Industrial Example: ANOVA

•Semiconductor Processing example: Photolithography Registration Improvements:

•***PROBLEM to SOLVE***: We are getting a 20% rework rate and 10% of contact layer wafers are getting rejected for failure to align.

We have an idea that we can improve this layer's alignment signal strength by changing the photoresist thickness. The alignment syestem siganl strength is based on thin films reflectivity.

DATA and background:

* Prolith simulations

* Reflectivity at 632nm

* CD swing curves for various oxide thickness

* Actual data and Statistical analysis

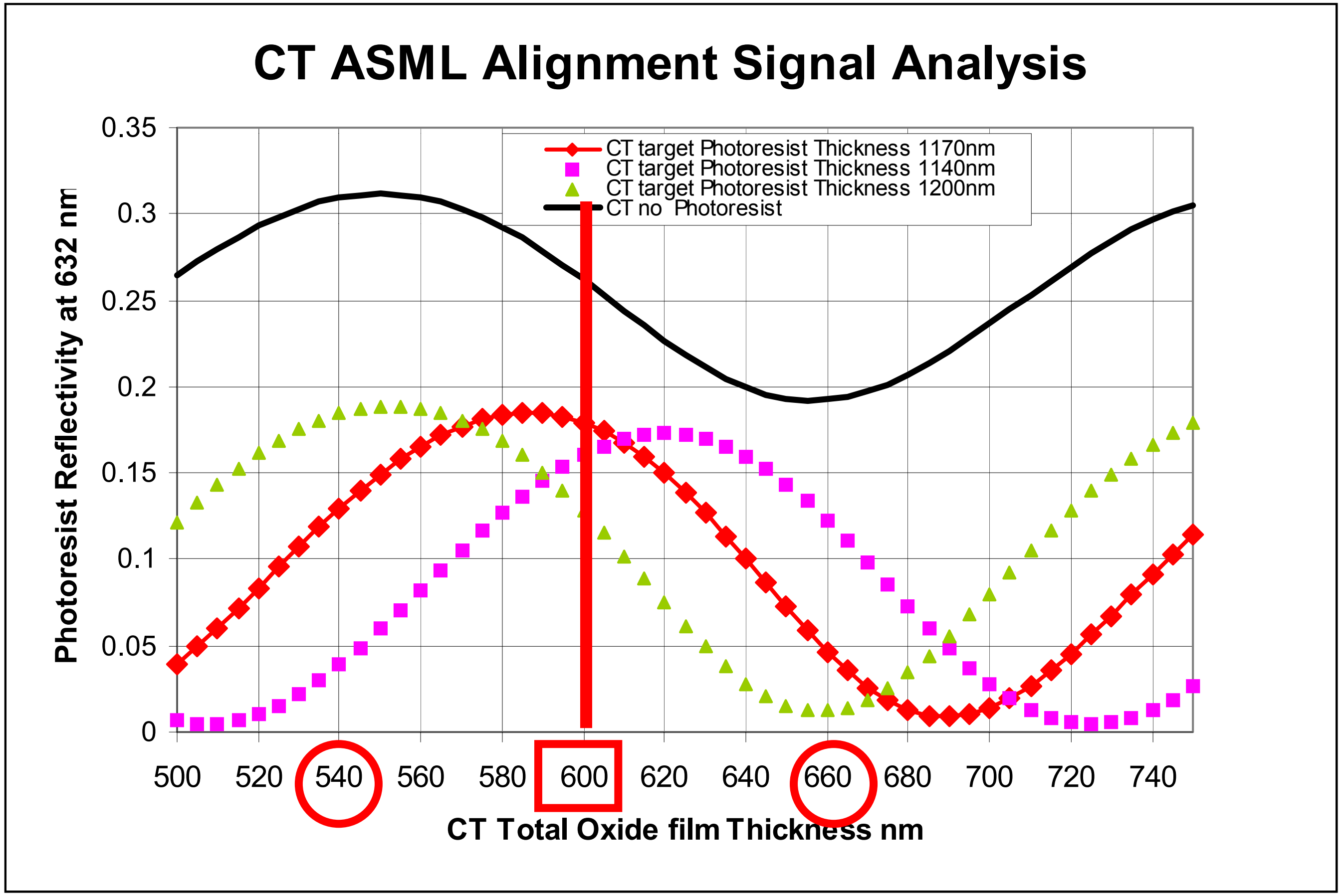
Industrial Example: ANOVA Data and background

ALIGNMENT SIGNAL STRENGTH: CT-P1 alignment How the AMSL align 632 nm illumination system "sees" the ASML marker PROLITH Modeling Reflectivity. Film thickness varaiations

CT Oxide thickness over marker at CT	***TiSi2***	***SiCr Overcoat***	***TOTAL***
TiSi2 lo SiCr lo	4050	1350	**5400**
TiSi2 lo SiCr high	4050	1650	**5700**
TiSi2 target SiCr lo	**4500**	1350	**5850**
TiSi2 target SiCr high	**4500**	1650	**6150**
TiSi2 target SiCr Target	**4500**	1500	**6000**
TiSi2 lo SiCr Target	4050	1500	**5550**
TiSi2 high SiCr Target	4950	1500	**6450**
TiSi2 high SiCr lo	4950	1350	**6300**
TiSi2 high SiCr high	4950	1650	**6600**
PHOTORESIST	**Low**	**Target**	**High**
Photo resist IX405 0 ASML marker depth	**1140**	**1170**	**1200**
Photo resist IX405 1200 ASML marker depth	**1260**	**1290**	**1320**

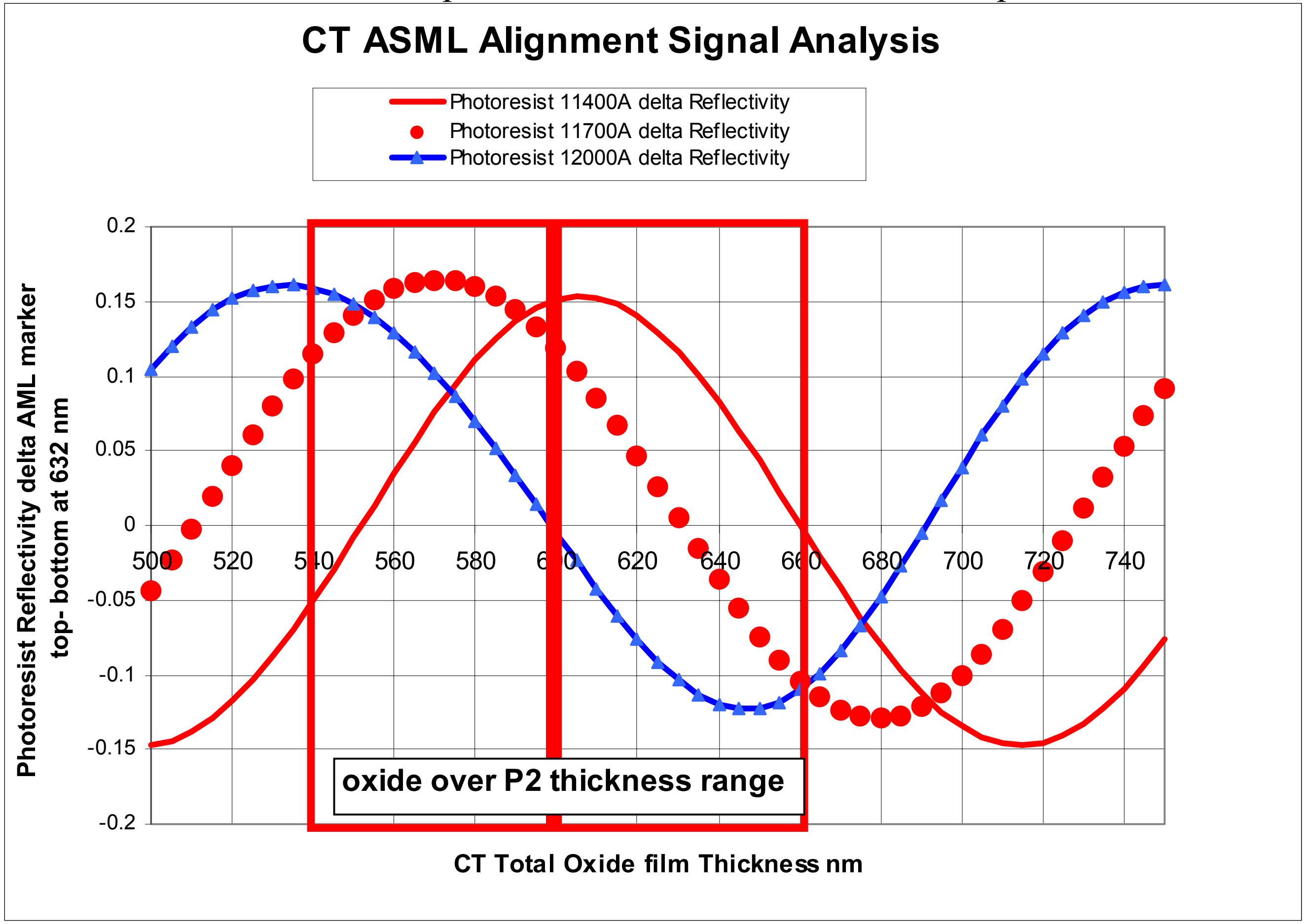
Industrial Example: ANOVA Data and background

ALIGNMENT SIGNAL STRENGTH: CT-P1 alignment How the AMSL align 632 nm illumination system “sees” the ASML aligmnent marker PROLITH Modeling Reflectivity ASML marker zero depth.



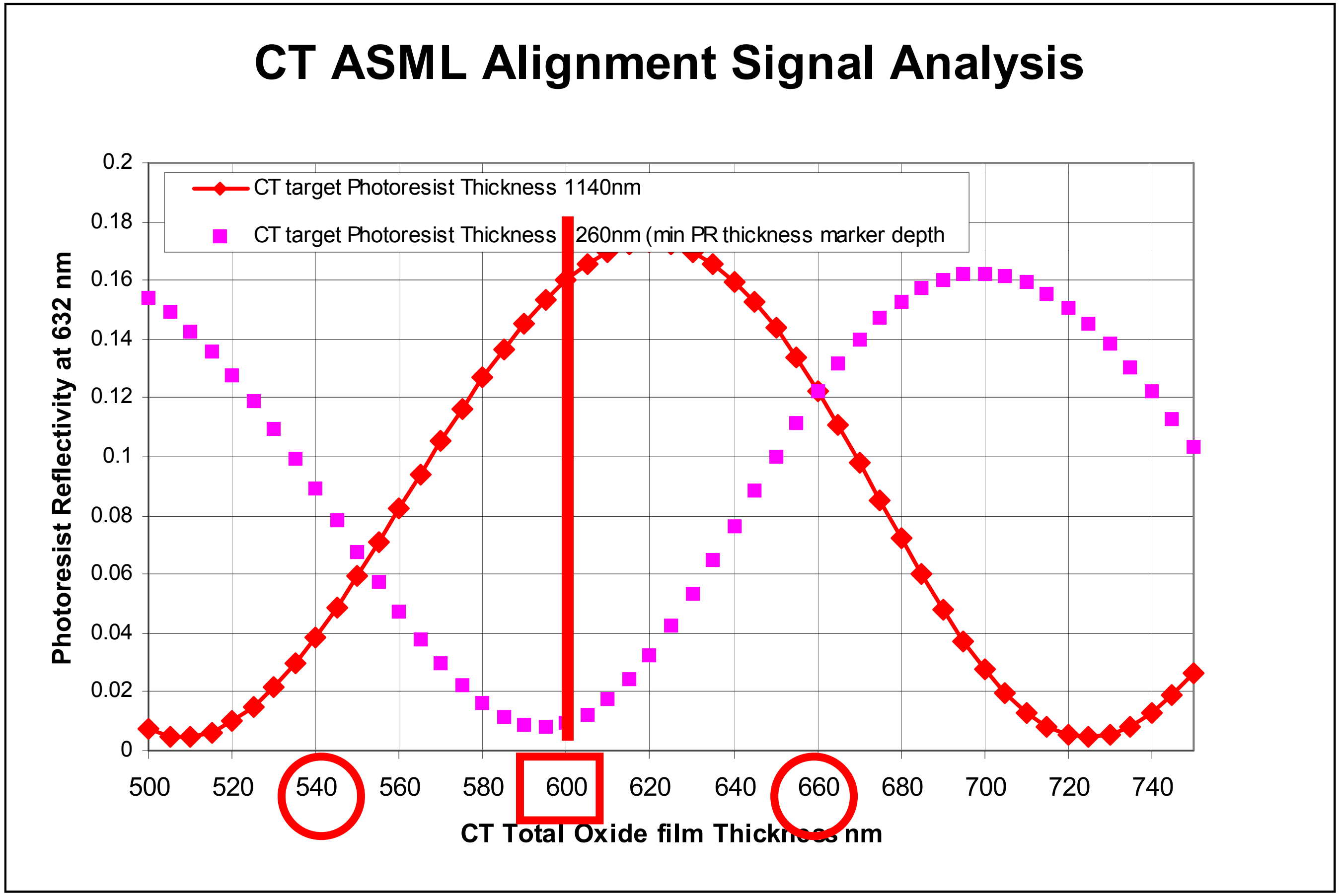
Industrial Example: ANOVA Data and background

<u>ALIGNMENT SIGNAL STRENGTH:</u> CT-P1 alignment How the AMSL align 632 nm illumination system "sees" the ASML marker PROLITH Modeling Reflectivity delta top of marker to bottom of marker 1200A depth. Desire maximum delta = thinner photoresist!



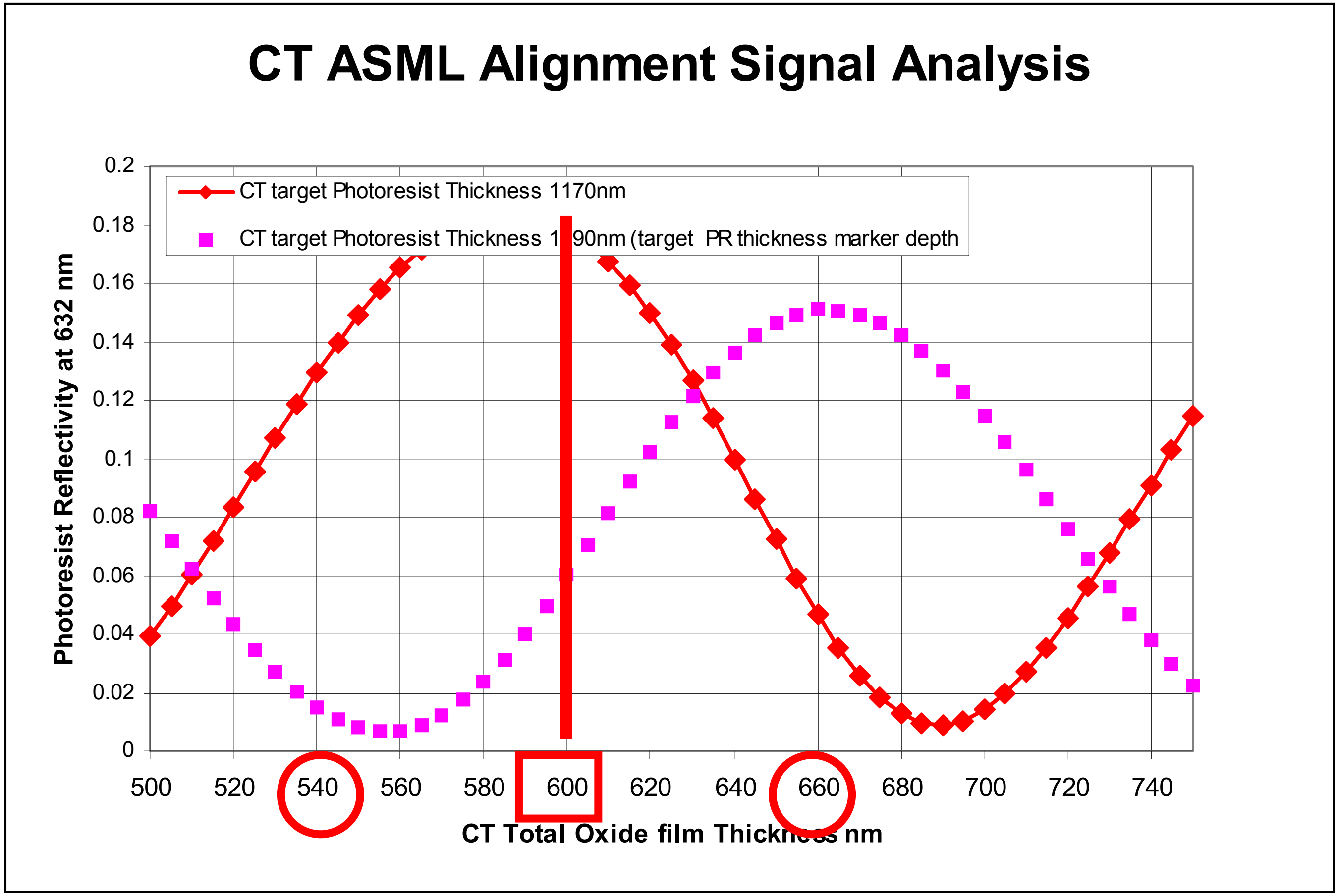
Industrial Example: ANOVA Data and background

ALIGNMENT SIGNAL STRENGTH: CT-P1 alignment How the AMSL align 632 nm illumination system “sees” the ASML marker PROLITH Modeling Reflectivity ASML marker 0 and 1200A depths Minimum photoresist thickness



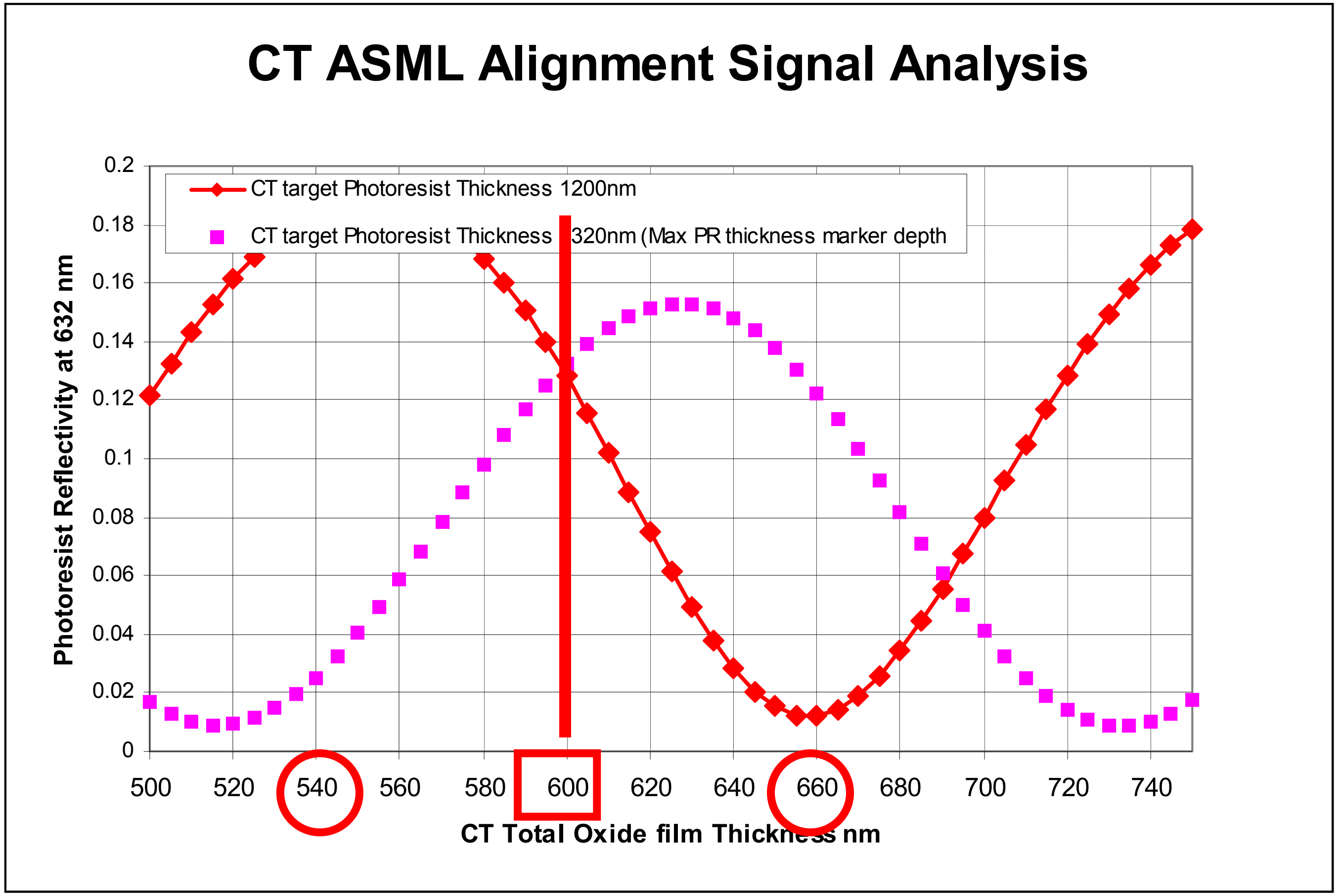
Industrial Example: ANOVA Data and background

<u>ALIGNMENT SIGNAL STRENGTH:</u> CT-P1 alignment How the AMSL align 632 nm illumination system "sees" the ASML marker PROLITH Modeling Reflectivity ASML marker 0 and 1200A depths Target photoresist thickness



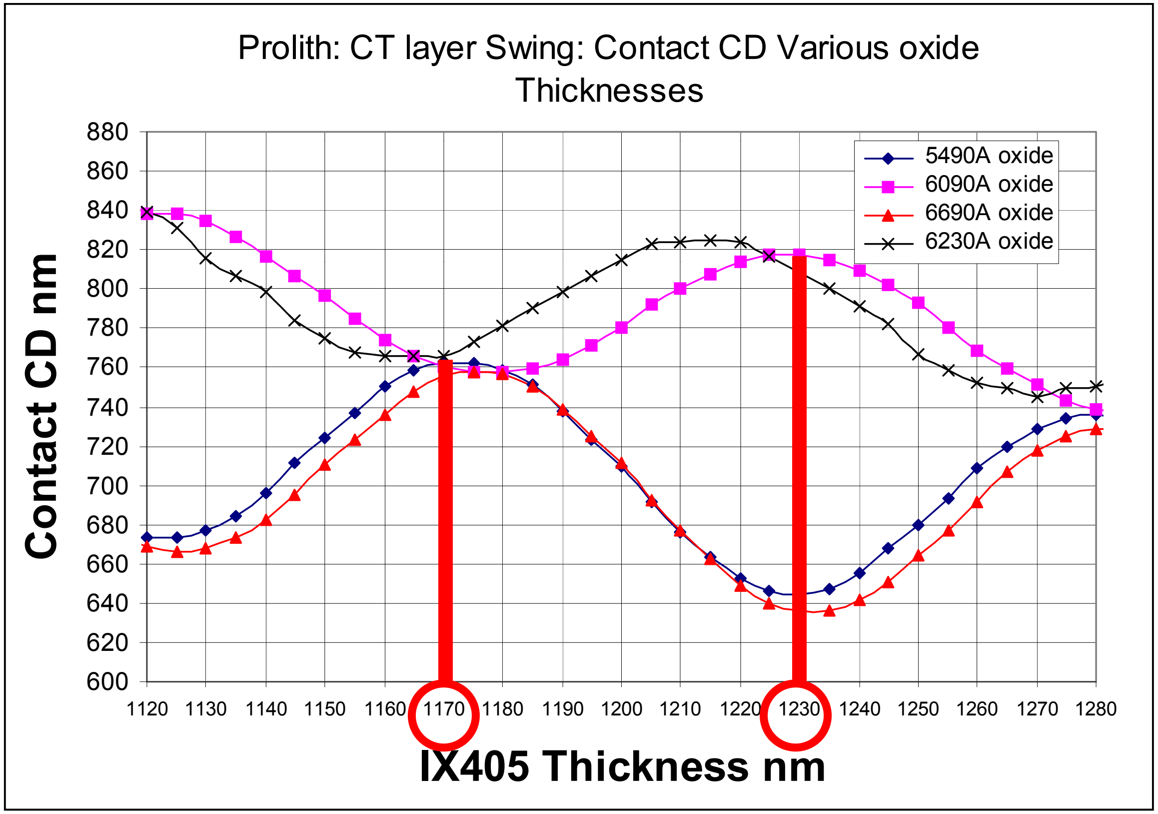
Industrial Example: ANOVA Data and background

<u>ALIGNMENT SIGNAL STRENGTH:</u> CT-P1 alignment How the AMSL align 632 nm illumination system "sees" the ASML marker PROLITH Modeling Reflectivity ASML marker 0 and 1200A depths maximum photoresist thickness



Industrial Example: ANOVA Data and background

ALIGNMENT SIGNAL STRENGTH: CT-P1 alignment signal improves with thinner or thicker photoresist film. We'd prefer to go thicker: 12300A but for nominal oxide thickness the swing curve is not optimal (desire a CD minimum thickness): hence we need to run an actual swing curve for all three contact types: CT over DI, P1, and P2/P1.



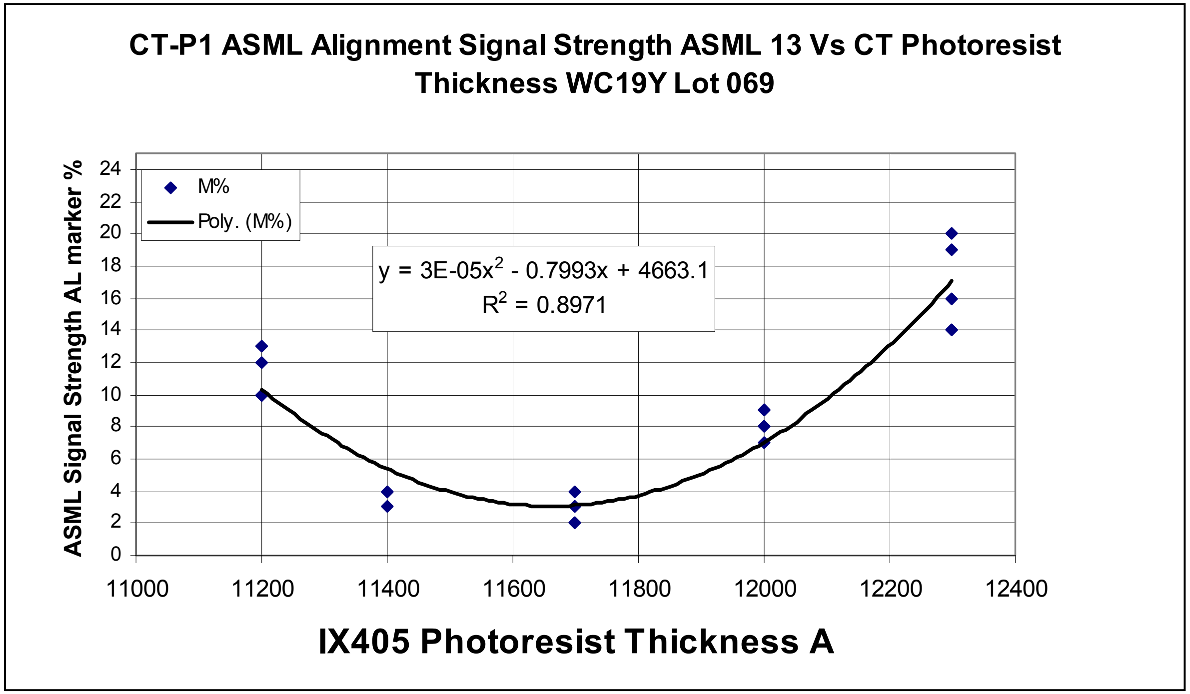
Industrial Example: ANOVA Actual data

•Experimental data Photoresist impact on alignment and registration

•Run experiment: look at the effect of five different photoresist thicknesses on align ment varaibles:

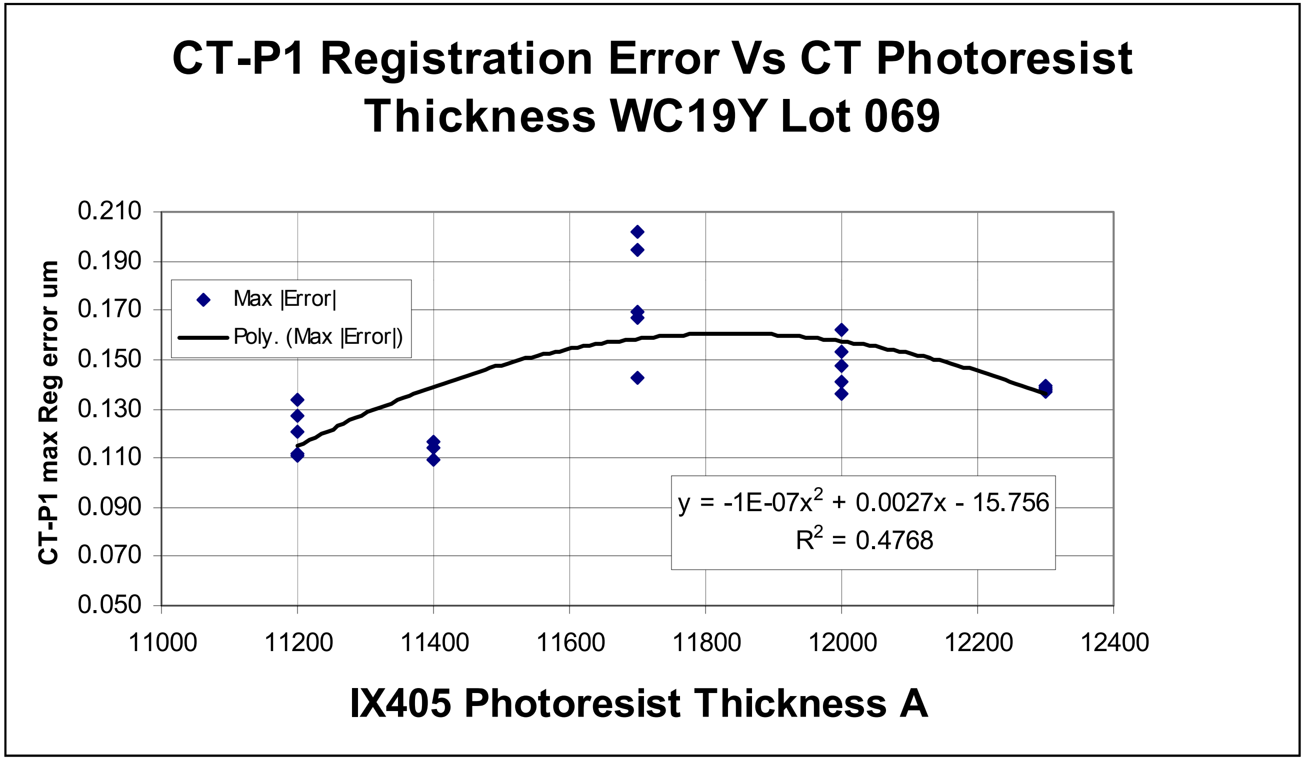
•<u>Independent variables or factors:</u> Photoresist thickness: Levels = 5

•<u>Response variables:</u> Alignment signal strength %; X axis registration error amd Y axis error



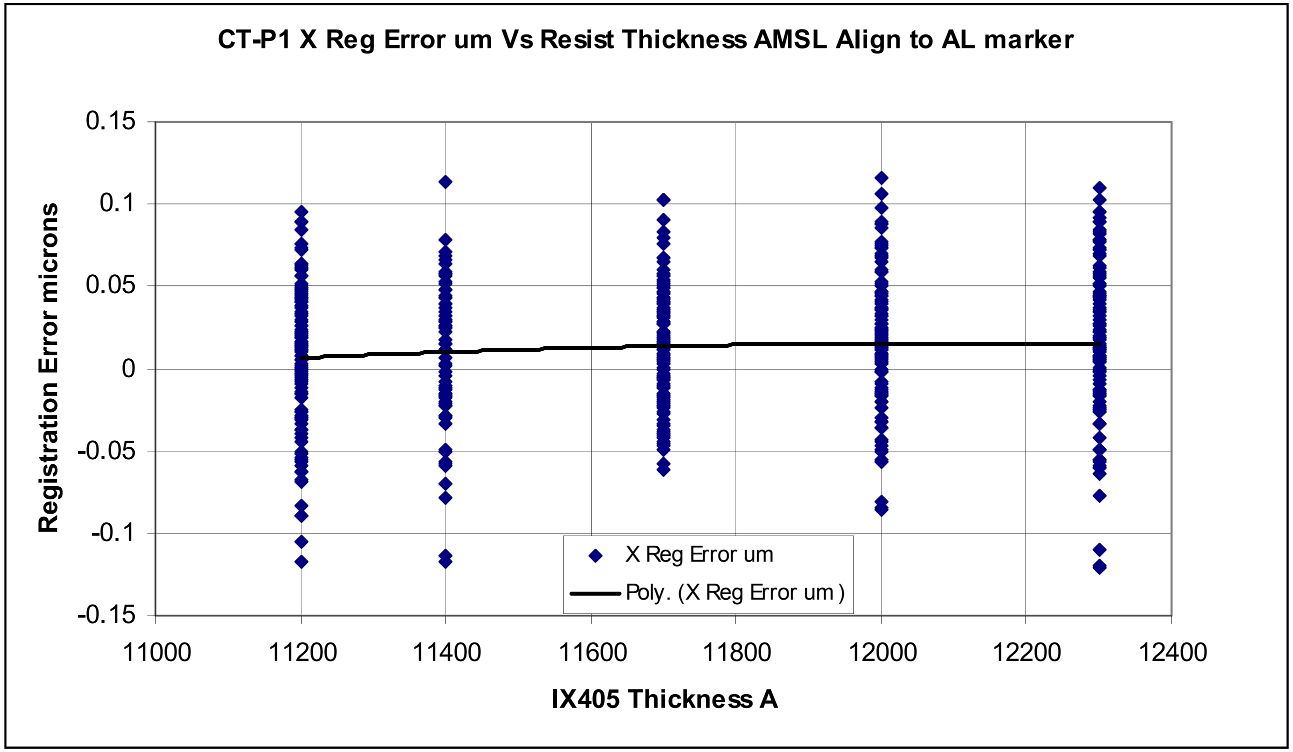
Industrial Example: ANOVA Actual data

- Experimental data Photoresist impact on alignment and registration
- Maximum registration error



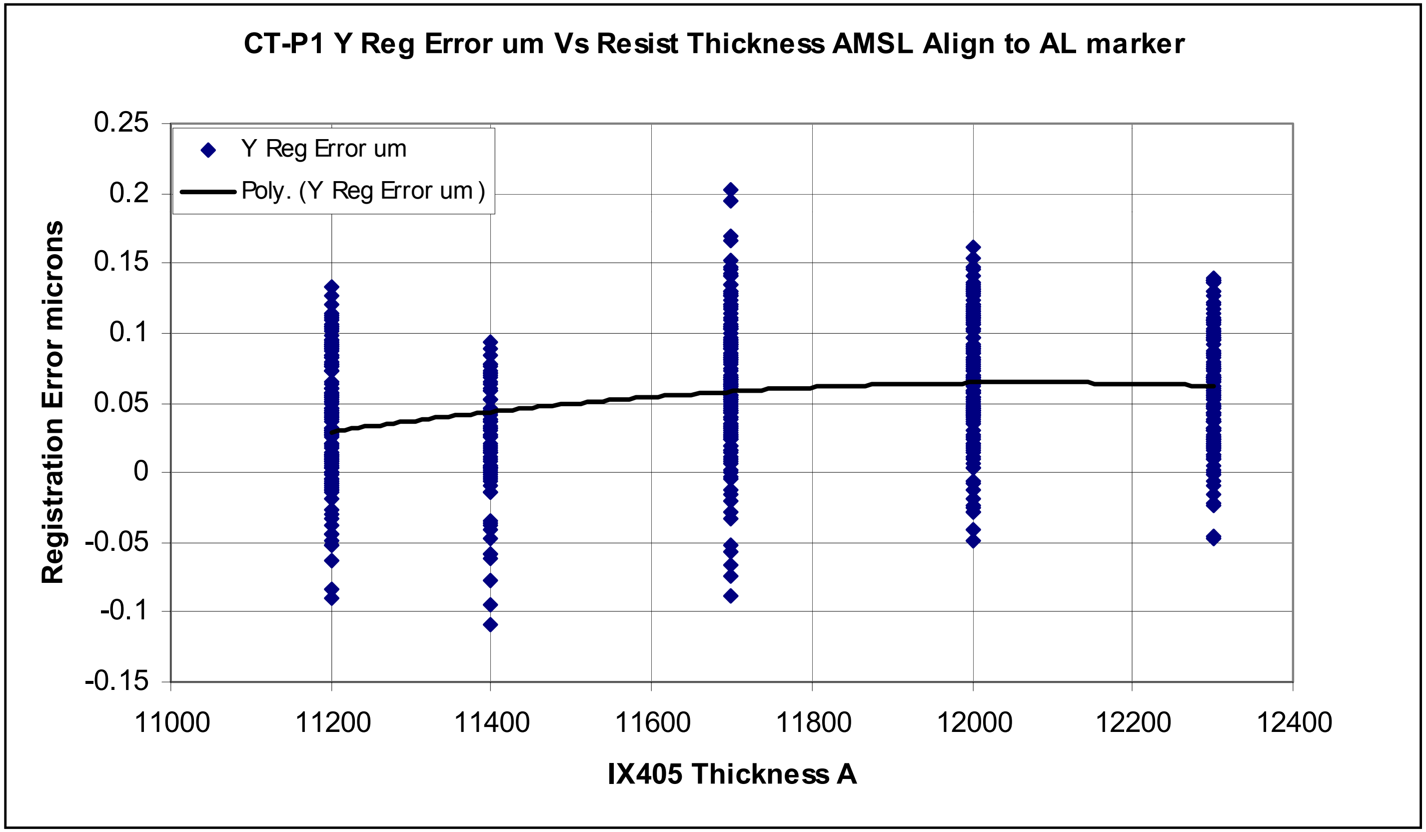
Industrial Example: ANOVA Actual data

•Experimental data Photoresist impact on alignment and registration
• X axis registration error



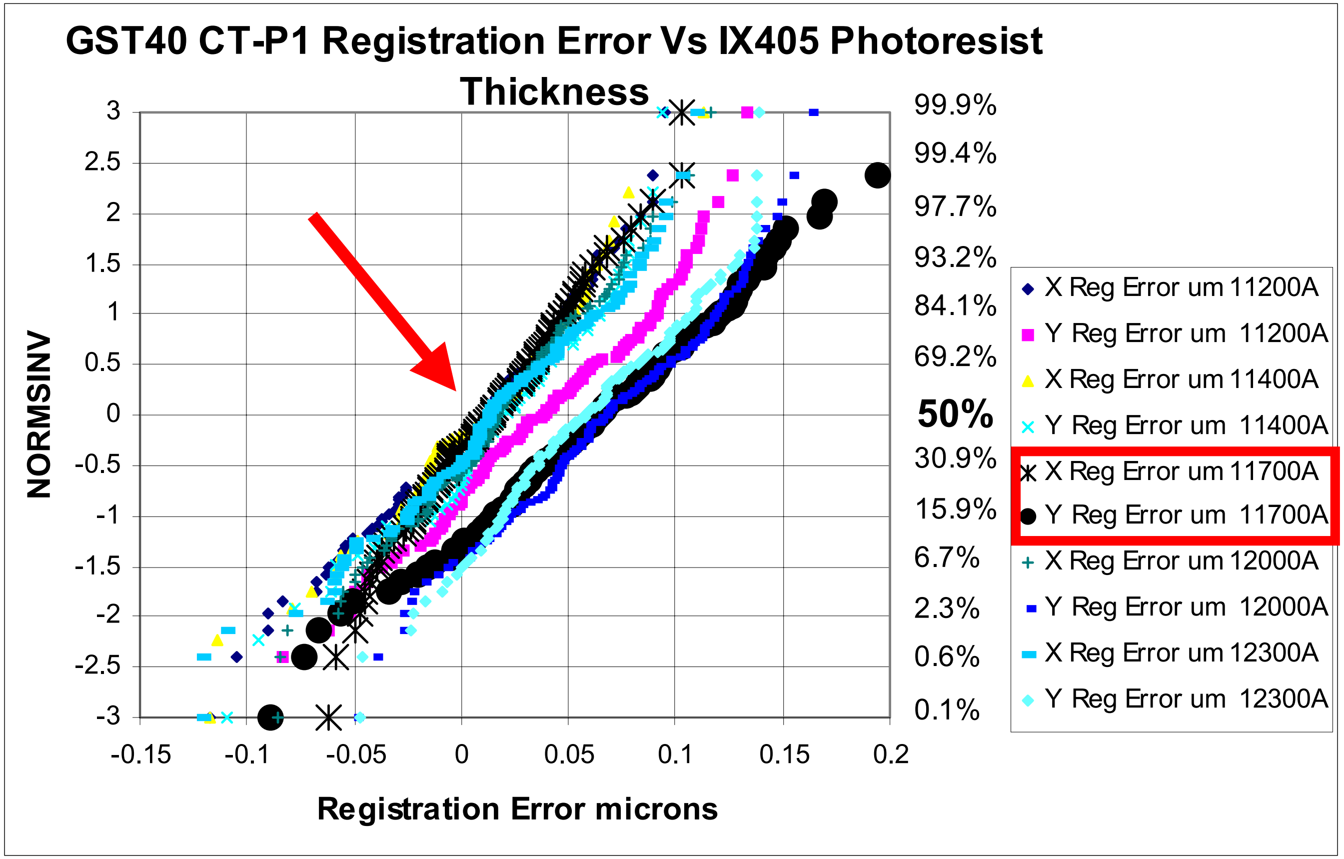
Industrial Example: ANOVA Actual data

- Experimental data Photoresist impact on alignment and registration
- Y axis registration error



Industrial Example: ANOVA Actual data

* Experimental data Photoresist impact on alignment and registration



Industrial Example: ANOVA Descriptive statistics

- Experimental data Photoresist impact on alignment and registration
- Descriptive statistics

Statistic	X Reg Error um 11200A	Y Reg Error um 11200A	X Reg Error um 11400A	Y Reg Error um 11400A	**X Reg Error um 11700A**	**Y Reg Error um 11700A**	X Reg Error um 12000A	Y Reg Error um 12000A	X Reg Error um 12300A	Y Reg Error um 12300A
Mean error microns	0.007682	0.037253	0.007973	0.018339	**0.013398**	**0.064718**	0.01713	0.067392	0.014404	0.059578
Mean Error nm	**8**	**37**	**8**	**18**	**13**	**65**	**17**	**67**	**14**	**60**
Standard Error	0.003827	0.004213	0.005065	0.004991	**0.003127**	**0.004863**	0.003546	0.00411	0.004112	0.003792
Median	0.0126	0.038	0.012	0.0197	**0.0145**	**0.0641**	0.0169	0.0668	0.0125	0.0582
Mode	0.057	0.0103	0.0257	0.0033	**0.0158**	**0.0552**	0.0121	0.0575	0.008	0.0095
Standard Deviation	0.042784	0.047106	0.043866	0.043224	**0.034965**	**0.054372**	0.039641	0.04595	0.045978	0.042397
Std Deviation nm	43	47	44	43	35	54	40	46	46	42
3 sigma	***128***	***141***	***132***	***130***	***105***	***163***	***119***	***138***	***138***	***127***
mean + 3 Sigma	***136***	***179***	***140***	***148***	***118***	***228***	***136***	***205***	***152***	***187***
Spec	***230***	***231***	***232***	***233***	***234***	***235***	***236***	***237***	***238***	***239***
Sample Variance	0.00183	0.002219	0.001924	0.001868	**0.001223**	**0.002956**	0.001571	0.002111	0.002114	0.001798
Kurtosis	0.084449	-0.353122	0.461491	0.480213	**-0.3367**	**0.247761**	0.17415	-0.399276	0.345385	-0.49423
Skewness	-0.488511	-0.229216	-0.493331	-0.678253	**0.14626**	**-0.20979**	-0.134692	-0.258289	-0.377258	-0.014239
Range	0.2123	0.2241	0.2305	0.2032	**0.1645**	**0.2905**	0.2013	0.2115	0.2301	0.186
Minimum	-0.1175	-0.0904	-0.117	-0.1094	**-0.0618**	**-0.0886**	-0.0853	-0.0493	-0.1204	-0.0469
Maximum	0.0948	0.1337	0.1135	0.0938	**0.1027**	**0.2019**	0.116	0.1622	0.1097	0.1391
Sum	0.9602	4.6566	0.598	1.3754	**1.6748**	**8.0897**	2.1412	8.424	1.8005	7.4472
Count	125	125	75	75	**125**	**125**	125	125	125	125

Industrial Example: ANOVA Single Factor X error

* Experimental data Analysis ANOVA Photoresist impact on alignment and registration run using EXCEL Single Factor ANOVA

H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$ H_i: $\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5$

F cal < Fcrit and P = 0.34 so we accept H_o. Means if we reject H_o we have a 34 % chance of being wrong!

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
X Reg Error um 11200A	125	0.9602	0.007682	0.00183
X Reg Error um 11400A	75	0.598	0.007973	0.001924
X Reg Error um 11700A	125	1.6748	0.013398	0.001223
X Reg Error um 12000A	125	2.1412	0.01713	0.001571
X Reg Error um 12300A	125	1.8005	0.014404	0.002114

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.007672	4	0.001918	1.117886	0.347089	2.387566
Within Groups	0.977949	570	0.001716			
Total	0.985621	574				

Industrial Example: ANOVA Single Factor Y error

* Experimental data Analysis ANOVA Photoresist impact on alignment and registration using EXCEL Single Factor ANOVA

$H_o: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$ $H_i: \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5$

F cal > Fcrit and P = 0.00 so we reject H_o. Means if we reject H_o we have a 0% chance of being wrong! We know at least one mean is different!

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Y Reg Error um 11200A	125	4.6566	0.037253	0.002219
Y Reg Error um 11400A	75	1.3754	0.018339	0.001868
Y Reg Error um 11700A	125	8.0897	0.064718	0.002956
Y Reg Error um 12000A	125	8.424	0.067392	0.002111
Y Reg Error um 12300A	125	7.4472	0.059578	0.001798

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.16916	4	0.04229	19.06016	1E-14	2.387566
Within Groups	1.264698	570	0.002219			
Total	1.433858	574				

Industrial Example: ANOVA Single Factor

- What did we learn?
- 1, Endure you randomize experiment
- 2. Plot the data different ways>> graphically look at it before running statistica analysis.
- 3, Test data for normalcy
- 4. When a difference is found>>Look at how large the difference is with the P value.
- 5. Remember this ANOVA just tells us : Yes at least one of the means is different, but not which one and not how much.

- EXCEL Single Factor ANOVA

H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$ H_i: $\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5$

If F cal > Fcrit we reject H_o. Means if we reject H_o we have a P% chance of being wrong! We know at least one mean is different!