QUANTITATIVE EVALUATION OF NON-UNIFORM COATING

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CARESTREAM HEALTH

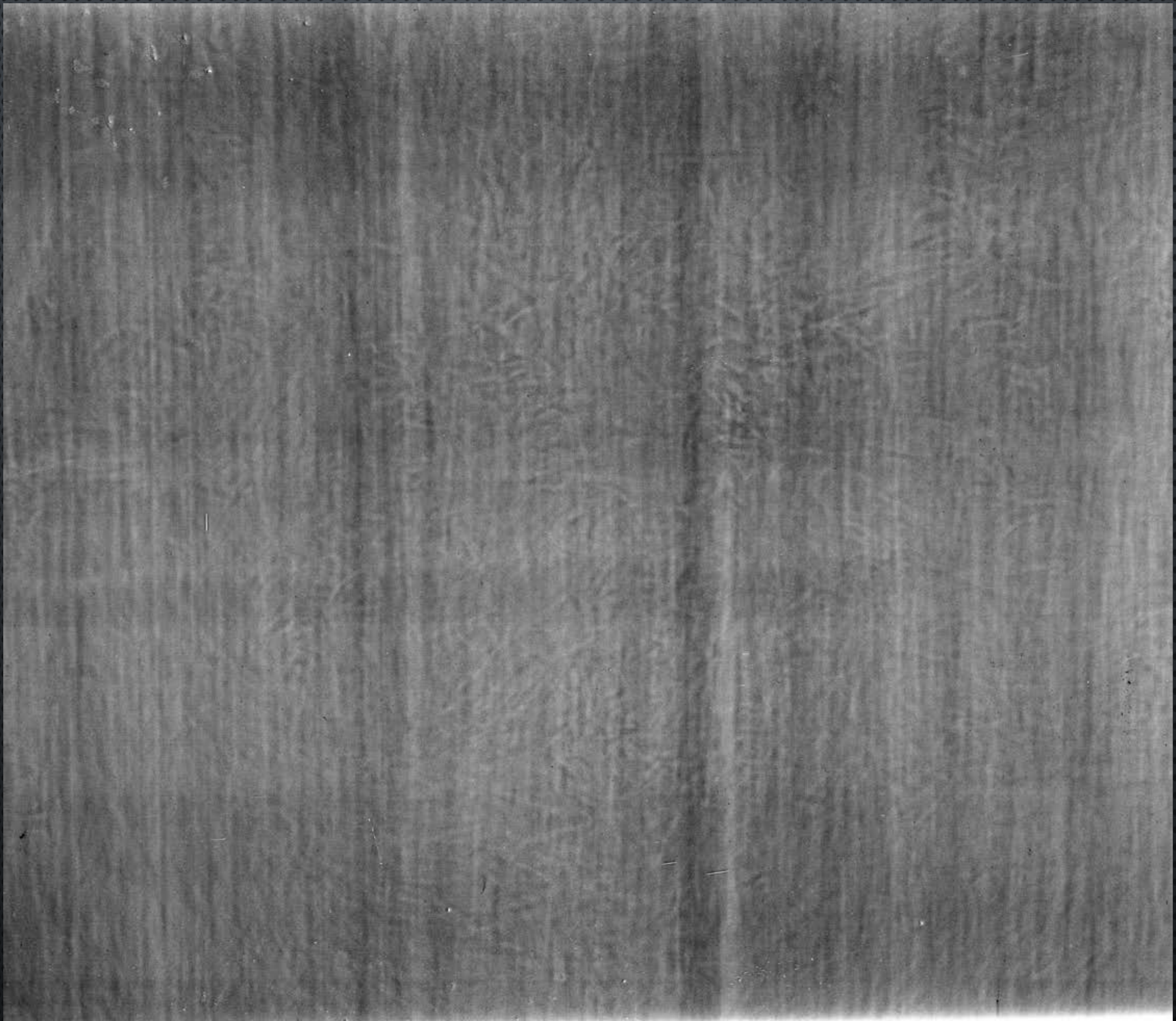
QUANTITATIVE EVALUATION OF NON-UNIFORM COATING

FLOW MOTTLE

- “Mottle is an irregular pattern of coverage variations on the surface of a coating that can vary in size up to several centimeters.”
- “(Flow Mottle) is believed to be caused by a nonuniform airflow blowing the coating around in early stages of the drying process.”

Gutoff, E. B. and Cohen, E. D. (2006) Introduction, in Coating and Drying Defects: Troubleshooting Operating Problems, Second Edition, John Wiley & Sons, Inc., Hoboken, NJ, USA

EXAMPLE



WHY DO ALL THIS WORK?

- THERE ARE TWO PRIMARY JUSTIFICATIONS FOR THIS RESEARCH.

1. MOTTLE IS A REJECTABLE DEFECT
2. LINE SPEED- FLOW MOTTLE IS BETTER AT LOWER LINE SPEEDS

CURRENT MEASUREMENT


6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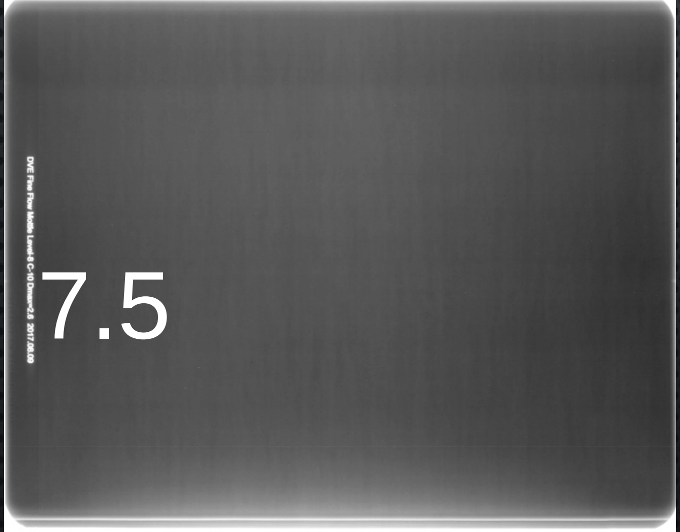
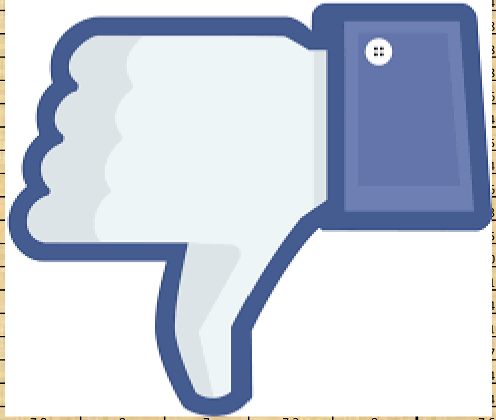

7.5


8

REPEATABILITY OF HUMANS

Per Sample Average	
Stdev	Spread
0.30	0.73

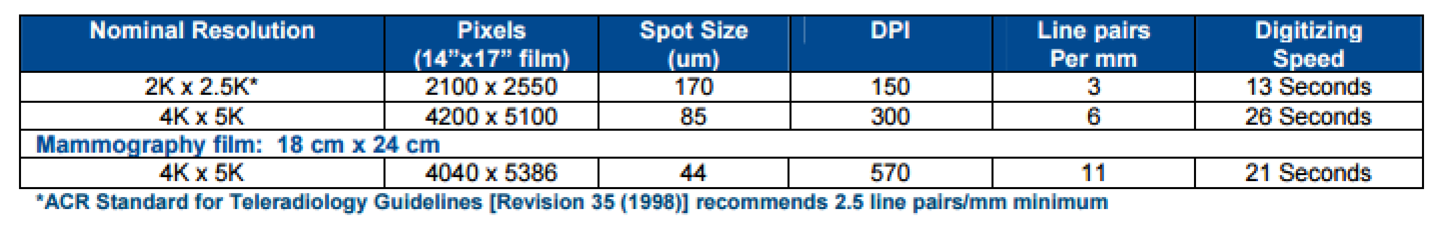
Sample #	Person #1	Person #2	Person #3	Person #4	Person #5	Person #6	Average	Stdev	Spread
1	7.2	7.3	8	7	7.3	7.5	7.4	0.34	1.00
2	6	7		6	6	6	6.2	0.45	1.00
3	8	7.8		8	8	8.5	8.1	0.26	0.70
4	7.5	7.5		7	7.5	7.5	7.4	0.22	0.50
5	7	7.1		7	7.1	8	7.2	0.43	1.00
6	7.1	7.6	7.6	7.2	7.5	7.5	7.4	0.21	0.50
7	8	7.7	7.6	7	7.7	8	7.7	0.37	1.00
8	7.5	7.6	7.6	7.2	7.3	7	7.4	0.24	0.60
9	7.2	7.7	7.5	7	7.3	7.5	7.4	0.25	0.70
10	7.5							0.23	0.60
11	7							0.39	1.00
12	7							0.39	1.00
13	8							0.24	0.50
14	6							0.55	1.10
15	7.3							0.22	0.60
16	7.5							0.36	1.00
17	7.2							0.24	0.60
18	7.5							0.15	0.30
19	7.2							0.23	0.50
20	7.5							0.23	0.60
21	7							0.08	0.20
22	8							0.22	0.50
23	7.5							0.22	0.50
24	8							0.13	0.30
25	7.5							0.33	0.80
26	7.5							0.25	0.70
27	7.2							0.40	1.00
28	7.5	7.8	8	7	7.3	8	7.6	0.40	1.00
29	6	7		6.5	6.2	6.9	6.5	0.43	1.00
30	6.5	7.1		6.5	6	6	6.4	0.45	1.10
31	6.7	7		7	6	6	6.5	0.51	1.00
32	7	7.1		7	6.8	6	6.8	0.45	1.10
33	6	7		7	6.5	6	6.5	0.50	1.00
34	7.2	7.5	7.5	7.2	7	7.5	7.3	0.21	0.50
35	7.5	7.6	8	7.5	7.8	8	7.7	0.23	0.50
36	7	7.4		7	7.5	8	7.4	0.41	1.00
37	7	7.3		7	7	7.5	7.2	0.23	0.50
38	7.5	7.6	7.5				7.5	0.06	0.10
39	7.5	7.6		7.5	7.5	7.5	7.5	0.04	0.10
40	6.5	7	6		7	7.5	6.8	0.57	1.50
41	8	7.8	7.5	7.5	7.5	7.5	7.6	0.22	0.50
42	8	7.6	8	7.5	7.5	7.5	7.7	0.25	0.50
43	6.5	7.1		7	6.5	6	6.6	0.44	1.10
44	6.5	7.1		7	6.5	6	6.6	0.44	1.10



HOW CAN WE DO THIS BETTER

VIDAR SCANNER

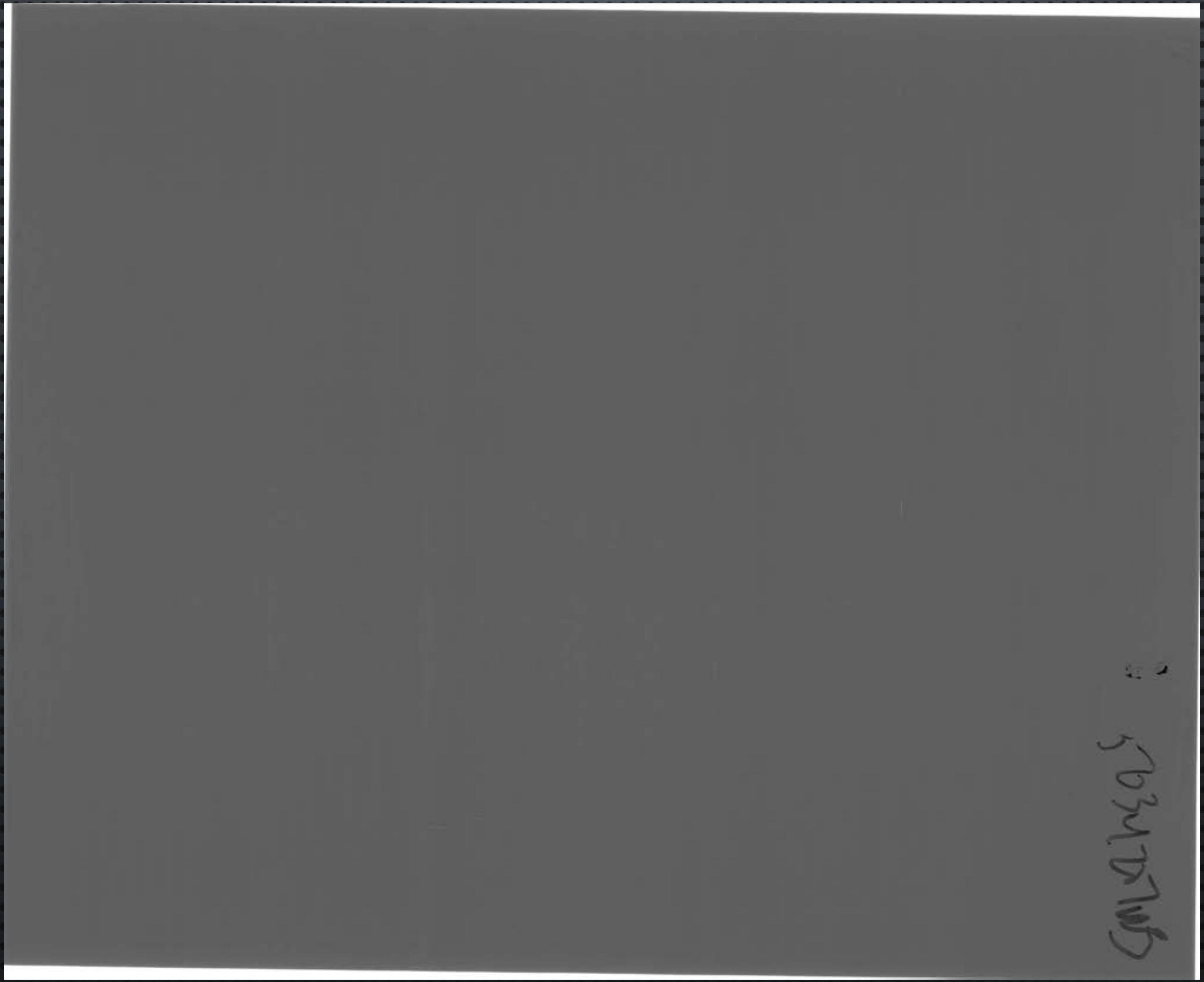
After experimenting with flatbed scanners without success, I found that Vidar manufactures scanners for digitizing X-Ray film. This Vidar Scanner retails for $21,000. Without proof this would work, we bought one on ebay for $500.



Nominal Resolution	Pixels (14"x17" film)	Spot Size (um)	DPI	Line pairs Per mm	Digitizing Speed
2K x 2.5K*	2100 x 2550	170	150	3	13 Seconds
4K x 5K	4200 x 5100	85	300	6	26 Seconds
Mammography film: 18 cm x 24 cm					
4K x 5K	4040 x 5386	44	570	11	21 Seconds

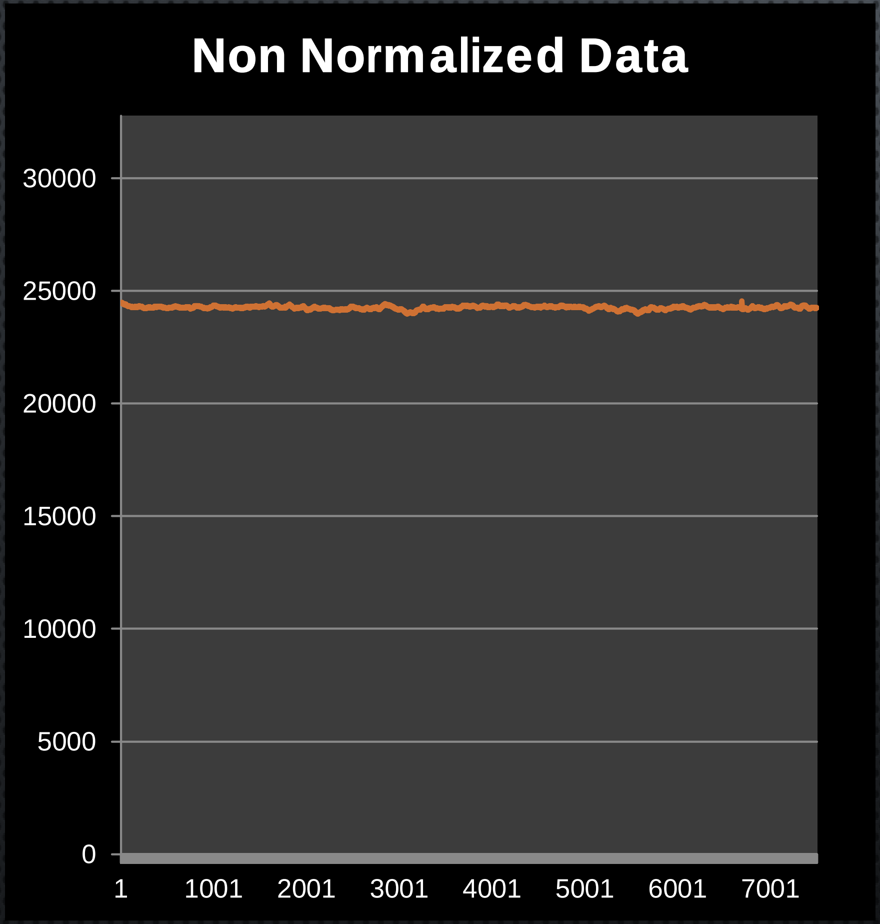
***ACR Standard for Teleradiology Guidelines [Revision 35 (1998)] recommends 2.5 line pairs/mm minimum**

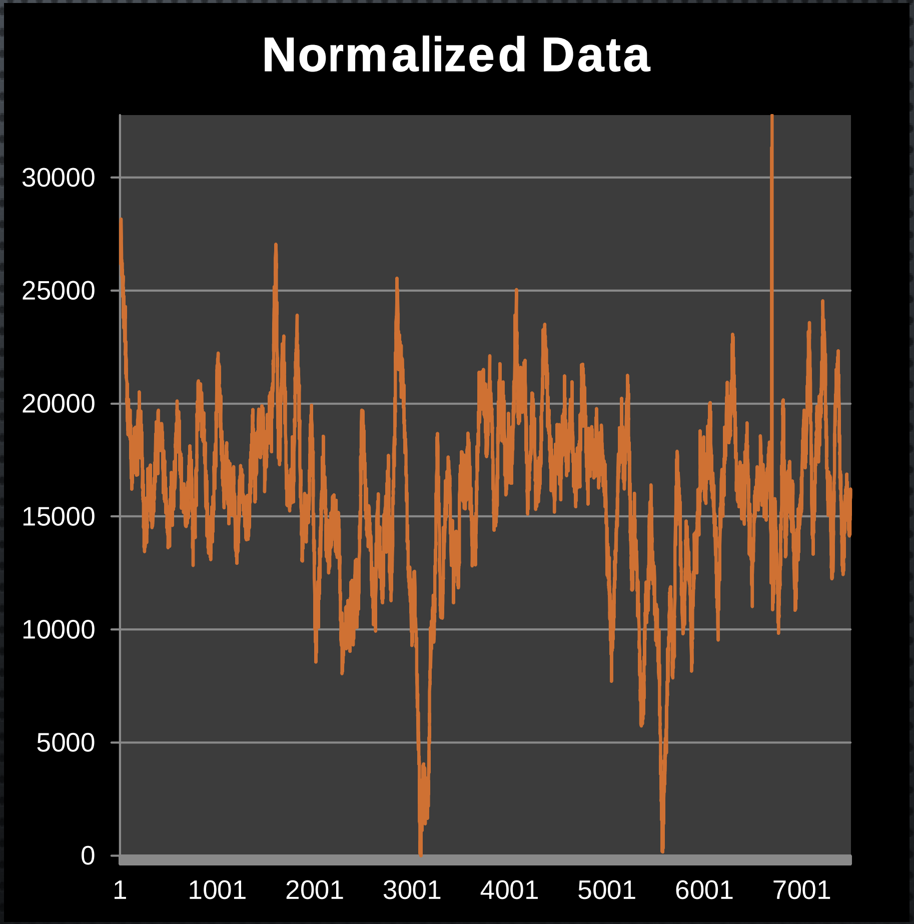
RESULT:



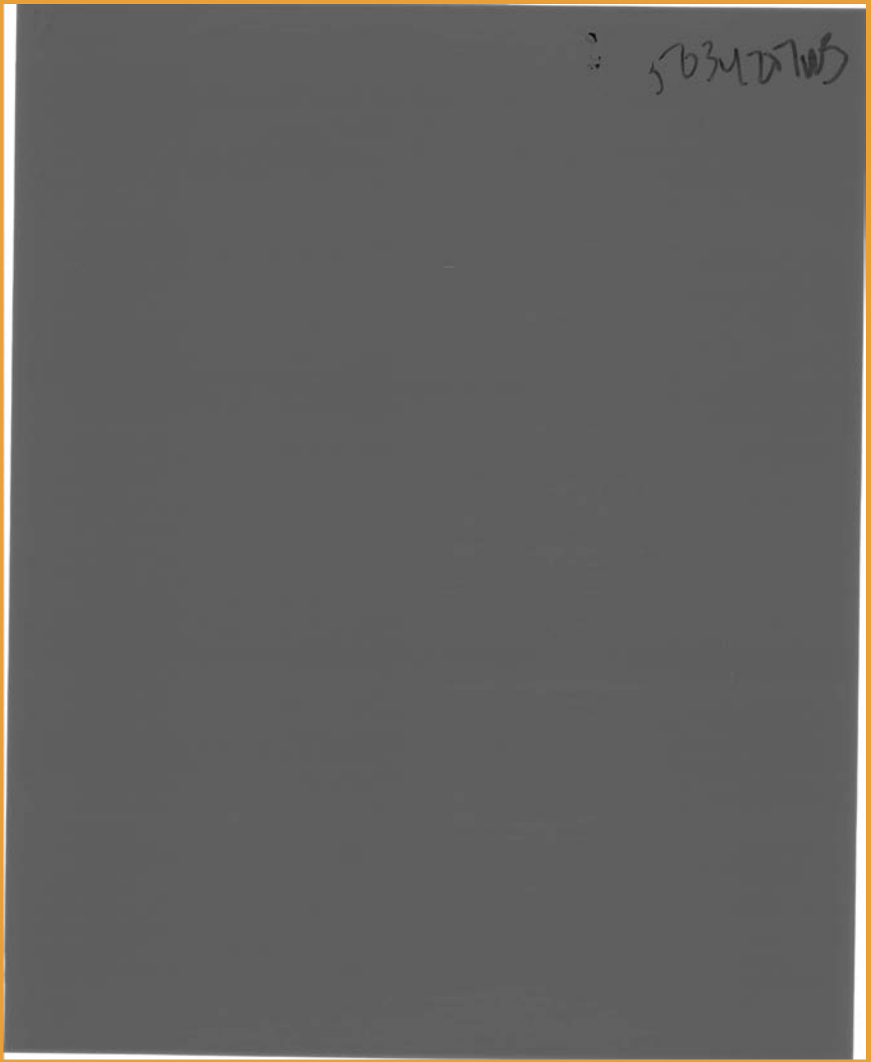
THE FIRST STEP WAS VISUALIZING THE PROBLEM

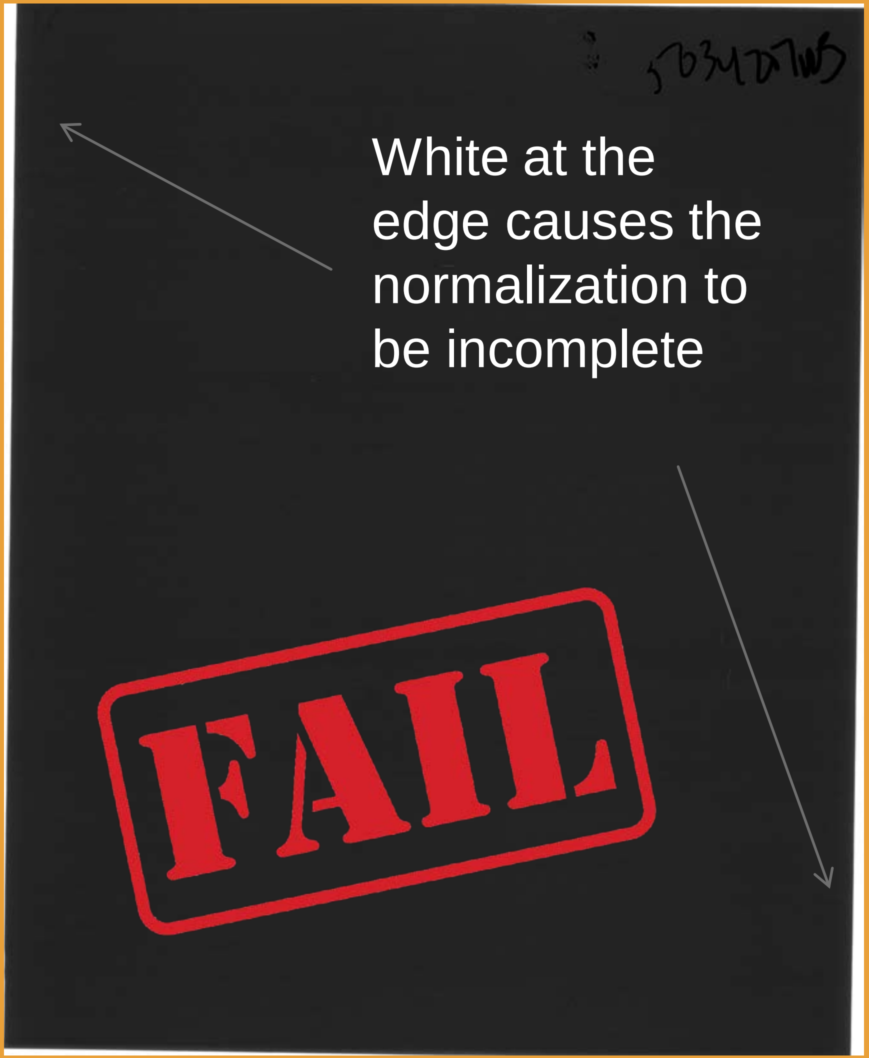
- TO ENABLE US TO ACTUALLY SEE WHAT WE WERE DEALING WITH WE HAD TO DIGITALLY ENHANCE THE DEFECT. THIS WAS DONE BY NORMALIZING THE PIXEL VALUES.





NORMALIZED IMAGE

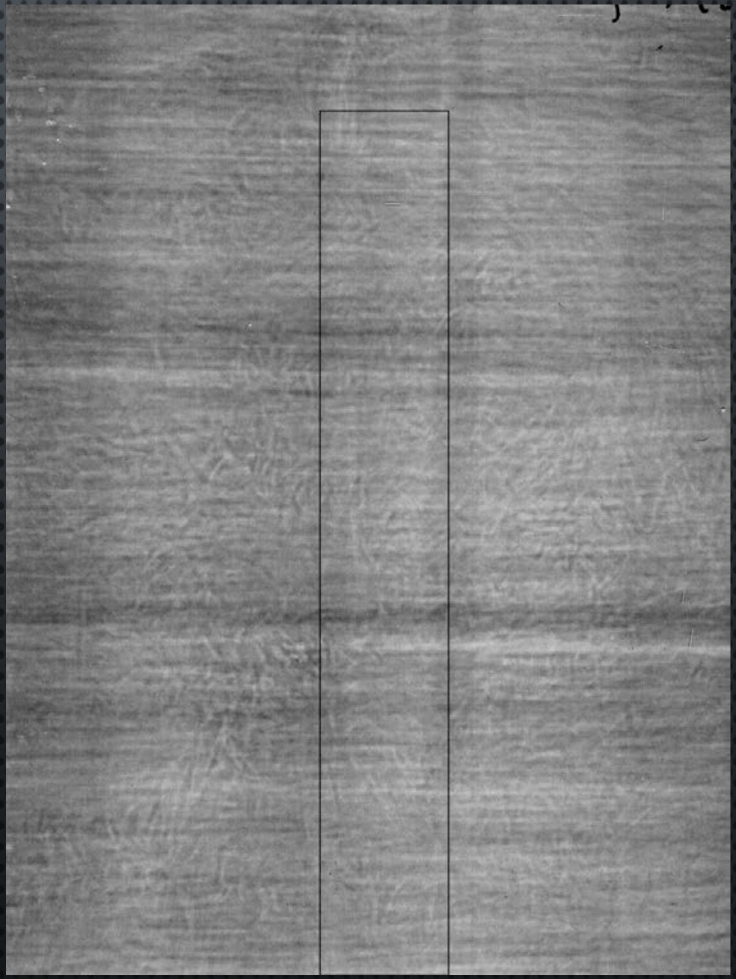




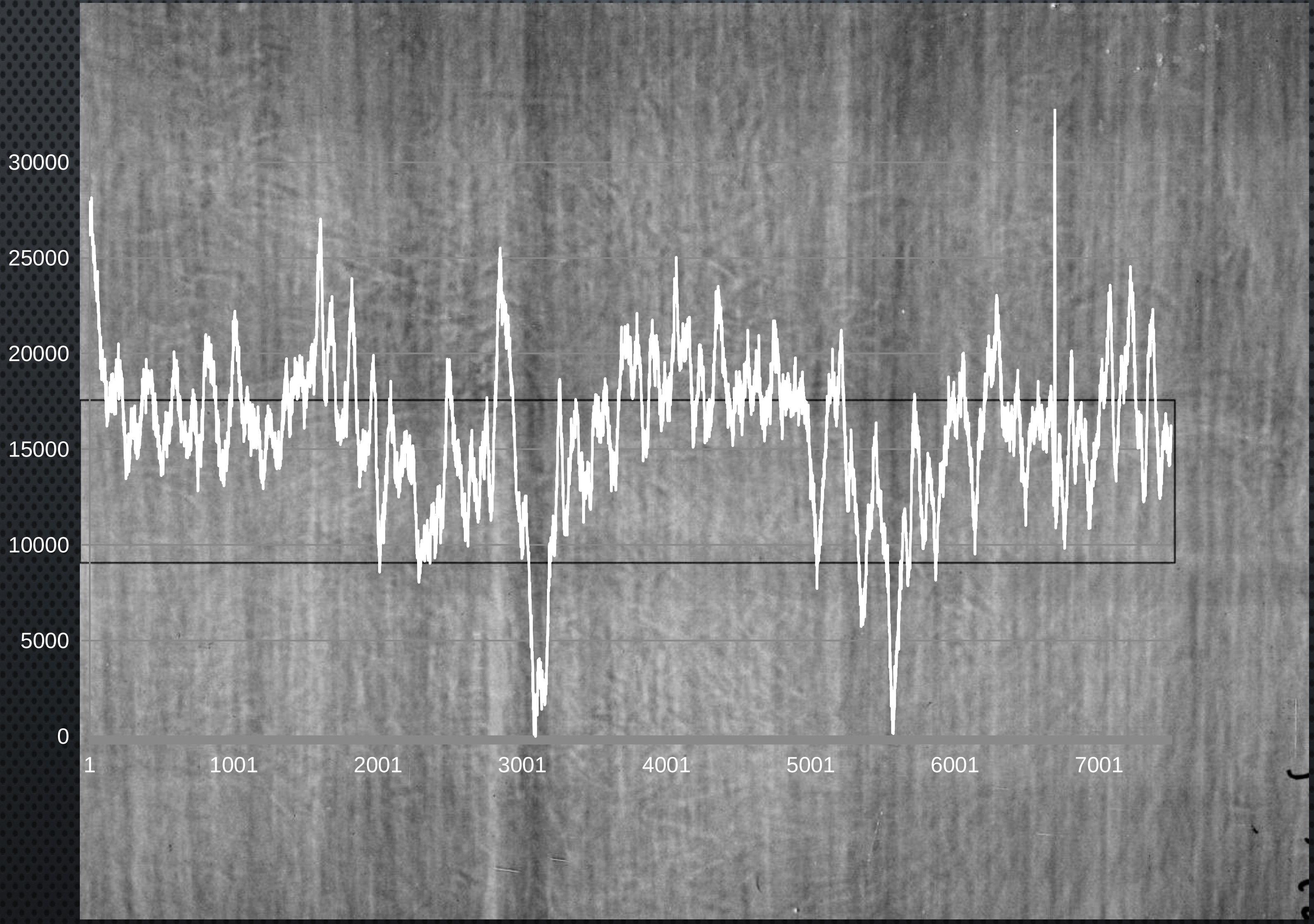
White at the edge causes the normalization to be incomplete

NORMALIZED IMAGE

When one inch was removed from each edge before normalization, the process worked as intended.



EVALUATING DENSITY CROSSWEB



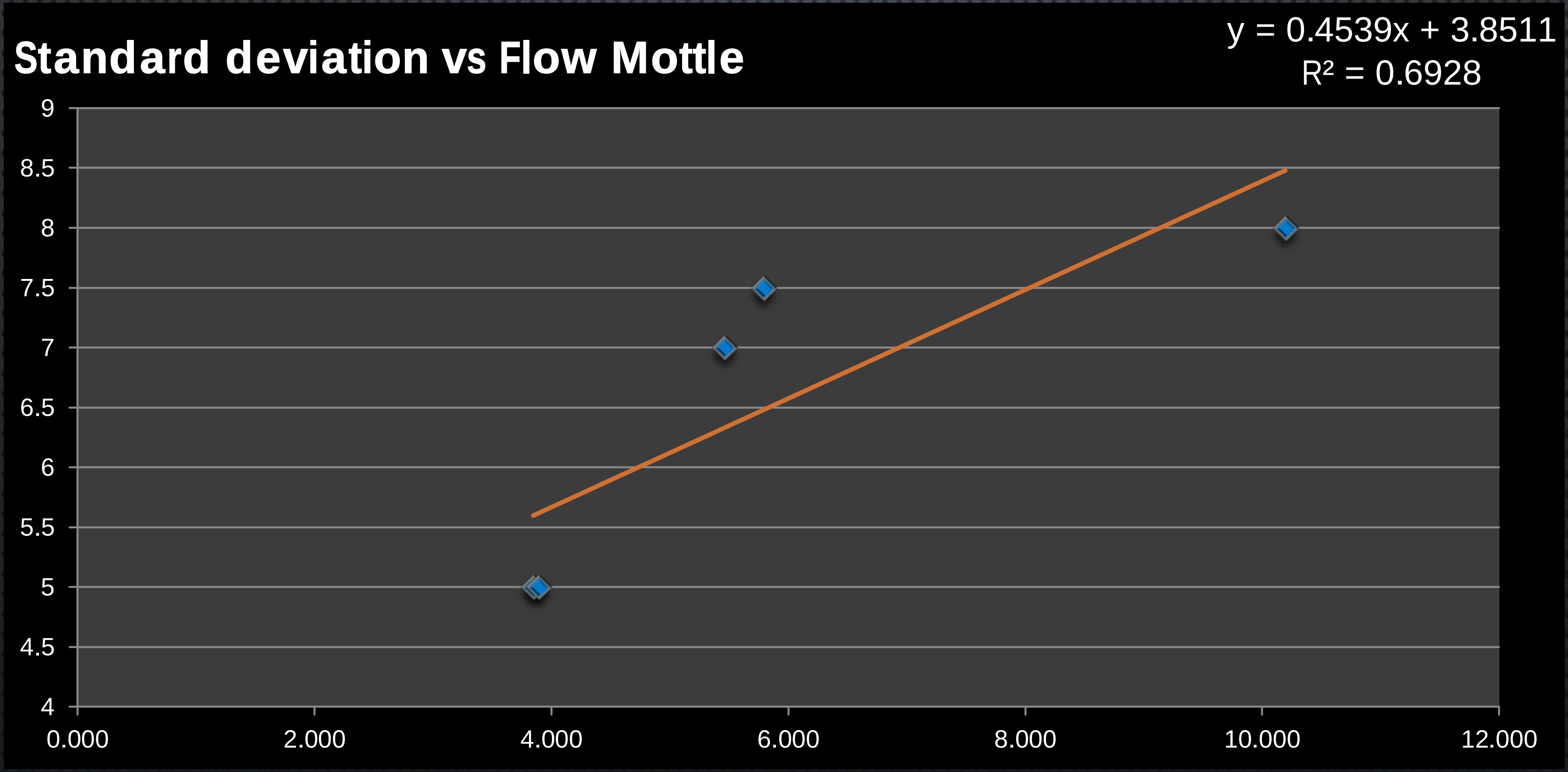
WHAT DO WE DO WITH THE DATA?

3 Theoretical methods

- Standard Deviation
- Line Slope
- Step Height

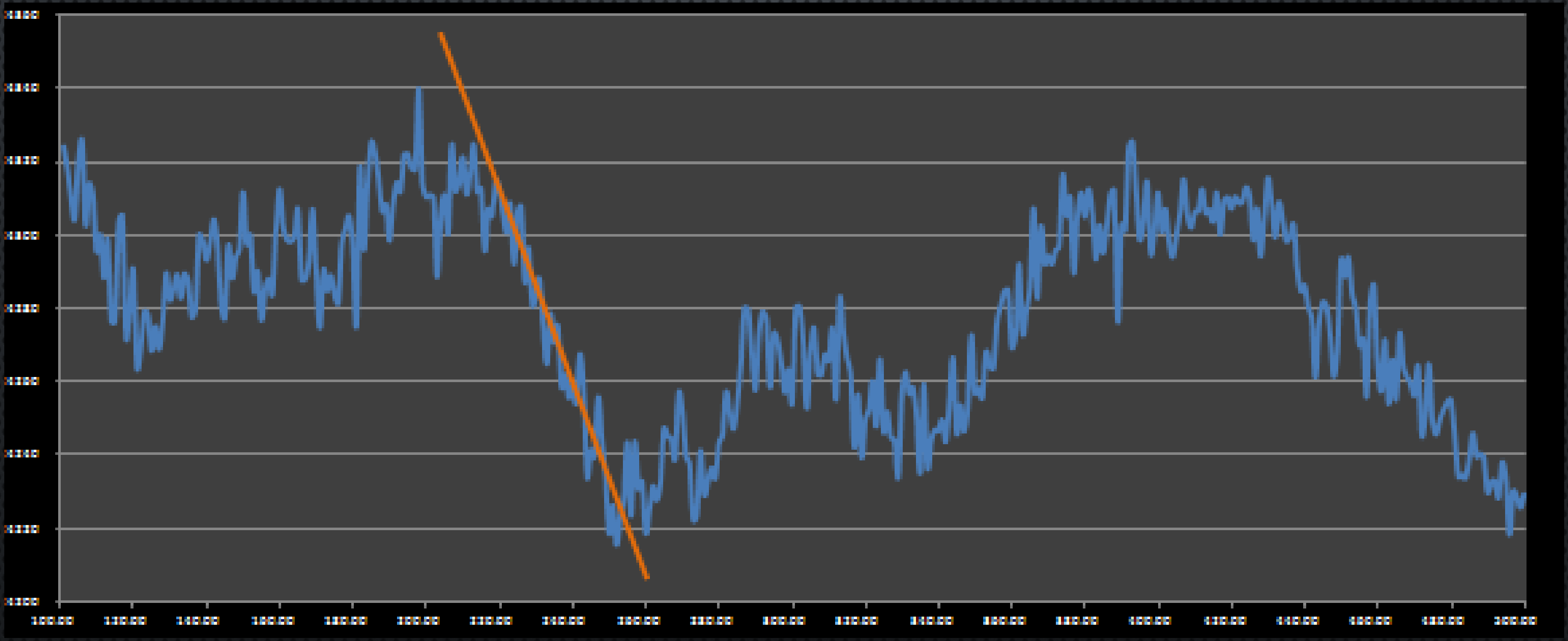
STANDARD DEVIATION METHOD

- THE THEORY WAS THAT SINCE THE DEFECT WAS CHARACTERIZED BY RANDOM VARIATION IN TRANSPARENCY, THAT A SIMPLE STANDARD DEVIATION OF THE VALUES IN DENSITY WOULD CORRESPOND TO MOTTLE.



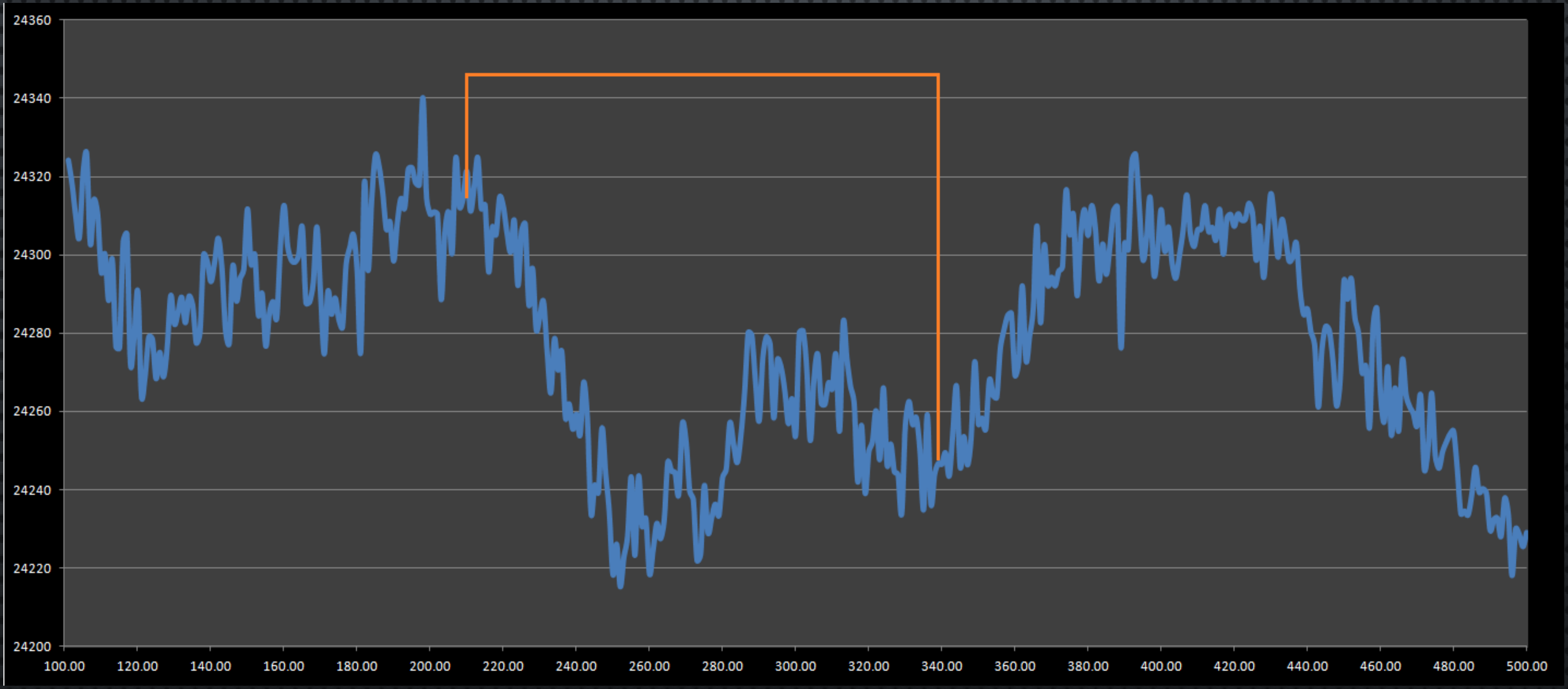
SLOPE METHOD

- THIS WORKS BY EXAMINING THE SLOPE OF THE LINE OVER SMALL REGIONS ACROSS THE ENTIRE LENGTH OF THE SHEET. IF THE SLOPE OF THE LINE IS GREAT, IT REPRESENTS A RAPID CHANGE IN DENSITY OVER A SHORT DISTANCE.

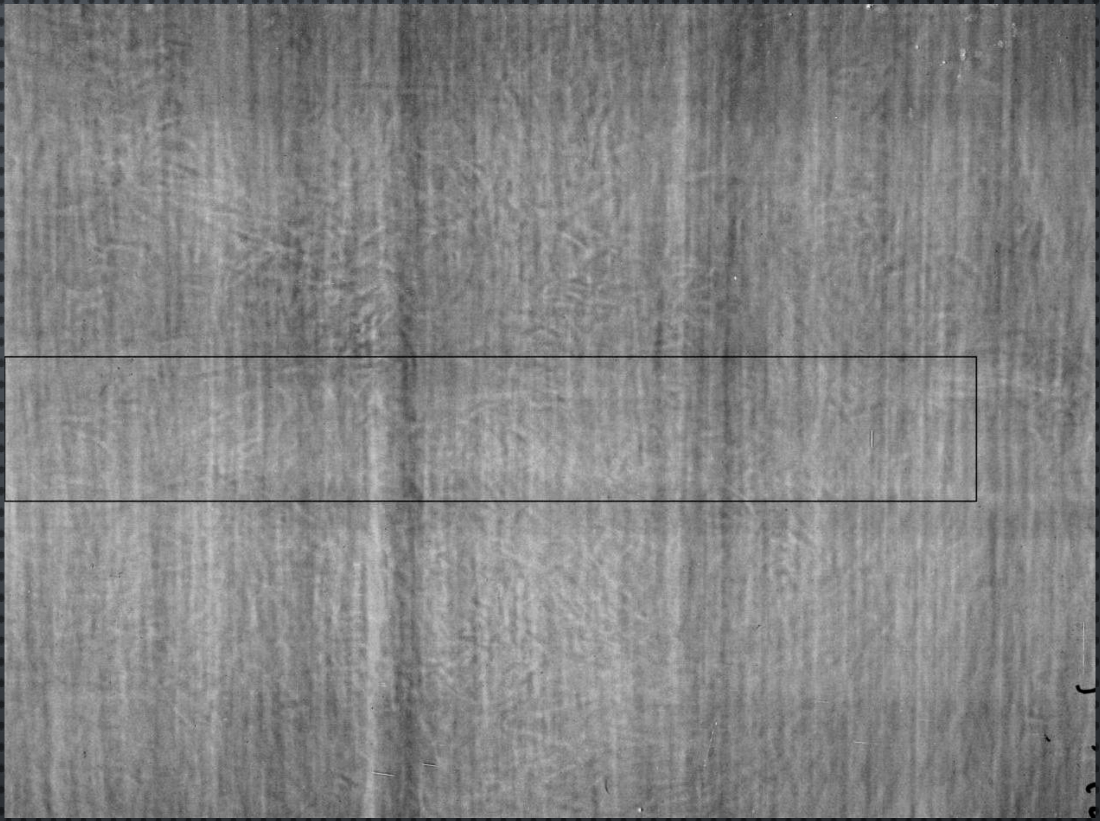


STEP HEIGHT

- THIS WORKS BY TAKING DATA POINTS A FIXED DISTANCE APART (~1/5") AND MEASURING THE AMPLITUDE OF THE DENSITY DIFFERENCE. IF IT EXCEEDS A THRESHOLD OF 60 THEN IT GETS COUNTED AS A TALLY. THIS COUNT CAN THEN BE CORRELATED TO MOTTLE GRADING.



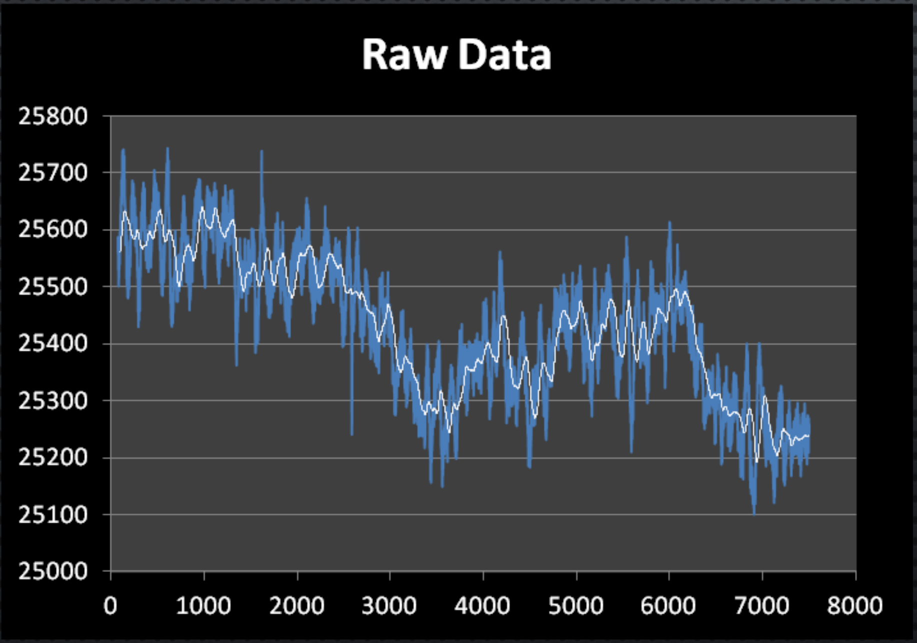
LEARNING #1

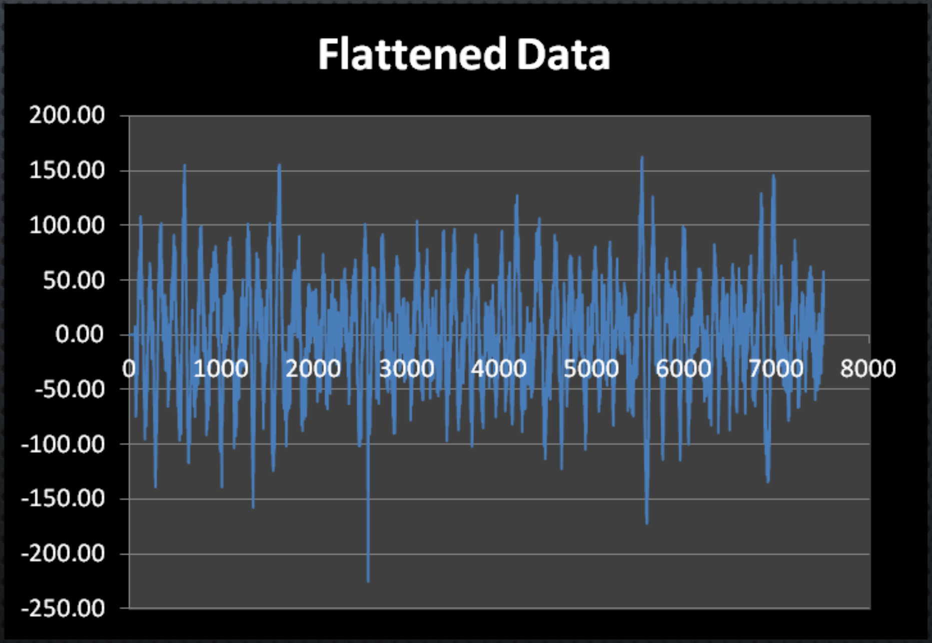


- THE DATASET USED WAS AN AVERAGE OF A SMALL SECTION DOWNWEB. INITIALLY, I HAD SELECTED ALMOST THE ENTIRE SHEET, BUT THIS AVERAGED OUT MUCH OF THE VARIATION IN THE SHEET. SO TOO LARGE OF AN AREA AND THE VARIATION IS AVERAGED OUT. TOO SMALL AND YOU ARE JUST LOOKING AT NOISE.

LEARNING #2

- THE VARIATION ACROSS A SHEET CAN BE QUITE LARGE (~2%) RELATIVE TO FLOW MOTTLE AND SKEWS THE DATA. TO ELIMINATE THIS I CREATED A MOVING AVERAGE TO REMOVE THIS LONG TERM DRIFT AND ISOLATE THE SHORT TERM VARIABILITY.





USER INTERFACE

- Using ImageJ I created a macro to analyze the image for variations in density cross web. It rotates the image 90°, selects a region of interest (ROI), and averages the downweb density of all the pixels in the downweb line. This will give us crossweb variation for a 2 inch wide strip down the center of the web excluding the edges.

USER INTERFACE

- A colleague of mine took over where I fell short and enabled the macro to process all images stored in a particular folder and then move them to an archive folder
- He then created a VBA macro in excel to take all of the processed image data and run it through our algorithm to assign it a flow mottle value.
- With these macros we are able to process dozens of sheets by pressing two buttons and walking away.

OPTIMIZING

- 42 SHEETS WERE SCANNED IN DUPLICATE AND GRADED BY 6 CERTIFIED INSPECTORS
- EACH SHEET TESTED CREATED WAS 4,200 DATA POINTS.
- TO PROCESS EACH SHEET TOOK 8,600 CALCULATIONS
- USING THE STEP HEIGHT MODEL THERE WERE THREE VARIABLE S TO SOLVE FOR.

1. MOVING AVERAGE DISTANCE- HOW MANY POINTS TO AVERAGE ACROSS
2. AMPLITUDE THRESHOLD -HOW HIGH DOES THE INTESNITY VARIATION NEED TO BE TO COUNT AS A VISIBLE DEFECT
3. SPACING DISTANCE- HOW FAR APART ARE THE STEPS.

OPTIMIZING

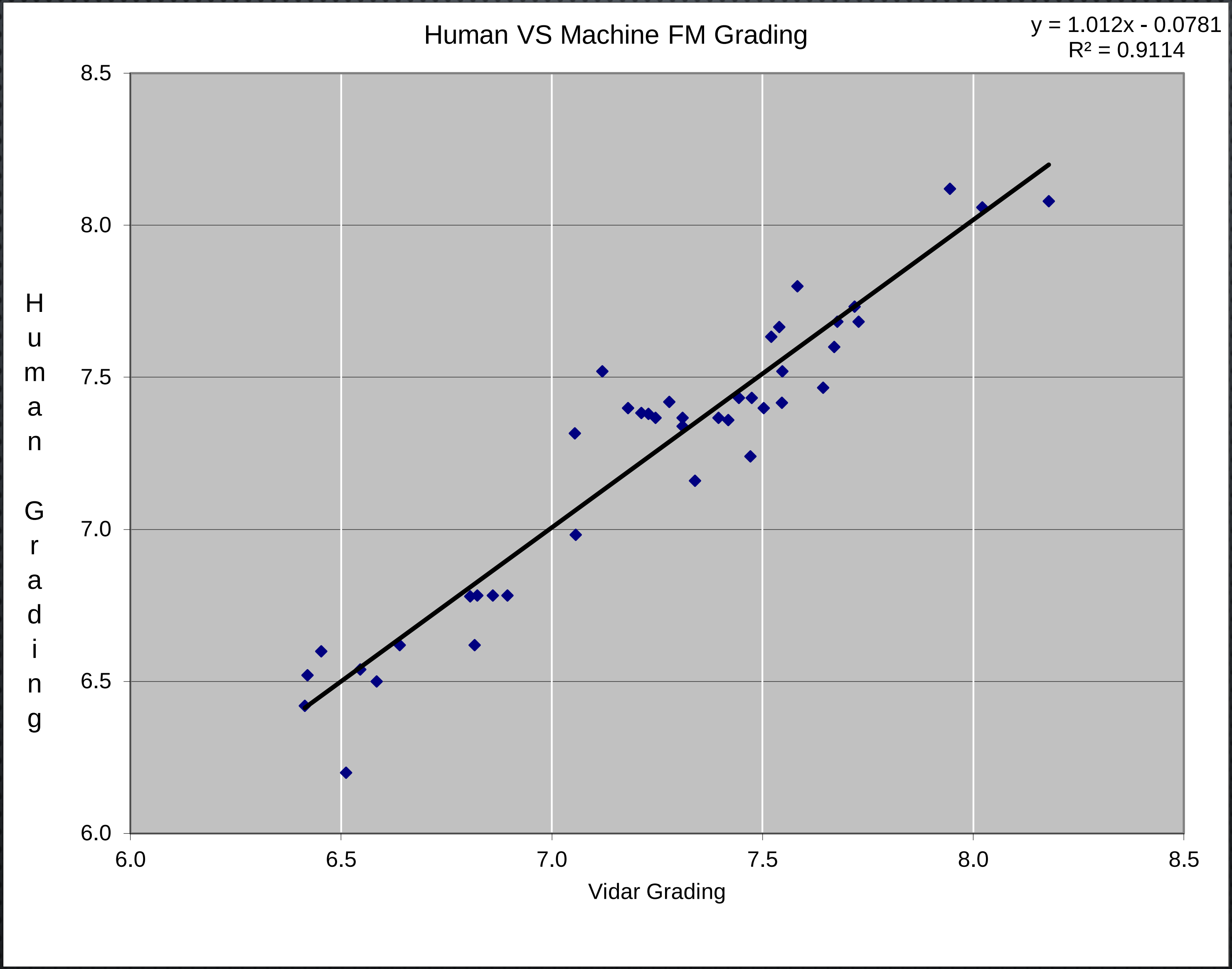
- Excel has built in functions to handle this

1. Goal seek only handles one variable at a time
2. Solver-doesn't handle complex formulas

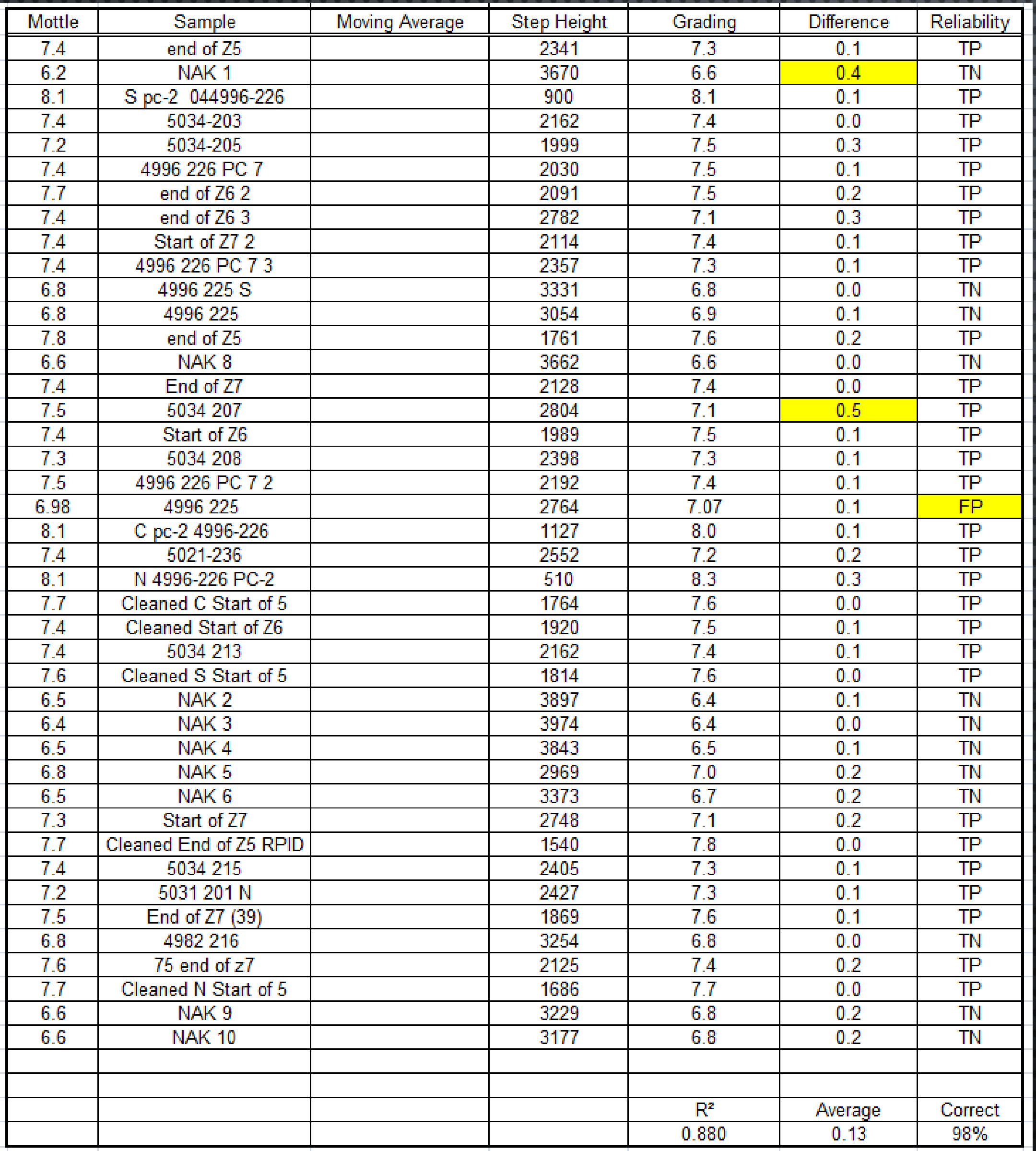
So I used brute force and wrote my own macro to evaluate the 84 scans at over 74,000 conditions.

This ended up being 54 billion calculations which took ~1 week to compute.

RESULTS


Human VS Machine FM Grading
y = 1.012x - 0.0781
R² = 0.9114
Human Grading
Vidar Grading
8.5
8.0
7.5
7.0
6.5
6.0
6.0
6.5
7.0
7.5
8.0
8.5

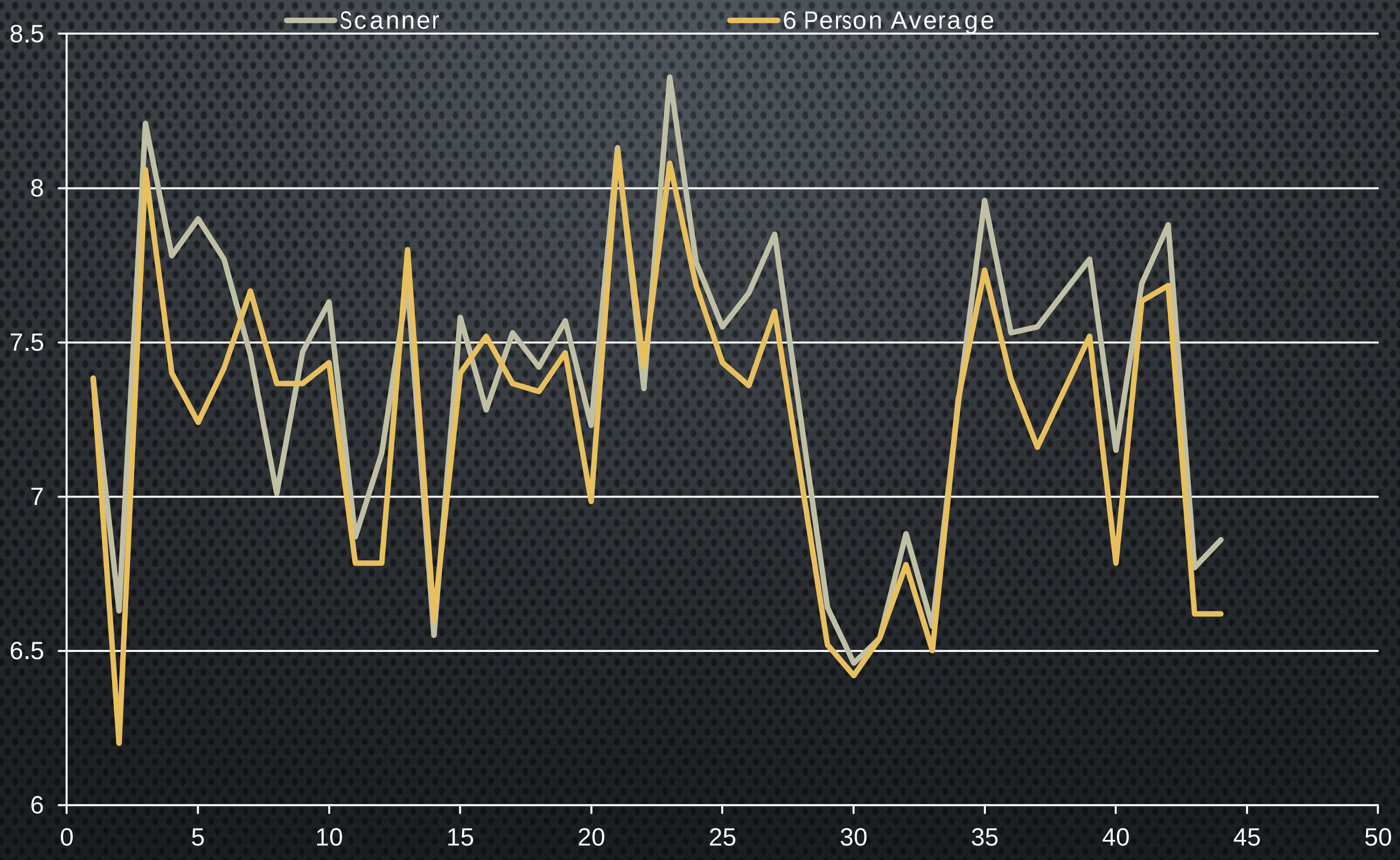
STEP HEIGHT



Mottle	Sample	Moving Average	Step Height	Grading	Difference	Reliability
7.4	end of Z5		2341	7.3	0.1	TP
6.2	NAK 1		3670	6.6	0.4	TN
8.1	S pc-2 044996-226		900	8.1	0.1	TP
7.4	5034-203		2162	7.4	0.0	TP
7.2	5034-205		1999	7.5	0.3	TP
7.4	4996 226 PC 7		2030	7.5	0.1	TP
7.7	end of Z6 2		2091	7.5	0.2	TP
7.4	end of Z6 3		2782	7.1	0.3	TP
7.4	Start of Z7 2		2114	7.4	0.1	TP
7.4	4996 226 PC 7 3		2357	7.3	0.1	TP
6.8	4996 225 S		3331	6.8	0.0	TN
6.8	4996 225		3054	6.9	0.1	TN
7.8	end of Z5		1761	7.6	0.2	TP
6.6	NAK 8		3662	6.6	0.0	TN
7.4	End of Z7		2128	7.4	0.0	TP
7.5	5034 207		2804	7.1	0.5	TP
7.4	Start of Z6		1989	7.5	0.1	TP
7.3	5034 208		2398	7.3	0.1	TP
7.5	4996 226 PC 7 2		2192	7.4	0.1	TP
6.98	4996 225		2764	7.07	0.1	FP
8.1	C pc-2 4996-226		1127	8.0	0.1	TP
7.4	5021-236		2552	7.2	0.2	TP
8.1	N 4996-226 PC-2		510	8.3	0.3	TP
7.7	Cleaned C Start of 5		1764	7.6	0.0	TP
7.4	Cleaned Start of Z6		1920	7.5	0.1	TP
7.4	5034 213		2162	7.4	0.1	TP
7.6	Cleaned S Start of 5		1814	7.6	0.0	TP
6.5	NAK 2		3897	6.4	0.1	TN
6.4	NAK 3		3974	6.4	0.0	TN
6.5	NAK 4		3843	6.5	0.1	TN
6.8	NAK 5		2969	7.0	0.2	TN
6.5	NAK 6		3373	6.7	0.2	TN
7.3	Start of Z7		2748	7.1	0.2	TP
7.7	Cleaned End of Z5 RPID		1540	7.8	0.0	TP
7.4	5034 215		2405	7.3	0.1	TP
7.2	5031 201 N		2427	7.3	0.1	TP
7.5	End of Z7 (39)		1869	7.6	0.1	TP
6.8	4982 216		3254	6.8	0.0	TN
7.6	75 end of z7		2125	7.4	0.2	TP
7.7	Cleaned N Start of 5		1686	7.7	0.0	TP
6.6	NAK 9		3229	6.8	0.2	TN
6.6	NAK 10		3177	6.8	0.2	TN
				R²	Average	Correct
				0.880	0.13	98%

The model was 98% accurate for dispositioning the rolls and on average varied by 0.13 FM units from the human average

RESULTS

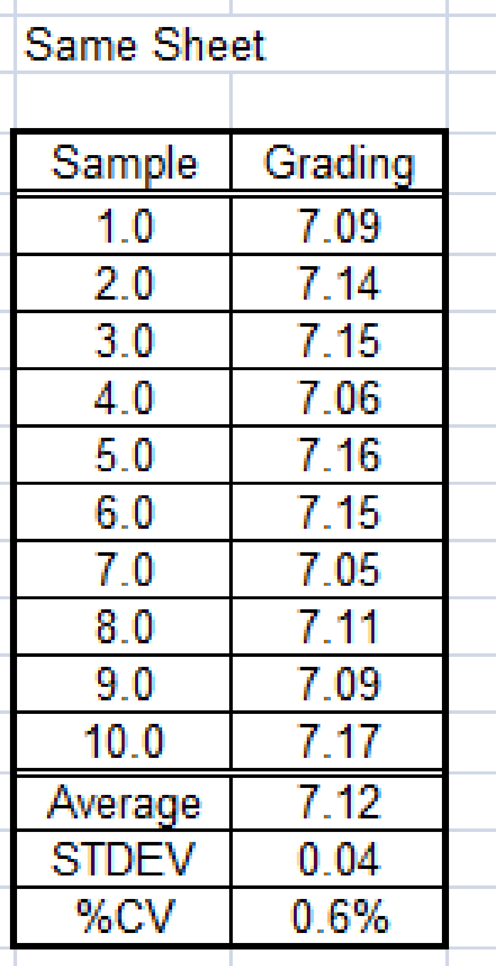

Scanner
6 Person Average
8.5
8
7.5
7
6.5
6
0
5
10
15
20
25
30
35
40
45
50

SUMMARY

- In today’s corporate environment, there is always a push towards continuous improvement. That is one of the main reasons this project was able to proceed. Identifying the contributing factors to mottle would allow the coater to run at an increased linespeed and reduce the cost per square meter. The scanner was purchased for ~2% of the price of a new scanner, while ImageJ was free and Excel was already on the computers. The cost of this project was virtually free.

REPEATABILITY

- We have done several tests to examine repeatability of the test along with consistency of the product with the following results.



Same Sheet

Sample	Grading
1.0	7.09
2.0	7.14
3.0	7.15
4.0	7.06
5.0	7.16
6.0	7.15
7.0	7.05
8.0	7.11
9.0	7.09
10.0	7.17
Average	7.12
STDEV	0.04
%CV	0.6%

REPEATABILITY

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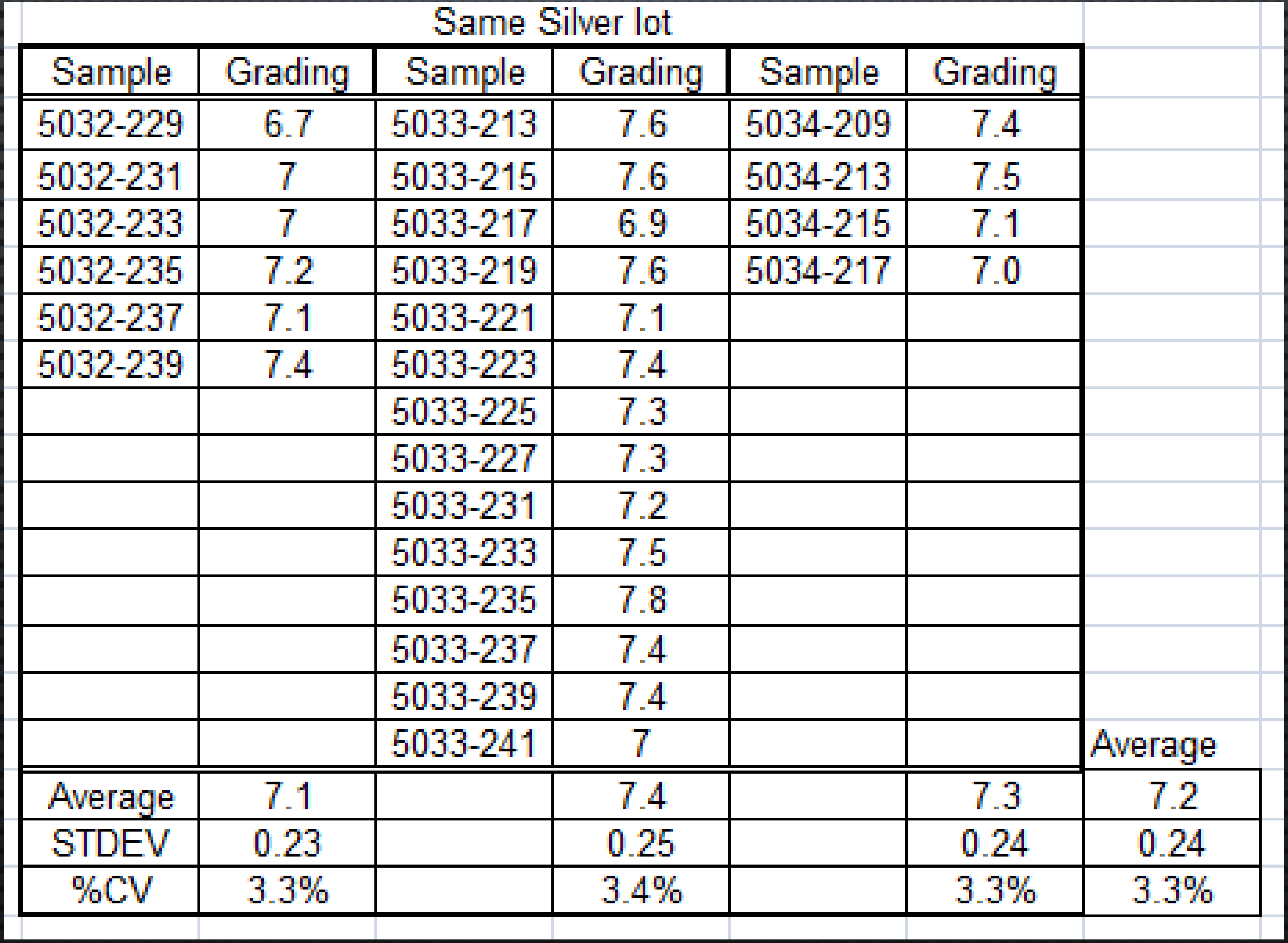


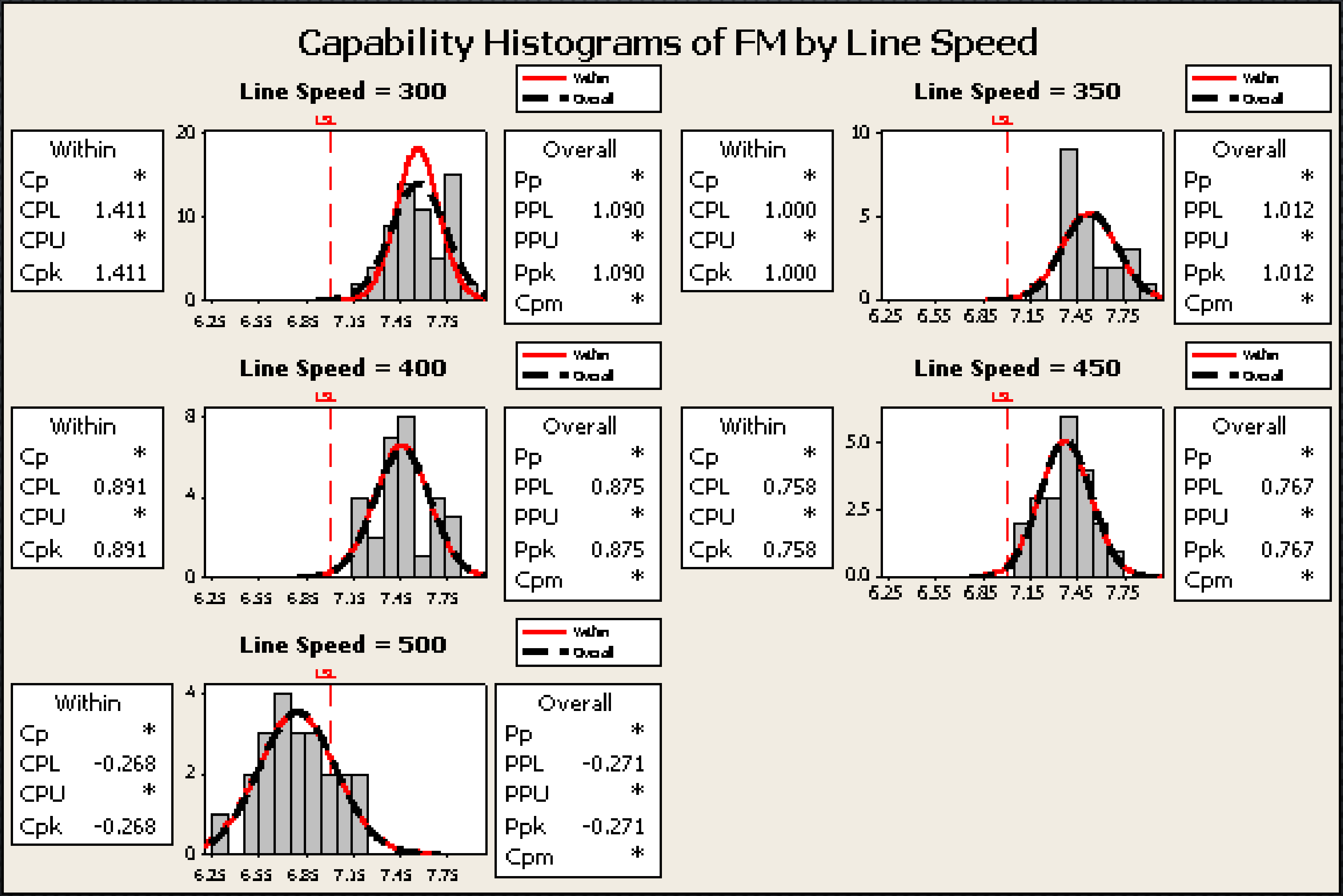
Same Silver lot

Sample	Grading	Sample	Grading	Sample	Grading	
5032-229	6.7	5033-213	7.6	5034-209	7.4	
5032-231	7	5033-215	7.6	5034-213	7.5	
5032-233	7	5033-217	6.9	5034-215	7.1	
5032-235	7.2	5033-219	7.6	5034-217	7.0	
5032-237	7.1	5033-221	7.1			
5032-239	7.4	5033-223	7.4			
		5033-225	7.3			
		5033-227	7.3			
		5033-231	7.2			
		5033-233	7.5			
		5033-235	7.8			
		5033-237	7.4			
		5033-239	7.4			
		5033-241	7			Average
Average	7.1		7.4		7.3	7.2
STDEV	0.23		0.25		0.24	0.24
%CV	3.3%		3.4%		3.3%	3.3%

PRACTICAL APPLICATION

- Now that we have accurate data on mottle, we can vary conditions to evaluate the effect on the defect.
- Some of the changes evaluated were line speed, fan speed, oven temperature, web path, coating thickness, and several more.

FLOW MOTTLE VS LINE SPEED



Capability Histograms of FM by Line Speed

Line Speed = 300

Within	
Cp	*
CPL	1.411
CPU	*
Cpk	1.411

Overall	
Pp	*
PPL	1.090
PPU	*
Ppk	1.090
Cpm	*

Line Speed = 350

Within	
Cp	*
CPL	1.000
CPU	*
Cpk	1.000

Overall	
Pp	*
PPL	1.012
PPU	*
Ppk	1.012
Cpm	*

Line Speed = 400

Within	
Cp	*
CPL	0.891
CPU	*
Cpk	0.891

Overall	
Pp	*
PPL	0.875
PPU	*
Ppk	0.875
Cpm	*

Line Speed = 450

Within	
Cp	*
CPL	0.758
CPU	*
Cpk	0.758

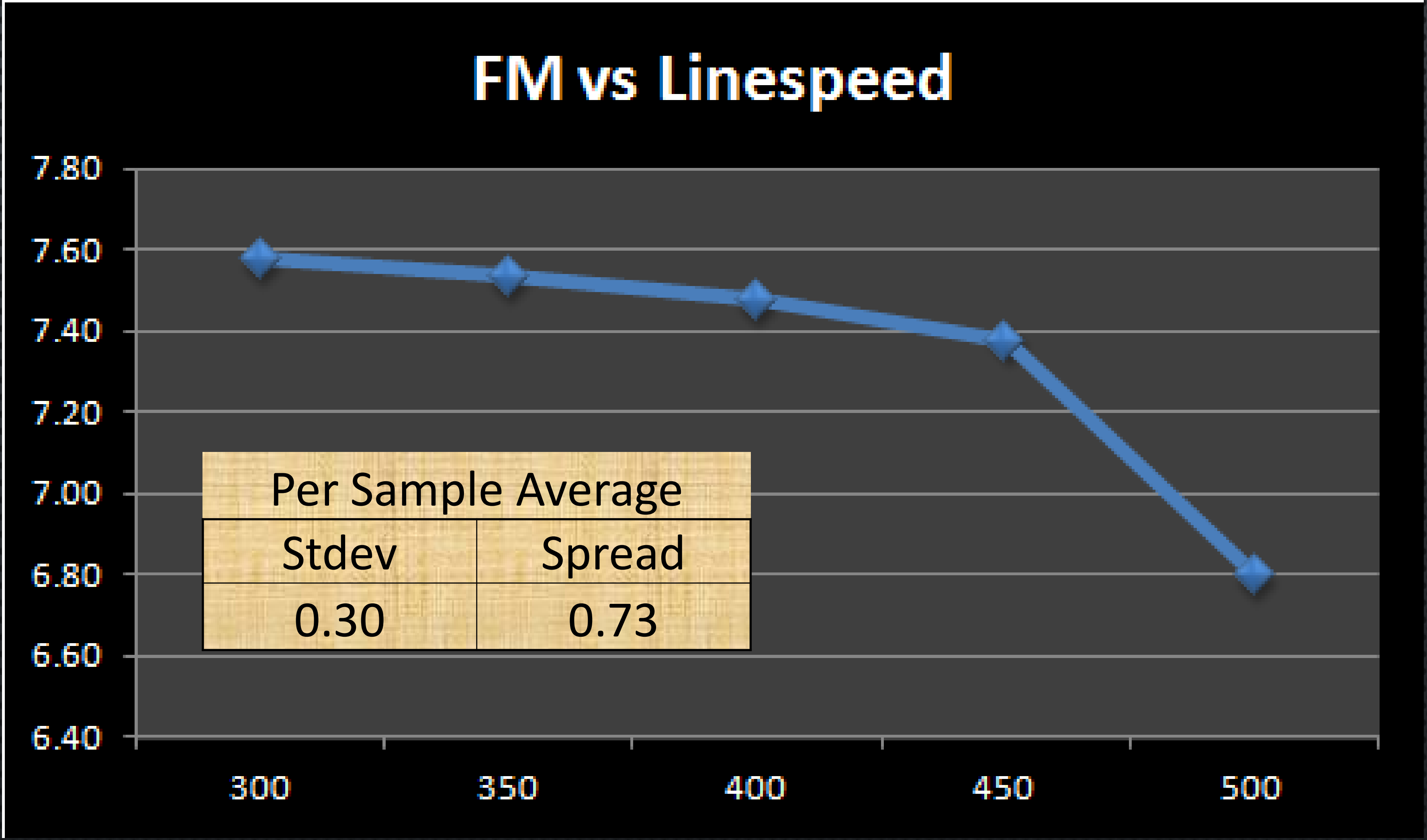
Overall	
Pp	*
PPL	0.767
PPU	*
Ppk	0.767
Cpm	*

Line Speed = 500

Within	
Cp	*
CPL	-0.268
CPU	*
Cpk	-0.268

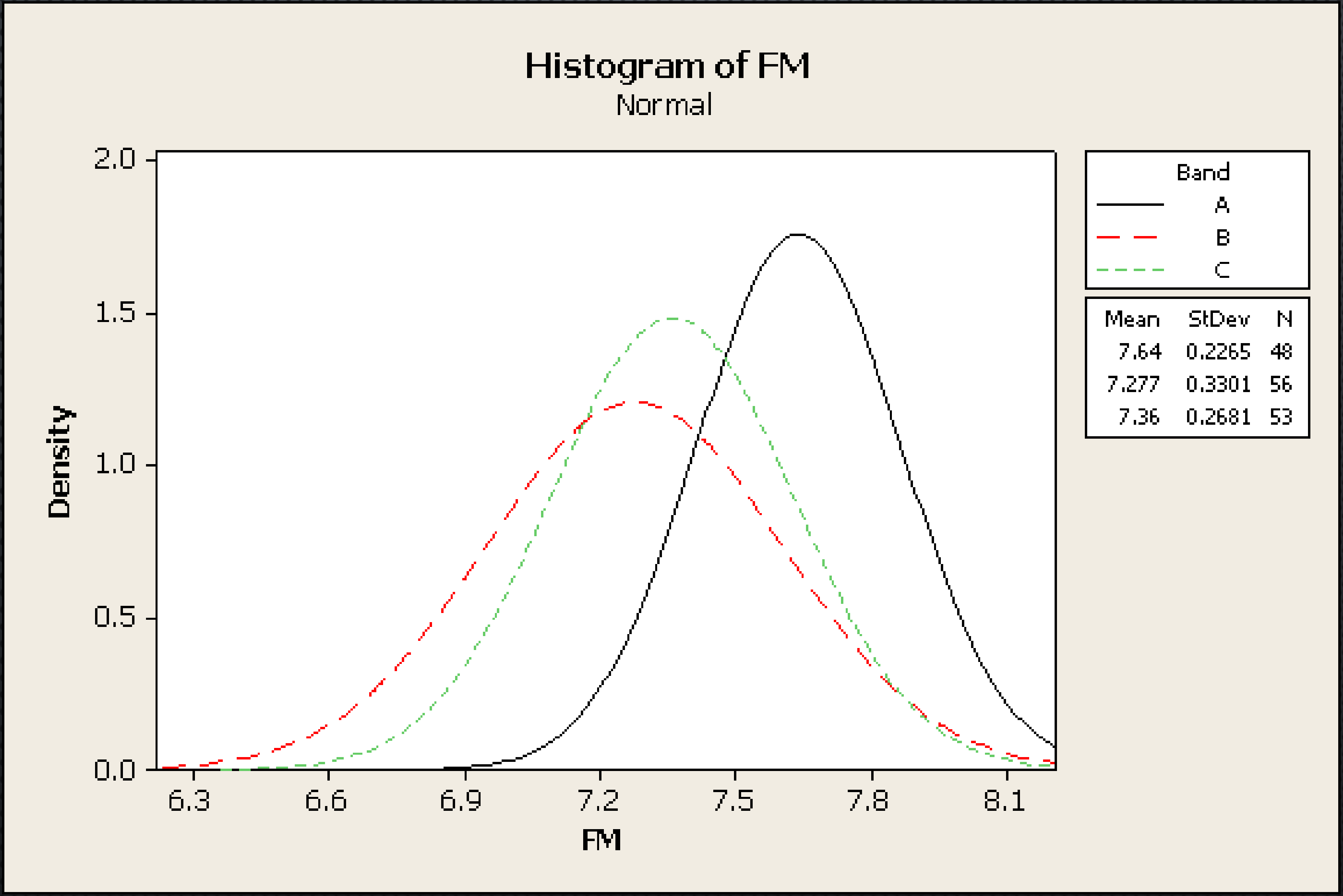
Overall	
Pp	*
PPL	-0.271
PPU	*
Ppk	-0.271
Cpm	*

FLOW MOTTLE VS LINE SPEED



Per Sample Average	
Stdev	Spread
0.30	0.73

CROSSWEB UNIFORMITY



WHAT'S NEXT

- This technology is still in its infancy at our plant. We have this equipment in the Analytical Lab and currently use it as supplementary testing. We have some evidence that this could be used to quantify line and streaks, white spots and, potentially imager cleanliness. We are also looking into using it to measure residual debris on a new product line.
- Once the full capabilities of this have been evaluated, then the possibility of implementing in production will be determined.

Carestream

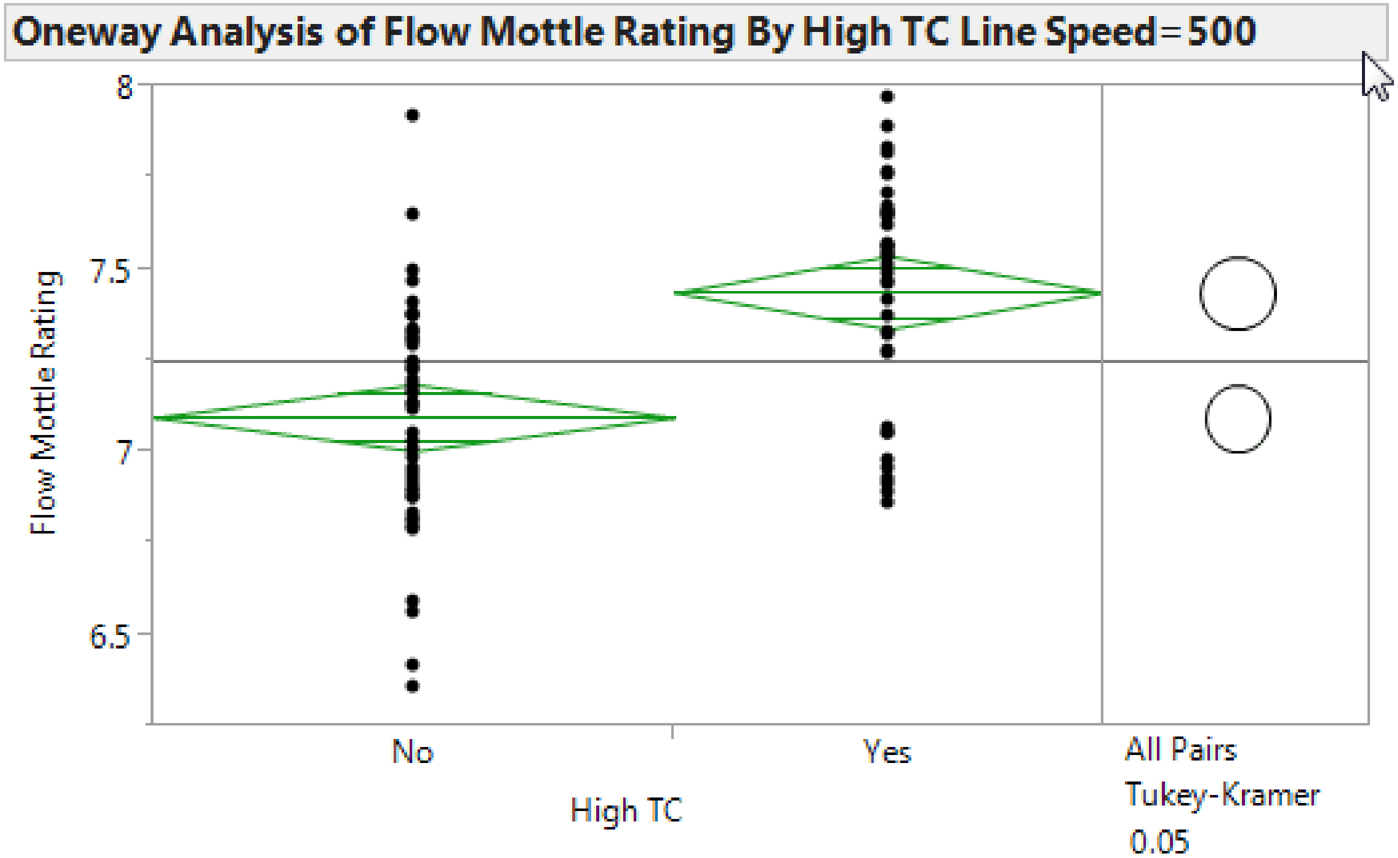
Contract Manufacturing

Precision Custom Coating Services

ACKNOWLEDGEMENTS

BENJAMIN RODRIGUEZ
ELLIOTT MECKLEY
JENNA SHERMAN
BLAINE WHISPELL

QUESTIONS?



Oneway Analysis of Flow Mottle Rating By High TC Line Speed=500

Carestream