 1)	39.002057	41.654085	2.652028	Catalyst x Stir Rate (Level (1, 1, 1))
120)	33.076577	35.336815	2.260238	Stir Rate x Temperature (Level (1, 1, 1))
120)	33.078552	35.334840	2.256288	Stir Rate x Concentration (Level (1, 1, 1))
80))	31.084975	32.787188	1.702213	Catalyst x Stir Rate x Temperature x Concentration (Level (1, 100, 1, 1))
ture	42.838787	44.261133	1.422346	Temperature (1, 100, 1, 1))
00))	73.773537	74.662427	0.888890	Feed Rate x Catalyst x Stir Rate x Temperature (Level (10, 2, 1, 1))
20))	33.919873	34.755293	0.835421	Feed Rate x Stir Rate x Concentration (Level (10, 1, 1, 1))
100)	52.600996	53.185451	0.584455	Stir Rate x Temperature (Level (100, 1, 1, 1))
80))	35.250281	35.423349	0.173068	Stir Rate x Temperature x Concentration (Level (120, 1, 1, 1))
1))	49.102910	49.114492	0.011582	Feed Rate x Catalyst x Concentration (Level (10, 1, 1, 1))
2))	44.273978	43.800952	-0.473026	Feed Rate x Catalyst x Temperature (Level (10, 1, 1, 1))
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 2, 120, 1, 1))	18.340451	17.052412	-1.288039	Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 2, 120, 1, 1))
40))	40.931690	39.508636	-1.423054	Feed Rate x Temperature x Concentration (Level (10, 1, 1, 1))
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 2, 120, 1, 1))	15.599452	13.949386	-1.650066	Feed Rate x Catalyst x Stir Rate x Temperature (Level (10, 2, 1, 1))
40))	14.774419	12.939476	-1.834943	Feed Rate x Catalyst x Temperature x Concentration (Level (15, 1, 1, 1))
40))	39.503878	36.204483	-3.299394	Feed Rate x Stir Rate x Temperature x Concentration (Level (10, 100, 1, 1))
80))	65.459379	62.062297	-3.397082	Catalyst x Temperature (Level (1, 2, 1, 1))
1 2)	48.667309	44.876387	-3.790922	Temperature x Concentration (Level (180, 1, 1, 1))
180)	46.371165	42.151102	-4.220063	Feed Rate x Catalyst x Temperature x Concentration (Level (10, 2, 1, 1))
80))	46.020584	41.581319	-4.439266	Feed Rate x Catalyst (Level (10, 1, 1, 1))
10)	49.108701	44.037465	-5.071237	Feed Rate (Level (1, 1, 1, 1))
Rate	46.573083	40.526837	-6.046246	Feed Rate x Catalyst x Stir Rate x Concentration (Level (15, 1, 1, 1))
00))	37.628922	31.580940	-6.047982	Feed Rate x Catalyst x Stir Rate (Level (15, 1, 1, 1))
1))	34.604931	28.489952	-6.114979	Feed Rate x Concentration (Level (10, 1, 1, 1))
10)	49.890462	43.255704	-6.634757	Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 100, 1, 1))
40))	37.454012	30.424224	-7.029788	Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 100, 1, 1))

			Feed Rate x Catalyst x Temperature (Level (15,
2))	53.060640	45.951823	-7.108817
			Concentra
tion	47.511706	39.588214	-7.923492
00))	43.205839	34.798276	Catalyst x Stir Rate x Concentration (Level (1, 1
80))	57.492048	48.878854	Stir Rate x Temperature x Concentration (Level (100, 1
00))	51.345665	42.610064	Feed Rate x Stir Rate x Temperature (Level (15, 1
80))	19.787181	10.848727	Catalyst x Stir Rate x Temperature x Concentration (Level (2, 120, 1
20))	18.416682	9.297214	Feed Rate x Catalyst x Stir Rate x Concentration (Level (10, 2, 1
15)	45.132950	35.920723	Feed Rate x Concentration (Level
15)	45.457410	35.596263	Feed Rate x Temperature (Level
00))	48.782757	38.015611	Feed Rate x Catalyst x Stir Rate x Concentration (Level (10, 1, 1
20))	39.569156	28.582461	Feed Rate x Stir Rate x Temperature (Level (15, 1
140)	48.652247	37.025326	Temperature x Concentration (Level
80))	58.849234	47.002773	-11.626921
1))	37.854181	25.240702	Feed Rate x Catalyst x Temperature (Level (15,
15)	46.977864	34.075809	Feed Rate x Stir Rate (Level
2))	50.678013	37.396917	Feed Rate x Catalyst x Concentration (Level (10,
40))	46.212988	32.925325	-13.281096
80))	49.524717	35.695411	Feed Rate x Stir Rate x Temperature x Concentration (Level (15, 120, 1
80))	51.843151	37.909623	Feed Rate x Stir Rate x Temperature x Concentration (Level (15, 100, 1
00))	65.861050	51.756116	-13.829306
00))	46.068033	31.936082	Catalyst x Temperature x Concentration (Level (2, 1
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 100, 1	60.111501	45.606998	-14.131951
80))	21.233911	4.645041	Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 2, 120, 1
80))	35.447857	18.070756	-16.588870
20))	82.939344	65.496620	Catalyst x Stir Rate x Concentration (Level (2, 1
100)	61.944860	43.841587	-17.377101
40))	55.326703	36.809363	Feed Rate x Catalyst x Stir Rate x Concentration (Level (10, 2, 1
Rate	52.893224	34.206696	-18.517340
			Stir
			Rate

	Catalyst x Stir Rate x Temperature x Concentration (Level (2, 100, 1
80))	83.899121 64.970520 -18.928602
	Feed Rate x Catalyst x Temperature x Concentration (Level (10, 1, 1
80))	71.677883 52.424228 -19.253655
	Feed Rate x Catalyst x Stir Rate (Level (15,
2))	59.350798 39.661666 -19.689132
	Feed Rate x Stir Rate x Temperature x Concentration (Level (10, 120, 1
80))	52.239088 31.943249 -20.295838
	Feed Rate x Temperature x Concentration (Level (15, 1
40))	56.372805 34.542016 -21.830788
	Feed Rate x Stir Rate x Concentration (Level (15, 1
00))	58.028669 35.927059 -22.101610
	Feed Rate x Catalyst x Temperature x Concentration (Level (10, 2, 1
40))	55.335441 33.212515 -22.122927
	Catalyst x Concentration (Leve
1 2)	58.065869 35.477828 -22.588041
	Catalyst x Stir Rate x Temperature (Level (2, 1
20))	38.200659 15.317954 -22.882705
	Feed Rate x Catalyst x Temperature x Concentration (Level (15, 2, 1
80))	57.665718 34.237928 -23.427790
	Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 120, 1
80))	83.244264 59.241457 -24.002807
	Feed Rate x Stir Rate (Level
10)	58.808583 34.337583 -24.471000
	Feed Rate x Stir Rate x Temperature x Concentration (Level (10, 100, 1
40))	66.262721 41.449934 -24.812788
	Feed Rate x Catalyst x Stir Rate x Concentration (Level (15, 2, 1
20))	52.479033 26.844298 -25.634734
	Catalyst x Stir Rate x Temperature x Concentration (Level (2, 120, 1
40))	51.108533 25.292785 -25.815748
	Stir Rate x Temperature x Concentration (Level (100, 1
40))	66.397671 38.804321 -27.593350
	Catalyst x Stir Rate x Concentration (Level (2, 1
00))	80.683881 52.884899 -27.798981
	Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 1, 100, 1
40))	73.199394 43.194502 -30.004892
	Feed Rate x Stir Rate x Temperature x Concentration (Level (15, 100, 1
40))	66.532621 36.158708 -30.373913
	Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 2, 100, 1
40))	59.865848 29.122914 -30.742934
	Catalyst x Temperature x Concentration (Level (2, 1
40))	64.288586 33.046032 -31.242555
	Feed Rate x Catalyst x Concentration (Level (15,
2))	65.453725 33.558739 -31.894986
	Catalyst x Stir Rate x Temperature x Concentration (Level (2, 100, 1
40))	77.468640 40.799279 -36.669361
	Feed Rate x Catalyst x Stir Rate x Concentration (Level (15, 2, 1
00))	78.428417 40.273179 -38.155238
	Catalyst x Stir Rate (Leve
1 2)	66.784390 26.759307 -40.025083
	Feed Rate x Catalyst x Temperature x Concentration (Level (15, 2, 1
40))	73.241731 32.879549 -40.362182
	Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 2, 100, 1
40))	95.071431 52.475643 -42.595787
	Feed Rate x Catalyst x Stir Rate x Temperature (Level (15, 2, 1
20))	61.626899 17.696432 -43.930468

Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 2, 100, 1 80))	96.990985	51.423444 -45.567541
Feed Rate x Catalyst x Stir Rate x Temperature (Level (15, 1, 1 00))	58.196948	11.012914 -47.184034
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 2, 120, 1 40))	86.617615	36.636184 -49.981430
Feed Rate x Catalyst x Stir Rate (Level (10, 2))	74.217982	13.856948 -60.361034

## Conclusion

With our randomly generated responses (percent reacted) and with our random seed (42), we find that increasing the Catalyst level is the most impactful, single factor that can improve percent reacted with a 6% contribution. An overall grading of factors is as follows in the following form (Factor, Percented Reacted Change)

1. Catalyst (+6%)
2. Temperature (+1.4%)
3. Feed Rate (-6%)
4. Concentration (-7.9%)
5. Stir Rate (-18.7%)

Notice that increasing the level of Feed Rate, Concentration, and Stir Rate negatively impacts percent reacted if we are examining these factors individually. However, the individual examination in itself doesn't fully capture coupled impacts, therefore investigating combinations of factors percented reacted change is more valuable. I generated 121 combinations of different factors and ultimately found some combinations of the 5 factors yield the best mean change in percent reacted. For example the top 2 combinations include:

1. Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 120, 140))  
which has a Percent Reacted Change of +45.6%
2. Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 1, 120, 180))  
which has a Percent Reacted Change of +42.6%

In essence, if we have those factors with their accompanying factors and then increase the concentration, this will dramatically and positively impact our overall chemical reaction percent reacted. Following these combos of 5 factors, the next most impactful combos are 4 factors that follow a similar trend. Commenting on some pair combinations, the top two paired combinations positively impacting percent reacted are:

1. Feed Rate x Catalyst (Level 15) which has a Percent Reacted Change of +18%
2. Feed Rate x Temperature (Level 10) which has a Percent Reacted Change of +12.7%
3. Catalyst x Concentration (Level 1) which has a Percent Reacted Change of +6.7%

As evidenced, each of these factors has unique, coupled impacts when combined and it's important to understand the nuance associated with each of these. If I was an engineer on this experiment, I would keep in the back of my mind the overall net increase that increasing

the catalyst level can bring, however, I would specifically pay attention to the coupled impacts with multiple factors and attempt to understand the underlying physical reasoning to better increase the overall net, percent reacted for my chemical reactions.