ST 516 Final Project Report

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Executive summary

In this project, we are working for an optical fiber manufacturer and trying to find the best operational specs for minimizing the optical signal attenuation. There are eight operational factors, namely fiber draw speed, furnace temperature, draw tension, germanium concentration, fiber design, draw tower, raw material supplier, and coating type. The first four factors are continuous and the rest of them are categorical. Fifty experiments in a sequential procedure in four days were performed to find the significant factors and develop a model for predicting the optical signal attenuation. Results indicate that coating type, raw material suppliers, draw tower, draw tension and fiber draw speed are not significant while furnace temperature, germanium concentration and fiber design are significant main effects. The significant interactions derived from the optimal model are furnace temperature*germanium concentration, draw tension*raw material supplier, germanium concentration*fiber design and furnace temperature^2. The optimal design suggests furnace temperature, germanium concentration and fiber design should be at 2051.62 C, 0.01 and 1, respectively in order to minimize the optical signal attenuation, which is 0.17. The other factors and their interactions are not significant and can be set to either levels according to economic or safety factors.

Introduction

We are hired as statisticians to work for a manufacturer of optical fiber which is going to introduce a new fiber manufacturing design that can minimize the optical signal attenuation. The field experts introduced 8 factors (Fiber draw speed, Furnace temperature, Draw tension, Germanium concentration, Fiber design, Draw tower, Raw material supplier, and Coating type) that they believe might impact the objective function. Our goal in this project is to design an effective experiment (with a minimum number of runs) to determine the significant factors and interactions on the attenuation, and the optimal setting to minimize the attenuation. Given we have only the budget for 50 runs overall (50,000$ budget), we need to manage the budget, carefully. The rest of this report is as follows: In experimental design section, we will go through the sequential procedure taken to find the significant factors and their interactions. The analysis and results section will cover the final results of our design of experiment. We will state a summary of our experiments and results in the conclusion section along with recommendations to improve the model.

Experimental design

Due to our limited budget ($50,000) and our relatively large number of factors, (4 continuous and 4 categorical) designing a full factorial DOE will not be feasible. Therefore, we need to carefully design a fractional DOE to represent a full factorial DOE. Note that by reducing the number of runs, fractional DOE will be unable to evaluate the impact of some of the factors (or their interactions) independently, as we might have many confounding interactions (usually higher-order interactions). As shown in the Sparsity of Effects Principle, the higher-order interactions are rare, therefore, we can obtain meaningful results from fractional factorials DOE.

The other approach to reduce the number of runs, is to design screening experiments. Screening results moves us from the point of having no idea about the effect of each factor to a point where some of the significant factors have been realized. The goal here is to identify the most important factors that might minimize the attenuation.

On the other hand, we are told that we can only run 16 times each day which might be a source of unexpected variability in the model. To overcome this issue, we need to block the experiments by day. Then, we can analyze whether or not the day is significant in the final model.

Having said that, two different designs have been considered for the screening experiments:

1- 16 runs with one block (resolution IV)

2- 32 runs with two blocks (because of the limit of 16 runs per day, resolution IV).

As it is shown in figure below, 16 runs in one day result in aliasing four two-ways interactions which might cause to exceed our budget in the next steps, whereas running 32 runs will decrease the aliasing to couples of two-way interactions for all of them except one, which is aliased with 2 others.

Aliasing of Effects

Effects	Aliases	Block Aliases
Fiber draw speed*Draw tension	= Fiber design*Coating type	
Fiber draw speed*Germanium concentration	= Fiber design*Raw material supplier	
Fiber draw speed*Fiber design	= Draw tension*Coating type = Germanium concentration*Raw material supplier	
Fiber draw speed*Raw material supplier	= Germanium concentration*Fiber design	
Fiber draw speed*Coating type	= Draw tension*Fiber design	
Draw tension*Germanium concentration	= Raw material supplier*Coating type	
Draw tension*Raw material supplier	= Germanium concentration*Coating type	

Aliasing of Effects

Effects	Aliases
Fiber draw speed*Furnace temp	= Draw tension*Coating type = Germanium concentration*Raw material supplier = Fiber design*Draw tower
Fiber draw speed*Draw tension	= Furnace temp*Coating type = Germanium concentration*Draw tower = Fiber design*Raw material supplier
Fiber draw speed*Germanium concentration	= Furnace temp*Raw material supplier = Draw tension*Draw tower = Fiber design*Coating type
Fiber draw speed*Fiber design	= Furnace temp*Draw tower = Draw tension*Raw material supplier = Germanium concentration*Coating type
Fiber draw speed*Draw tower	= Furnace temp*Fiber design = Draw tension*Germanium concentration = Raw material supplier*Coating type
Fiber draw speed*Raw material supplier	= Furnace temp*Germanium concentration = Draw tension*Fiber design = Draw tower*Coating type
Fiber draw speed*Coating type	= Furnace temp*Draw tension = Germanium concentration*Fiber design = Draw tower*Raw material supplier

Furthermore, since we can only have 16 runs per day, and we wanted to consider the effect of blocking and see if it has a significant effect on the response, we ended up choosing 32 runs within 2 days.

After conducting an analysis on the results obtained from resolution IV and running 32 experiments in 2 days, we observe that block is not significant in the effect tests, where the ANOVA shows that the whole model is significant, and the REML test verifies this observation by showing us that only 11.92% of the total variation is explained with blocks and the confidence interval of blocks are very tight around zero. Aforementioned tables are given below:

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	29	14.994348	0.517046	200.0175
Error	2	0.005170	0.002585	**Prob > F**
C. Total	31	14.999518		0.0050*

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Wald p-Value	Pct of Total
Block	0.1353199	0.0003498	0.000741	-0.001103	0.0018022	0.6369	11.919
Residual		0.002585	0.002585	0.0007008	0.1021023		88.081
Total		0.0029348	0.002529	0.0009015	0.0517006		100.000

-2 LogLikelihood = 92.298081529

Note: Total is the sum of the positive variance components.

Total including negative estimates = 0.0029348

In the screening experiments, we tolerate more type I error, so at the $\alpha = 0.2$ level, we removed the insignificant factors. We found 2 significant interactions which were confounded with another interaction. Confounded interactions were as follows:

- Fiber Draw Speed*Raw Material=Germanium Concentration*Fiber Design
- Draw Tension*Raw Material=Germanium Concentration*Coating type

As we can see from the above aliased interactions, Raw material and Germanium Concentration were common factors in both confounded lines. We have two options for dealiasing these interactions. We can either multiply raw material or Germanium concentration with -1 for a new set of experiments, and we chose raw material for this purpose. Again, using resolution IV, a set of 16 new experiments were run to dealias the aforementioned confounded interactions, and 2 additional runs were requested for center points to help us in optimization process, resulting in a total of 50 runs. Since we have 4 categorical factors, we need to set them to one level and get the center points with regard to other continuous factors. However, we only have one categorical factor that was significant, Fiber design, so we needed to get one center points for each level of this factor.

Analysis and Results

As discussed in experimental design section, we started with 32 screening runs in two days. Tables below show the results of effect test and ANOVA. As we can see block is not a significant factor but the overall model is significant. It is in line with the results from REML test given in the previous section. In addition, if we consider a significance level of 0.2 (just for the purpose of screening), we will have Furnace temperature, Germanium concentration and Fiber design as significant factors among the main effects. Fiber draw speed, Draw tension, Draw tower and Coating type are marginally significant and Raw material supplier does not seem important here (it is also shown in the normal half plot given below). Significant interactions are Fiber design*Raw material supplier (which is aliased with Germanium concentration*Fiber design), Furnace temperature*Germanium concentration, Furnace temperature*Draw tower and Draw tension*Raw material supplier (which is aliased with Germanium concentration*Coating type).

Now that we know which factors and interactions are important, we can remove the rest from the model. The updated effect tests, parameter estimates and ANOVA table are as follows:

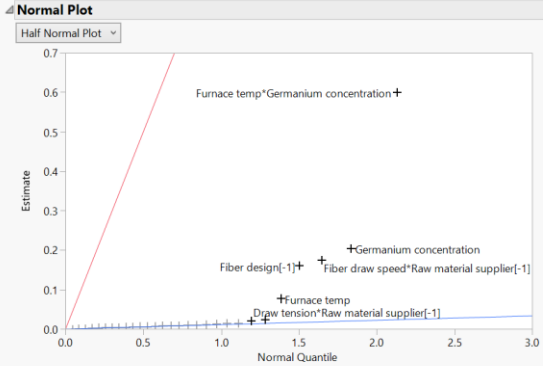
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Fiber draw speed	1	1	0.005669	2.1929	0.2768
Furnace temp	1	1	0.193777	74.9619	0.0131*
Draw tension	1	1	0.008118	3.1404	0.2184
Germanium concentration	1	1	1.344661	520.1771	0.0019*
Fiber design	1	1	0.832812	322.1703	0.0031*
Draw tower	1	1	0.004782	1.8500	0.3068
Raw material supplier	1	1	0.000732	0.2831	0.6479
Coating type	1	1	0.003911	1.5130	0.3437
Block	1	1	0.008182	3.1651	0.2172
Fiber draw speed*Furnace temp	1	1	0.000453	0.1752	0.7162
Fiber draw speed*Draw tension	1	1	0.001518	0.5874	0.5235
Fiber draw speed*Germanium concentration	1	1	0.001485	0.5743	0.5277
Fiber draw speed*Fiber design	1	1	0.000712	0.2755	0.6520
Fiber draw speed*Draw tower	1	1	0.001189	0.4601	0.5675
Fiber draw speed*Raw material supplier	1	1	0.987935	382.1790	0.0026*
Fiber draw speed*Coating type	1	1	0.000024	0.0091	0.9325
Furnace temp*Draw tension	1	1	0.002395	0.9265	0.4373
Furnace temp*Germanium concentration	1	1	11.550047	4468.092	0.0002*
Furnace temp*Fiber design	1	1	0.003912	1.5134	0.3437
Furnace temp*Draw tower	1	1	0.018455	7.1393	0.1162
Furnace temp*Raw material supplier	1	1	0.000888	0.3435	0.6171
Furnace temp*Coating type	1	1	0.000526	0.2035	0.6961
Draw tension*Germanium concentration	1	1	0.000031	0.0120	0.9226
Draw tension*Draw tower	1	1	0.000312	0.1208	0.7613
Draw tension*Raw material supplier	1	1	0.014900	5.7639	0.1384
Germanium concentration*Draw tower	1	1	2.98888e-6	0.0012	0.9760
Fiber design*Draw tower	1	1	0.002576	0.9965	0.4233
Draw tower*Raw material supplier	1	1	0.002040	0.7890	0.4681
Draw tower*Coating type	1	1	0.002303	0.8910	0.4449

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	29	14.994348	0.517046	200.0175
Error	2	0.005170	0.002585	Prob > F
C. Total	31	14.999518		0.0050*

Normal Plot



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	14.961888	1.36017	722.9195
Error	20	0.037630	0.00188	Prob > F
C. Total	31	14.999518		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.8253689	0.007668	238.05	<.0001*
Fiber draw speed	-0.01331	0.007668	-1.74	0.0980
Furnace temp	-0.077817	0.007668	-10.15	<.0001*
Draw tension	0.0159274	0.007668	2.08	0.0509
Germanium concentration	0.2049894	0.007668	26.73	<.0001*
Fiber design[-1]	0.1613239	0.007668	21.04	<.0001*
Draw tower[-1]	-0.012225	0.007668	-1.59	0.1266
Raw material supplier[-1]	-0.004782	0.007668	-0.62	0.5399
Fiber draw speed*Raw material supplier[-1]	0.1757071	0.007668	22.91	<.0001*
Furnace temp*Germanium concentration	0.600782	0.007668	78.35	<.0001*
Furnace temp*Draw tower[-1]	-0.024015	0.007668	-3.13	0.0053*
Draw tension*Raw material supplier[-1]	-0.021578	0.007668	-2.81	0.0107*

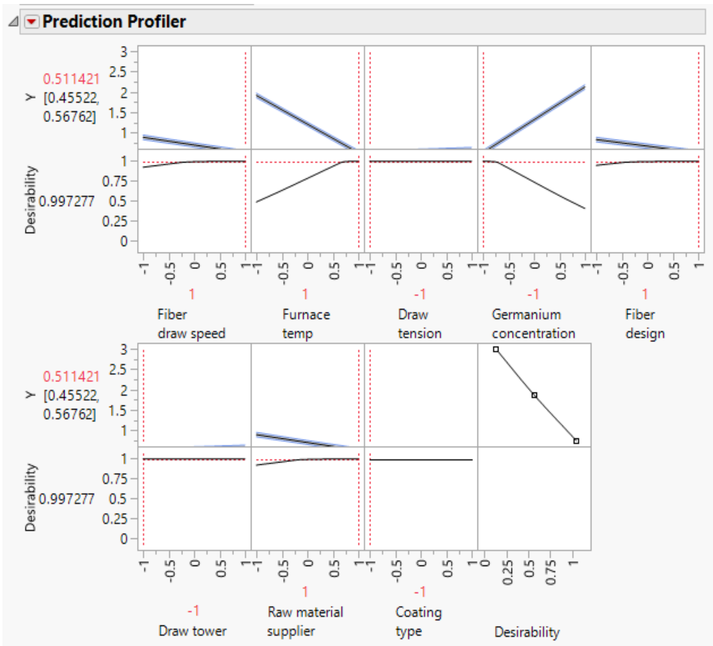
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Fiber draw speed	1	1	0.005669	3.0128	0.0980
Furnace temp	1	1	0.193777	102.9908	<.0001*
Draw tension	1	1	0.008118	4.3146	0.0509
Germanium concentration	1	1	1.344661	714.6759	<.0001*
Fiber design	1	1	0.832812	442.6326	<.0001*
Draw tower	1	1	0.004782	2.5418	0.1266
Raw material supplier	1	1	0.000732	0.3889	0.5399
Fiber draw speed*Raw material supplier	1	1	0.987935	525.0791	<.0001*
Furnace temp*Germanium concentration	1	1	11.550047	6138.750	<.0001*
Furnace temp*Draw tower	1	1	0.018455	9.8087	0.0053*
Draw tension*Raw material supplier	1	1	0.014900	7.9191	0.0107*

As above figures suggest, the overall model is significant, showing that we are able to explain more than 99% of the variability in the response. Also, after removing insignificant ones, we see that fiber draw speed, furnace temp, draw tension, germanium concentration, fiber design, draw tower, fiber draw speed*raw material supplier, furnace temp*germanium concentration, furnace temp*draw tower and draw tension*raw material supplier are significant at $\alpha = 0.2$, but Raw material supplier is still insignificant. In addition, since the whole model is significant, based on ANOVA table, we can conclude that these factors are important. We found 2 significant interactions which were confounded with another interaction. Confounded interactions were as follows:

- Fiber Draw Speed*Raw Material=Germanium Concentration*Fiber Design
- Draw Tension*Raw Material=Germanium Concentration*Coating type

The optimal design for our first experiment is fiber draw speed, furnace temp, fiber design and raw material supplier at high level, and draw tension, coating type, germanium concentration and draw tower at low level and the optimal response for this design is 0.511. We can also see that coating type, draw tension and draw tower have almost zero slope here, which is another confirmation for considering them as insignificant.



As explained in experimental design section, to dealias the confounded interactions, we have multiplied raw material by -1 and requested 16 more runs. The full model after adding 16 more runs is displayed below. We can see that from the first aliased interactions, both Germanium concentration*fiber design and Fiber Draw Speed*Raw Material are significant (the latter is significant at 0.2 significance level) and from the second one only Draw tension*Raw material supplier is marginally significant at 0.2 level. Furthermore, block is not again significant, whereas the ANOVA table is telling us that the whole model is.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	32	22.508366	0.703386	172.7091
Error	15	0.061090	0.004073	Prob > F
C. Total	47	22.569456		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.8212466	0.009211	197.72	<.0001*
Fiber draw speed	-0.007939	0.00977	-0.81	0.4292
Furnace temp	-0.075218	0.00977	-7.70	<.0001*
Draw tension	0.0128054	0.00977	1.31	0.2097
Germanium concentration	0.2069505	0.00977	21.18	<.0001*
Fiber design	-0.159266	0.00977	-16.30	<.0001*
Draw tower	0.0091009	0.009211	0.99	0.3388
Raw material supplier	0.0028729	0.00977	0.29	0.7727
Coating type	0.0027736	0.00977	0.28	0.7804
Block[1]	0.0201123	0.013027	1.54	0.1434
Block[2]	-0.011868	0.013027	-0.91	0.3767
Fiber draw speed*Furnace temp	0.0017035	0.00977	0.17	0.8639
Fiber draw speed*Draw tension	-0.001636	0.00977	-0.17	0.8693
Fiber draw speed*Germanium concentration	-0.001135	0.00977	-0.12	0.9090
Fiber draw speed*Fiber design	-0.007317	0.00977	-0.75	0.4655
Fiber draw speed*Draw tower	0.0016745	0.00977	0.17	0.8662
Fiber draw speed*Raw material supplier	0.0187895	0.011281	1.67	0.1166
Fiber draw speed*Coating type	0.0039619	0.00977	0.41	0.6908
Furnace temp*Draw tension	-0.000369	0.00977	-0.04	0.9703
Furnace temp*Germanium concentration	0.5988728	0.00977	61.30	<.0001*
Furnace temp*Fiber design	0.0056862	0.00977	0.58	0.5692
Furnace temp*Draw tower	0.0076326	0.009211	0.83	0.4203
Furnace temp*Raw material supplier	-0.003307	0.00977	-0.34	0.7397
Furnace temp*Coating type	-0.000932	0.00977	-0.10	0.9252
Draw tension*Germanium concentration	0.0034353	0.00977	0.35	0.7300
Draw tension*Draw tower	-0.002552	0.00977	-0.26	0.7975
Draw tension*Raw material supplier	0.0172639	0.011281	1.53	0.1468
Germanium concentration*Draw tower	-0.004947	0.00977	-0.51	0.6200
Fiber design*Draw tower	0.008972	0.011281	0.80	0.4389
Draw tower*Raw material supplier	-0.003162	0.00977	-0.32	0.7507
Draw tower*Coating type	-0.008484	0.011281	-0.75	0.4637
Germanium concentration*Coating type	0.0043143	0.011281	0.38	0.7075
Germanium concentration*Fiber design	-0.194497	0.011281	-17.24	<.0001*

As a result we can now remove all insignificant factors and interactions and we will end up with the following results. The reason why we decided to choose 0.2 significance level was that we wanted to include all marginal important factors so we could find the best ones at the end. So, after doing our screening analysis we can switch to 0.05 significance level again. Using 0.05 type I error, we can see that Furnace temperature, Germanium concentration and Fiber design are significant from the main effects and Draw tension is marginally significant. From the interactions, Furnace temperature*Germanium concentration, Draw tension*Raw material supplier and Germanium concentration*Fiber design are effective.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	22.465854	2.80823	1057.126
Error	39	0.103603	0.00266	Prob > F
C. Total	47	22.569456		<.0001*

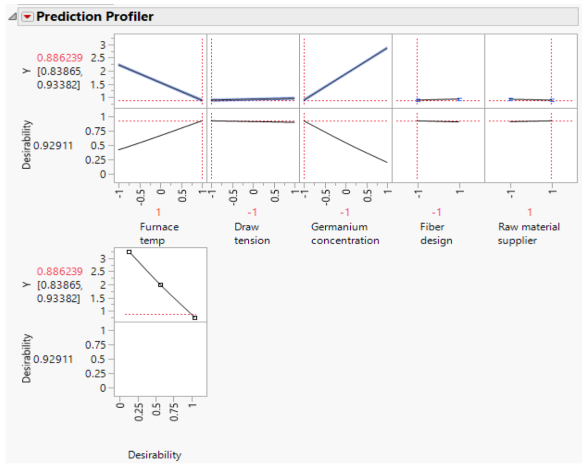
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.8212466	0.007439	244.81	<.0001*
Furnace temp	-0.072779	0.007439	-9.78	<.0001*
Draw tension	0.0131162	0.007439	1.76	0.0857
Germanium concentration	0.2058483	0.007439	27.67	<.0001*
Fiber design	-0.159834	0.007439	-21.48	<.0001*
Raw material supplier	0.0028729	0.007891	0.36	0.7178
Furnace temp*Germanium concentration	0.5988728	0.007891	75.90	<.0001*
Draw tension*Raw material supplier	0.0216926	0.007439	2.92	0.0059*
Germanium concentration*Fiber design	-0.185405	0.007439	-24.92	<.0001*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Furnace temp	1	1	0.254243	95.7069	<.0001*
Draw tension	1	1	0.008258	3.1085	0.0857
Germanium concentration	1	1	2.033928	765.6482	<.0001*
Fiber design	1	1	1.226244	461.6051	<.0001*
Raw material supplier	1	1	0.000352	0.1326	0.7178
Furnace temp*Germanium concentration	1	1	15.302339	5760.384	<.0001*
Draw tension*Raw material supplier	1	1	0.022587	8.5027	0.0059*
Germanium concentration*Fiber design	1	1	1.650010	621.1265	<.0001*

Using the prediction profiler, we can find the optimal setting with this data. Notice that, since we removed some of the main effects from the model, we do not have them in the profiler. The optimal setting here is furnace temp and raw material supplier at high level and draw tension, germanium concentration and fiber design at low level, other factors (Coating type, Fiber draw speed, etc.) can be set to either low or high because they are not significant here. Note that, Raw material supplier itself is not significant but its interaction is, so it does matter what setting we use for it.



After finding out the significant effects, the next step is to optimize the attenuation using these factors. To do this, we can first look at the prediction profiler plot we have above; we see that furnace temp and germanium concentration can get better, but we did not have enough range of data for them, so we need to run the experiment again by adding two center points which will end us up with 50 total runs and maximum budget limit.

After fitting the model, the results from the lack of fit table tells us that there is a curvature in the model and we need to add the square terms of the main effects in the model. However, if we add all of the square terms of the significant main effects (germanium concentration^2 and furnace temp^2) to the model, we end up with 2 singular effects that are aliased with each other. To solve this issue, we ran two additional analysis, each with only one of them in model. First, we removed furnace temp^2 and the results are shown below.

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	25	3.1734874	0.126939	49.7122
Pure Error	16	0.0408558	0.002553	**Prob > F**
Total Error	41	3.2143433		<.0001*
				Max RSq
				0.9984

Effect Summary

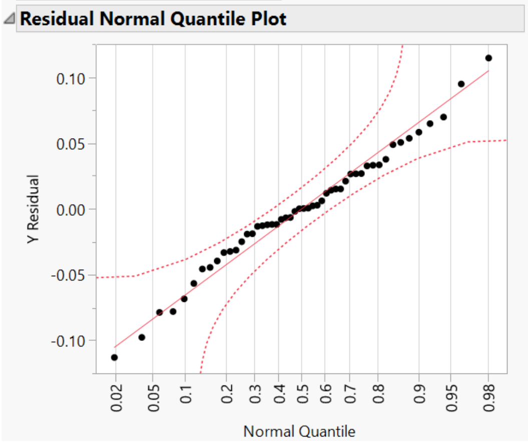
Source	LogWorth	PValue
Furnace temp*Germanium concentration	44.322	0.00000
Germanium concentration	27.159	0.00000 ^
Germanium concentration*Fiber design	25.437	0.00000
Fiber design	23.409	0.00000 ^
Furnace temp	11.580	0.00000 ^
Draw tension*Raw material supplier	2.275	0.00531
Draw tension	1.085	0.08218 ^
Raw material supplier	0.146	0.71467 ^
Furnace temp*Furnace temp	.	.
Germanium concentration*Germanium concentration	.	.

Effect Summary

Source	LogWorth	PValue
Furnace temp*Germanium concentration	44.322	0.00000
Germanium concentration*Germanium concentration	30.705	0.00000
Germanium concentration	27.159	0.00000 ^
Germanium concentration*Fiber design	25.437	0.00000
Fiber design	23.409	0.00000 ^
Furnace temp	11.580	0.00000 ^
Draw tension*Raw material supplier	2.275	0.00531
Draw tension	1.085	0.08218 ^
Raw material supplier	0.146	0.71467 ^

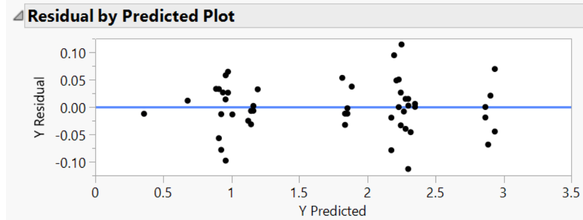
Remove Add Edit Undo ☐ FDR ('^' denotes effects with containing effects above them)

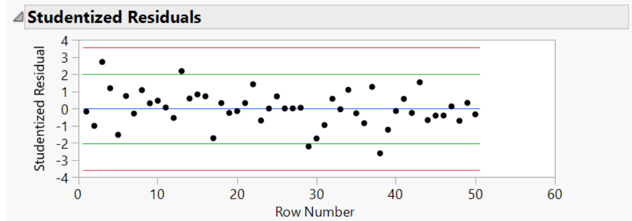
Lack of fit is no longer significant showing, by adding the quadratic term, we were able to explain the curvature in the model. The residual plots and studentized residuals look fine and the constant variance assumption holds. Also, the normality assumption seems to hold as well in the qq plot. At the end, the ANOVA table confirms that the quadratic model is significant.



Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	24	0.06304436	0.002627	1.0287
Pure Error	16	0.04085584	0.002553	Prob > F
Total Error	40	0.10390020		0.4878
				Max RSq
				0.9984

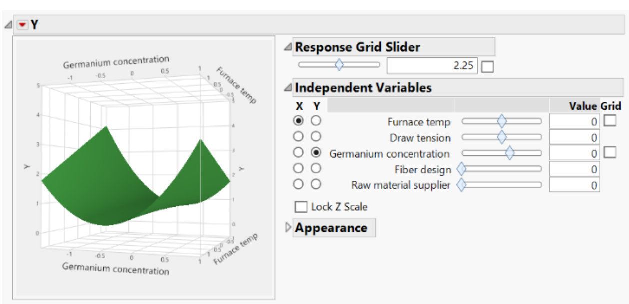


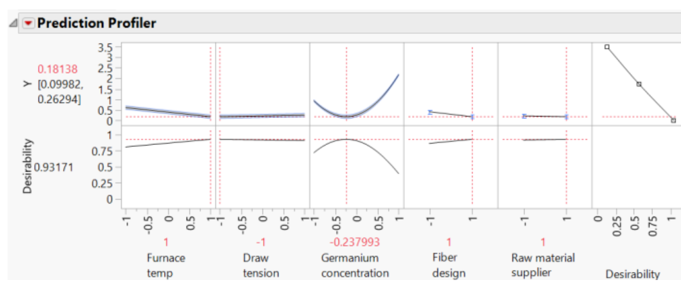


Analysis of Variance

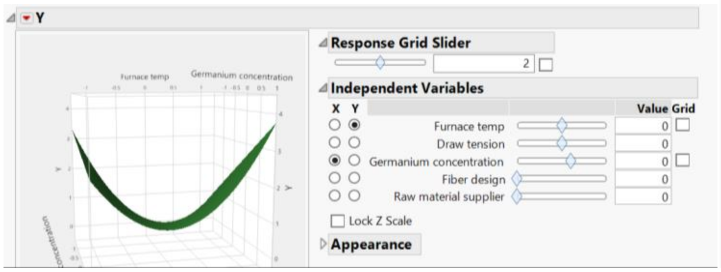
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	25.789701	2.86552	1103.183
Error	40	0.103900	0.00260	Prob > F
C. Total	49	25.893601		<.0001*

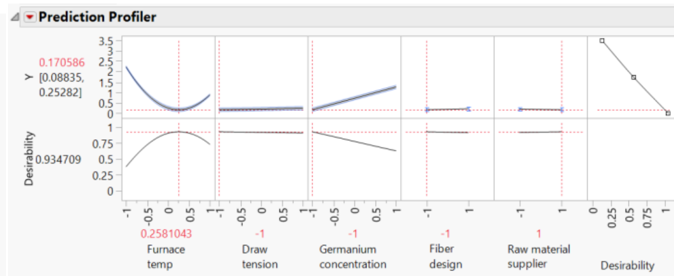
The optimized desirability is shown in the following prediction profiler and surface plot. The optimal setting in this experiment is furnace temp, fiber design and raw material supplier at the high level, draw tension at the low level and germanium concentration at -0.2379 which results to 0.18138 for the response.





If we remove Germanium^2 and keep Furnace temp^2 in the model, we end up with the similar parameter estimates, diagnostic plots and ANOVA. However, on prediction profiler we find different result as follow:





The optimal setting in this experiment is raw material supplier at the high level, draw tension, germanium concentration and fiber design at the low level and furnace temp at 0.2581 which results to 0.170586 for the response. So, this is the best result we got for this project.

Conclusion

In this project we were asked to design an experiment to optimize attenuation for an optical fiber under budget restrictions. Eight factors (Fiber draw speed, Furnace temperature, Draw tension, Germanium concentration, Fiber design, Draw tower, Raw material supplier, and Coating type) have been considered in this project.

The results show that furnace temp, germanium concentration, fiber design, furnace temp*germanium concentration, draw tension* raw material supplier, germanium concentration* fiber design, furnace temp* furnace temp are the significant factors at 0.05 significance level.

The optimal setting of factors that minimize the attenuation is shown below:

- Furnace temp = 0.258 (2051.62 C)
- Draw tension = -1 (note: it is not within our significant factors)
- Germanium concentration = -1 (0.01)
- Fiber design = -1 (index 1)
- Raw material supplier = 1 (note: it is not within our significant factors)

The given setting gives us the 0.170 for the optimal attenuation.

In this project we had 8 factors that potentially affect the attenuation with a possibility of existing variability for runs within different days (block). Therefore, to investigate the effect of each factor in detail, we need to have more runs. However, we have been limited by 50 runs. On the other hand, we chose 32 runs for the screening phase, and we were unable to double them for the dealiasing phase. So, we ended up with an extra 16 runs in one more day which might possibly make our analysis biased. Consequently, there were only two runs left for the optimization step which again might be source of biases in the final conclusion. To resolve orthogonality of factors, we need 8 more runs (2 runs for each continuous factor) plus the center points, but due to limitation of budget we compromised with 2 runs for center points. Having said that, the main limitation of this project was budget restrictions.