

Melt Pool Project: Milestone Report

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Data Science Career Track - Capstone Project

[GitHub Project Link](#)



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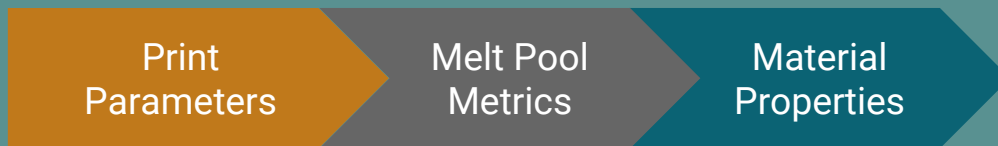
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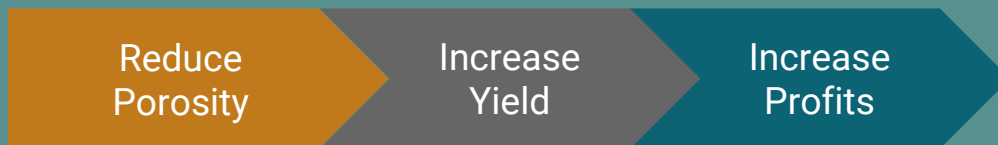
Section 1: Project Overview

Project Details

This is a Capstone Project for my Data Science Course with Springboard. The goal is to correlate 3 sets of data:

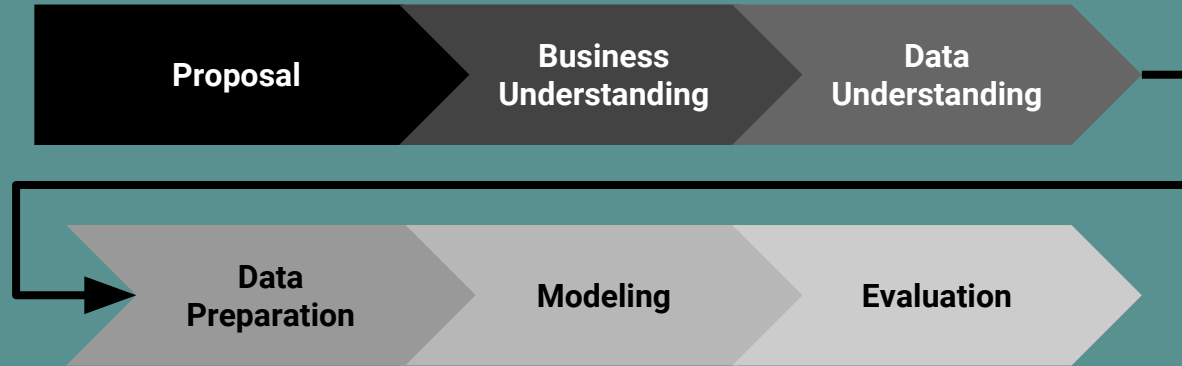


The result of these findings will allow the user to:



For Further Information on this Course: [Data Science Career Track Info](#)

Project Workflow



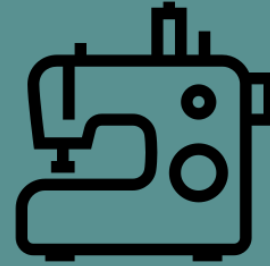
3D Printer



Sensor



Testing



Print Parameters

- Laser Power
- Print Speed
- Print Direction



Melt Pool Metrics

- Temperature
- Area / Length / Width
- Spatter



Material Properties

- Porosity



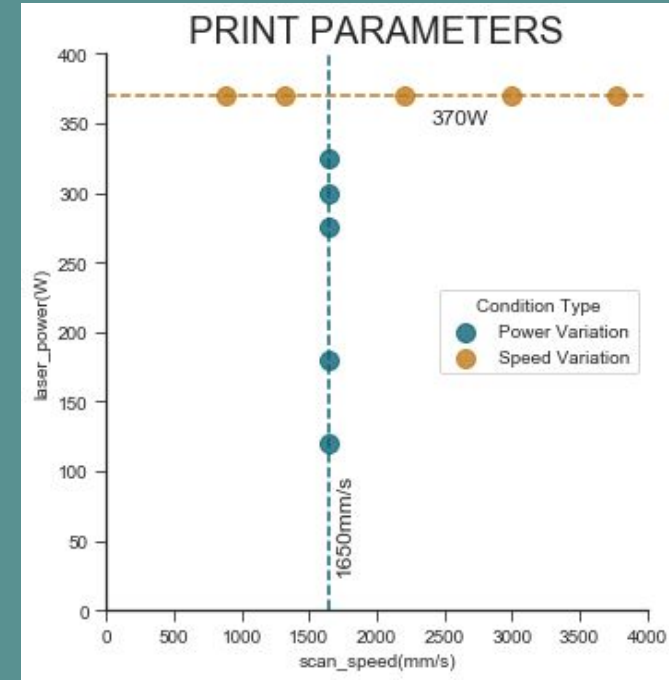


Section 2: Print Parameters

Printing Parameters

- Laser Power, Laser Speed, & Hatch Spacing varied throughout the experiment.
- Layer Thickness and Stripe Width were held constant at 0.03 mm and 100 microns respectively.

Category	Laser Power (W)	Scan Speed (mm/s)	Hatch Spacing (mm)
Nominal	300	1650	0.09
Power Variation	325	1650	0.09
	300		
	275		
	180		
	120		
Speed Variation	370	3780	0.14
		3000	
		2200	
		1320	
		880	





Section 3: Melt Pool Metrics

Melt Pool Metrics

- A visual thermal sensor placed inside the printer recorded images of the process and metrics were calculated
- The metrics were divided into two tables, shown below

	run	frame	time(s)	exp_time(ms)	int_s_p(counts)	int_l_p(counts)	int_s_avg_3(counts)	int_l_avg_3(counts)
0	16	51	0.064	0.024957	2788	1533	2010.1	1073.4
1	16	52	0.065	0.024957	2969	1579	1989.0	1177.9
2	16	53	0.066	0.024957	3185	1719	2259.8	1218.9
3	16	54	0.068	0.024957	3173	1783	2288.6	1375.7
4	16	55	0.069	0.024957	3149	1901	2478.2	1219.0

	run	frame	t1_temp_avg(C)	t1_length(pixels)	t1_width(pixels)	t1_orient(degrees)	t1_area(pixels)	t1_sat_num(-)
0	16	51	1834.1	79.429	19.615	-84.970	931	5
1	16	52	1856.9	72.962	21.994	-86.215	1036	18
2	16	53	1842.3	58.080	14.408	88.929	525	13
3	16	54	1853.2	39.585	12.303	-88.745	324	16
4	16	55	1804.5	32.979	11.086	89.202	230	7

**X4
Threshold
Temperatures**

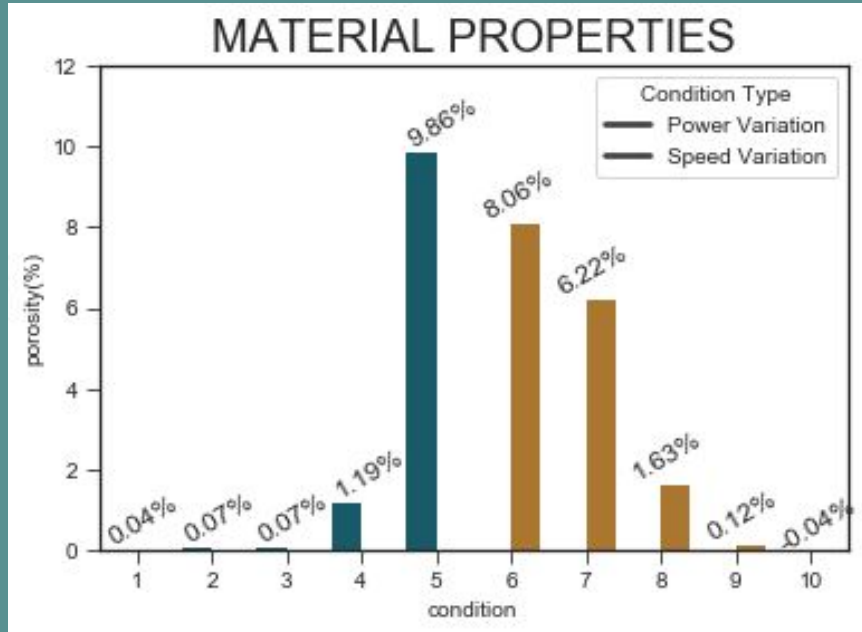
Metric	Units
Frame	-
Time	μs
Threshold	-
Peak X	pixels
Peak Y	pixels
Peak Temperature	°C
Average Temperature	°C
Area	micron ²
Length	micron
Width	micron
Spatter Counts	-
Spatter Area	pixels
X - Profile	°C
Y - Profile	°C



Section 4: Material Properties

Material Properties

- The Material used in this experiment is a metal
- The measured Material Property for this experiment is Porosity.



Condition (#)	Porosity (%)
1	0.068
2	0.039
3	0.068
4	0.067
5	1.189
6	9.860
7	8.060
8	6.225
9	1.630
10	0.115
11	-0.044



Section 5:

Data Cleaning & Data Wrangling

Data Cleaning

- Convert CSV files into Data Frames
- Printer Parameters
 - Extract constants into variables and remove those columns
- Melt Pool Metrics
 - Combine all Data Frames into a single Data Frame
- Porosity
 - N/A

Data Wrangling

- Printer Parameters
 - **LED** = Linear Laser Energy Density = LP/SS
 - **GED** = Global Energy Density = $LP/(SS*HS)$
 - **VED** = Volumetric Laser Energy Density = $LP/(SS*HS*LH)$
- Melt Pool Metrics
 - A “Length-Width Ratio” column was generated
 - Units were converted from Pixels to Microns
 - Metrics were grouped into categories
- Porosity
 - N/A

	laser_power(W)	scan_speed(mm/s)	hatch_spacing(mm)	cond_type	led	ged	ved
condition							
1	325	1650	0.09	PV	0.20	2.19	72.95
2	300	1650	0.09	PV	0.18	2.02	67.34
3	275	1650	0.09	PV	0.17	1.85	61.73
4	180	1650	0.09	PV	0.11	1.21	40.40
5	120	1650	0.09	PV	0.07	0.81	26.94
6	370	3780	0.14	SV	0.10	0.70	23.31
7	370	3000	0.14	SV	0.12	0.88	29.37
8	370	2200	0.14	SV	0.17	1.20	40.04
9	370	1320	0.14	SV	0.28	2.00	66.74
10	370	880	0.14	SV	0.42	3.00	100.11

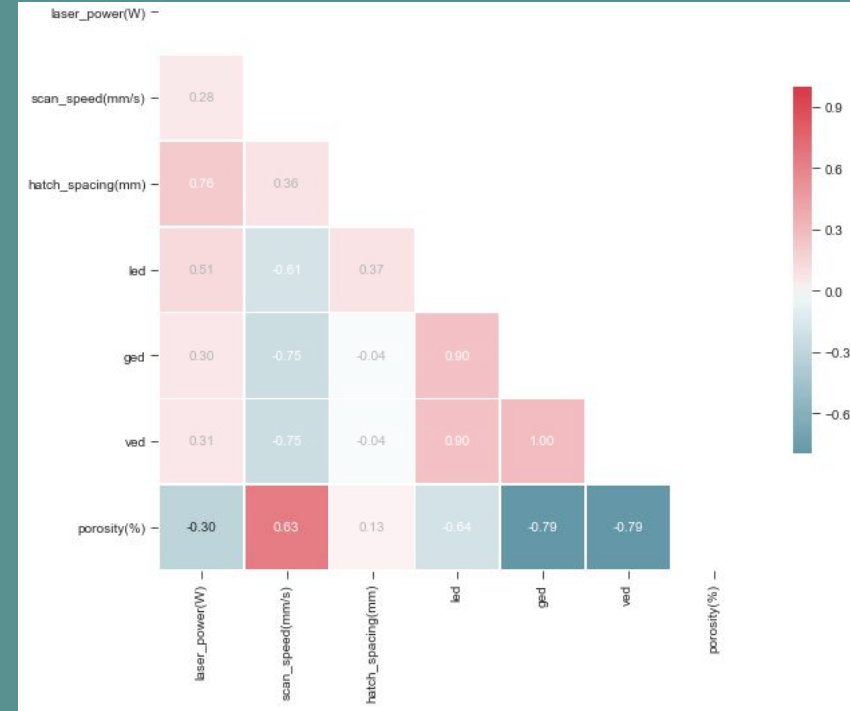
Print
Parameters
Table



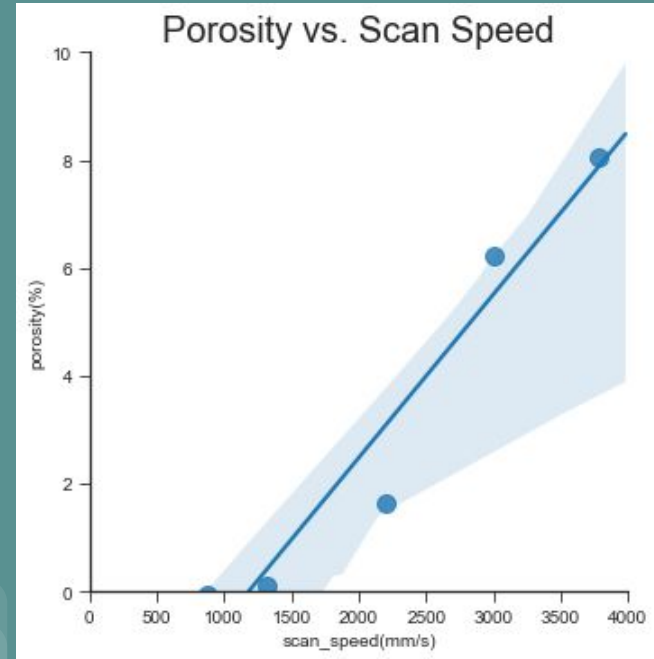
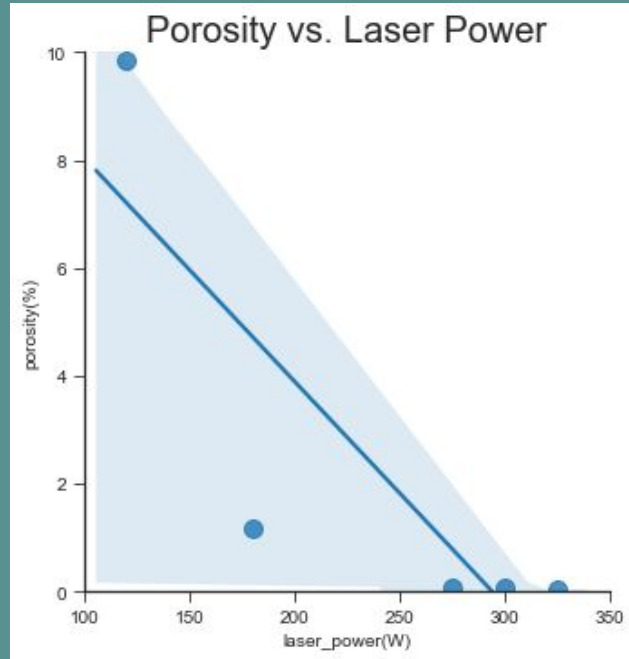
Section 6A: Print Parameters & Material Properties Correlations

Print Parameters vs. Material Properties

- As Laser Power increases, Porosity tends to decrease, but as Scan Speed increases, Porosity tends to increase.
 - Laser Power correlates with Porosity = -0.30
 - Scan Speed correlates with Porosity 0.63
- When Feature Engineering is used to create the Energy Densities like GED and VED, the correlation greatly increases
 - GED & VED correlate with Porosity = -0.79



Print Parameters vs. Material Properties

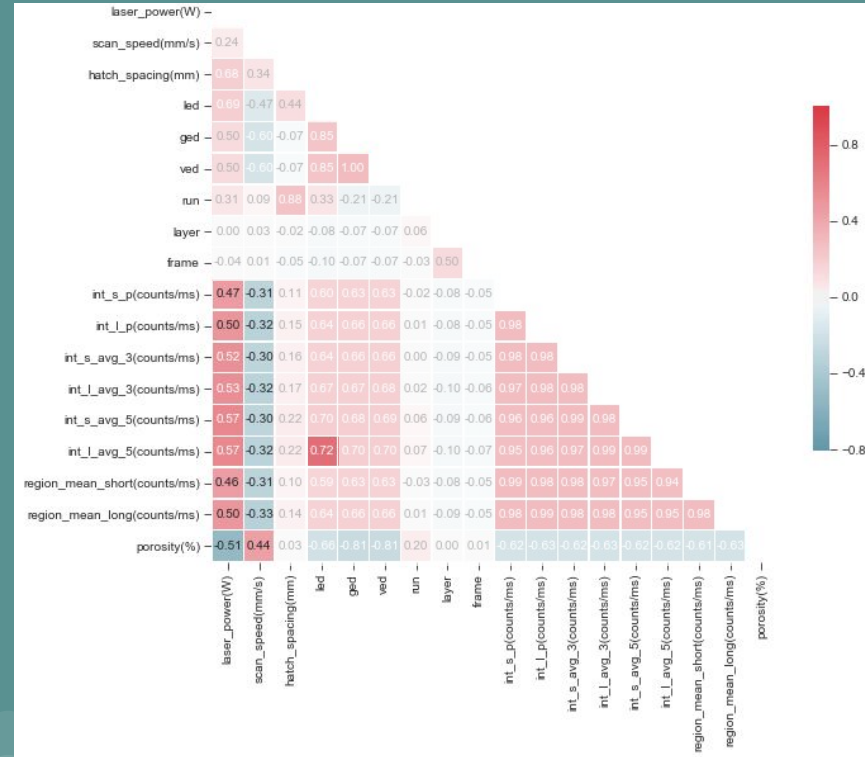




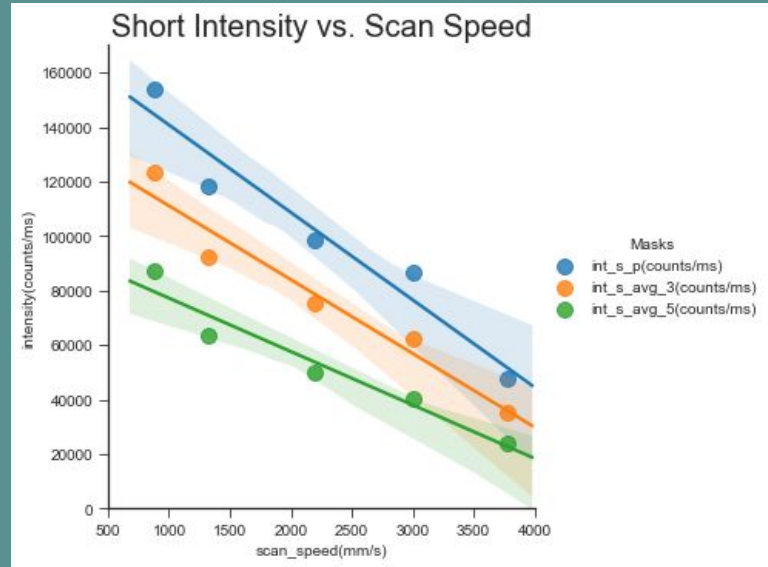
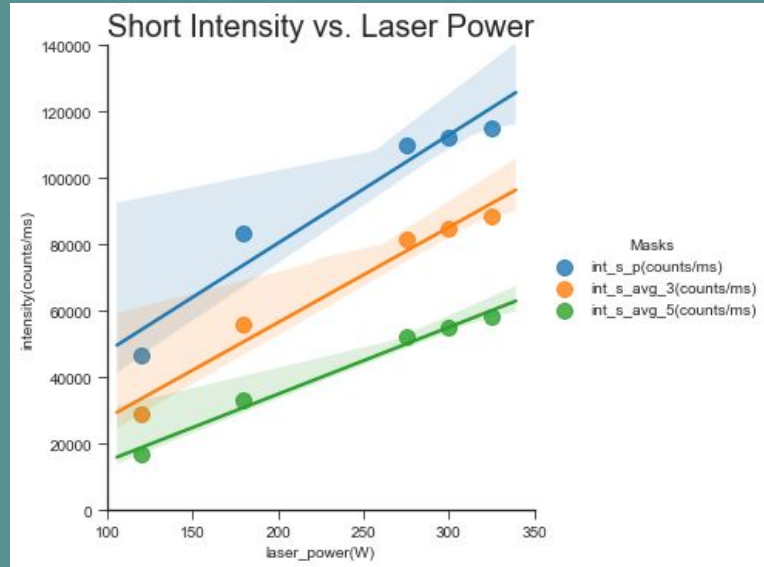
Section 6B: Print Parameters & Melt Pool Metrics Correlations

Print Parameters vs. Melt Pool Metrics

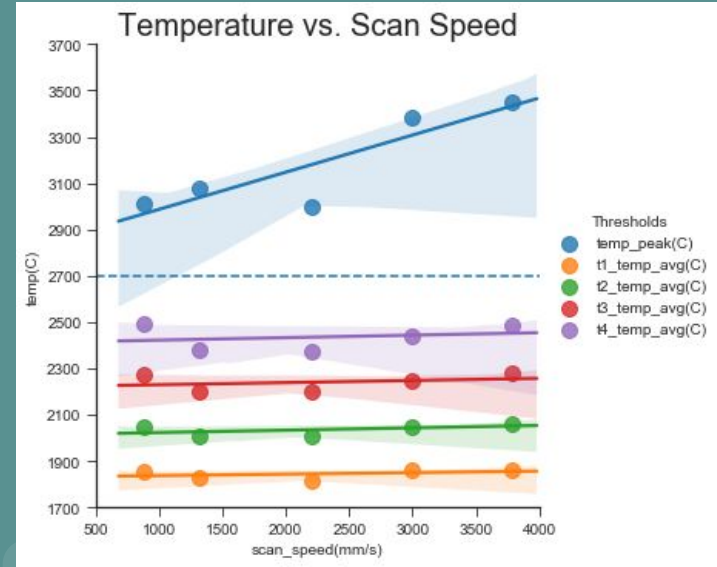
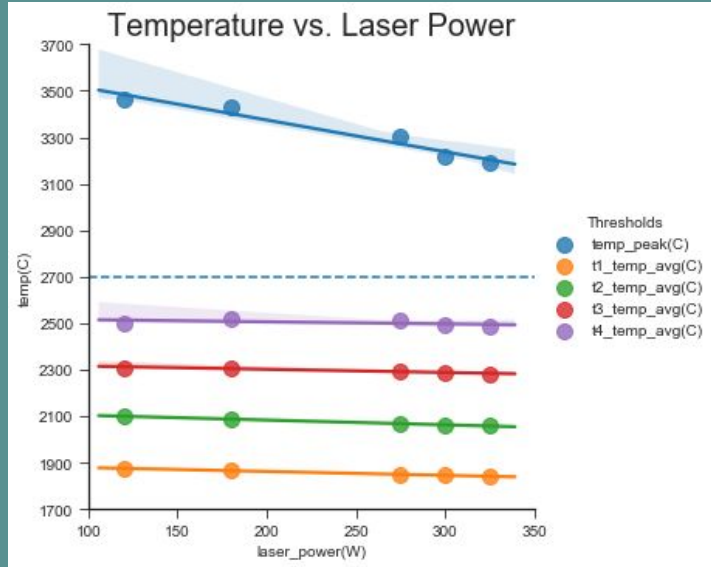
- Long Intensity (avg 5x5) correlates with LED = 0.72
- When Laser Power is increased, Intensity increases, but when Scan Speed is increased, Intensity decreased.
 - This trend follows conventional wisdom that the more energy output by the laser, the brighter the melt pool while the faster the laser is scanned, the more mass the laser has to melt and therefore the reflected light/energy is less.
- When Laser Power is increased, the Peak Temperature decreases, but when the Scan Speed is increased, the Peak Temperature increases.
 - At first, more Laser Power may seem to predict a higher Peak Temperature, but there is a theory that the additional energy is actually buried further down inside the part, not laterally on the surface of the powder bed, which then can't be detected by the sensor.
 - The increase in Peak Temperature due to an increase in Scan Speed hasn't been explained yet. Further testing must be down to try to explain this phenomenon.



Print Parameters vs. Melt Pool Metrics



Print Parameters vs. Melt Pool Metrics

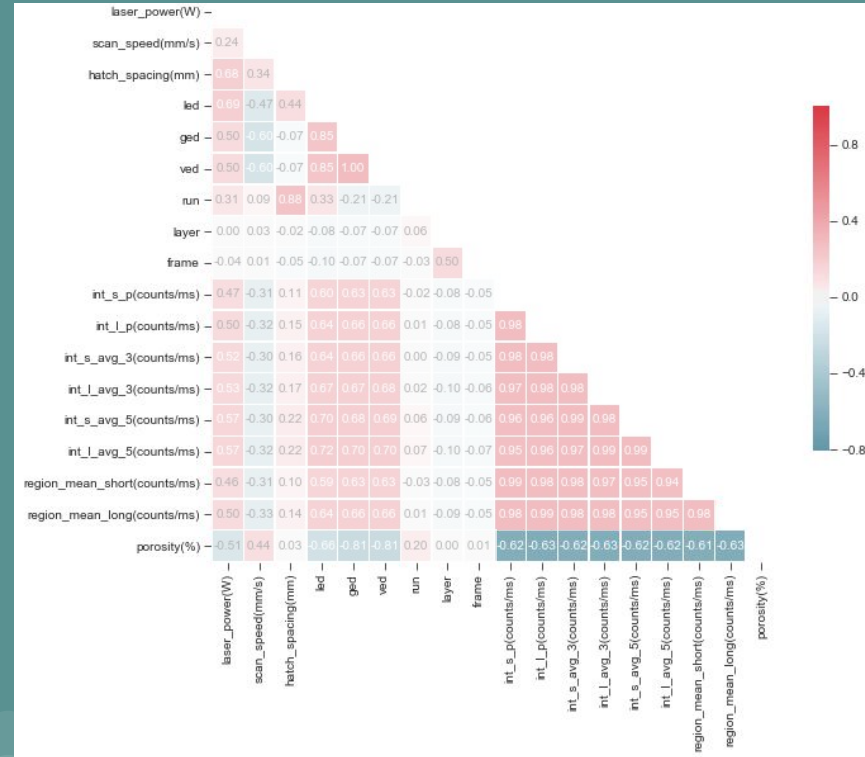




Section 6C: Melt Pool Metrics & Material Properties Correlations

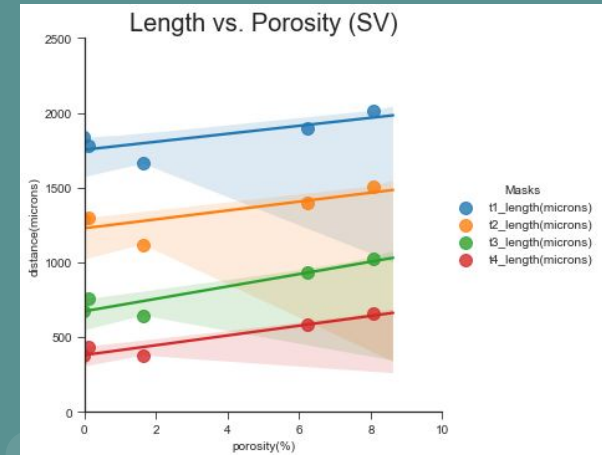
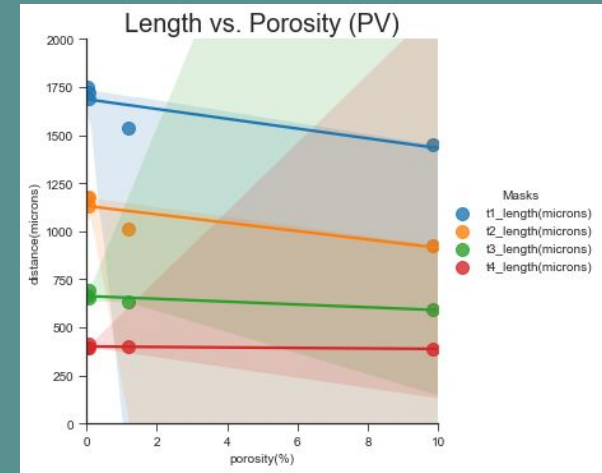
Melt Pool Metrics vs. Material Properties

- All the intensity columns inversely correlate roughly the same with Porosity (between -0.61 & -0.63)

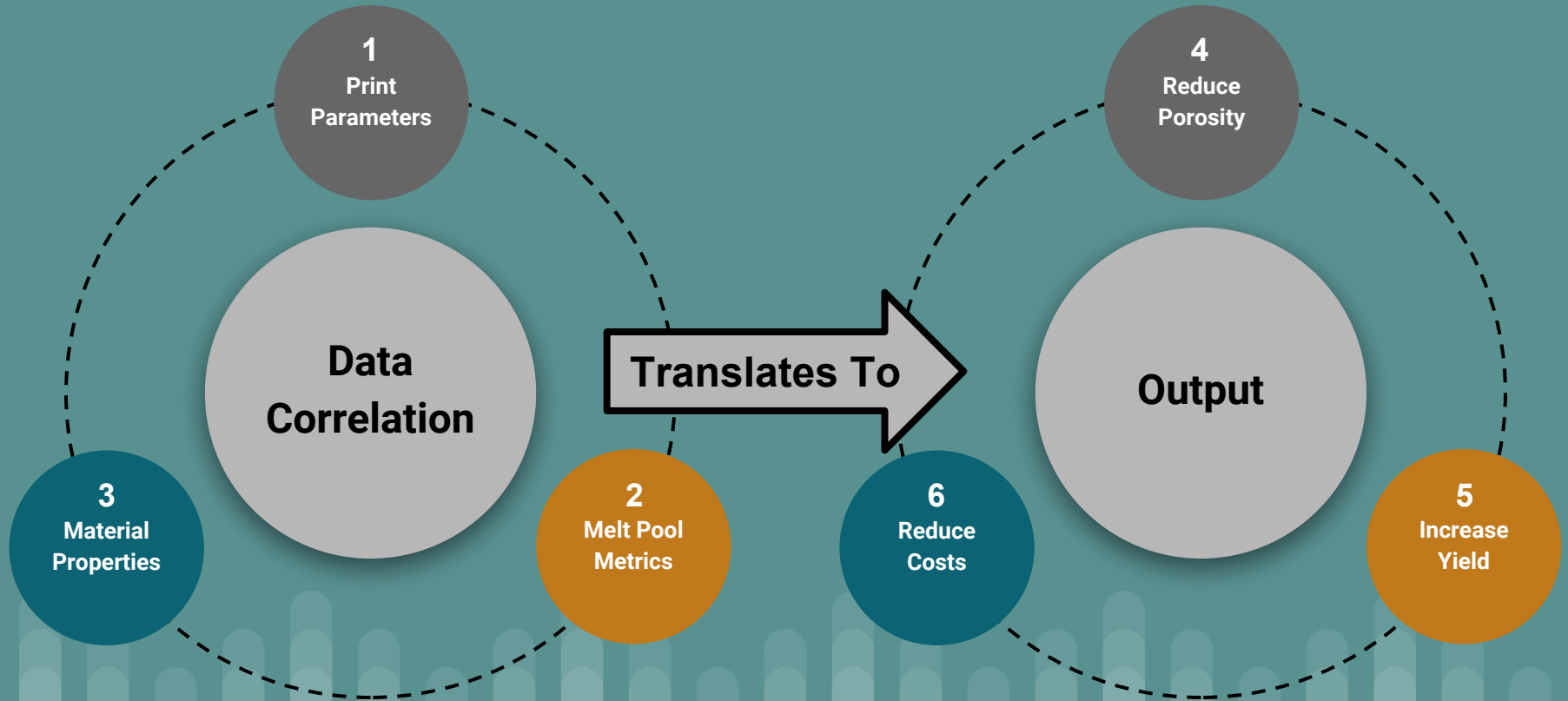





Melt Pool Metrics vs. Material Properties

- The Length of the Melt Pool when varying Laser Power has a real hard time correlating with Porosity, while the Length correlates much better with Porosity when varying the Scan Speed.
- This can be further tested by expanding the Print Parameter matrices for a future experiment.



Data Correlation





Section 6D: Conclusions

Conclusions

- Predicting Porosity with Print Parameters
 - The most highly correlated Parameters are GED and VED, with a correlation value of (-0.79)
- Predicting Porosity with Melt Pool Metrics
 - Long Peak Intensity Pixel value [int_l_p(counts/ms)] is the best indicator of Porosity (-0.63)
- Predicting Melt Pool Metrics with Print Parameters
 - Long Intensity Averaged by 5 [int_l_avg_5(counts/ms)] correlates fairly well with LED (0.72)
- By combining the assumptions, plots, and findings, the following table of variables should be expanded upon. Increase the size of the matrix of Print Parameters and analyze the correlation with Intensities and Porosity.

Print Parameters	Melt Pool Metrics	Material Properties
Laser Power	Intensities	Porosity
Scan Speed	-	-
LED, GED, VED	-	-

THE END

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