IEE 572: Design Engineering Experiments

Project Report

Investigation of the Cleaning Power of Detergent

Submitted by

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CONTENT

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Consumption of goods is very important in our daily lives. These goods are crucial for our well-being and convenience, from personal hygiene to domestic responsibilities. The effectiveness of a consumer product is critical to both the company that manufactures it and the person who uses it. For the firm, the product's effectiveness determines its price point, customer satisfaction levels, and, eventually, the company's profitability. The effectiveness of a product defines its worth and whether it matches the user's expectations.

Laundry detergent is an example of a consumer commodity that is used in almost every home. It is an essential substance that keeps our clothing clean, fresh, and free of stains and odors. With the increased demand for laundry detergent, producers are always seeking to develop new formulas that outperform those now available while being manufactured at a lower cost.

On the other hand, the efficiency of laundry detergent varies substantially depending on the brand and price range. While some may claim that more costly detergents are more effective, others think that less expensive detergents are just as effective. To settle this argument, an experiment will be carried out to assess the effectiveness of inexpensive and costly kinds of laundry detergent.

We seek to acquire insight into the effectiveness of laundry detergents and how it affects consumers and companies through this project. By studying the findings, we can discover which brand of laundry detergent is more effective and what variables contribute to its effectiveness. This experiment will assist customers in making educated purchasing decisions and producers in developing better and more effective goods. Finally, the effectiveness of laundry detergent is an important component of our everyday lives since we rely on it to keep our clothing clean and fresh. As a result, it is critical to understand the effectiveness of various products and make informed judgments when selecting laundry detergent.

1. Recognition of and Statement of the problem.

Aim: The goal of this experiment is to compare the cleaning efficiency of detergent combinations. This will be accomplished by experimenting with various washing settings, including all combinations of three water temperatures (Cold, Warm, and Hot), two washing times (10 minutes and 20 minutes), and three agitation levels (Low, Med, High). The goal of the experiment is to identify which combination is more successful in removing stains and grime from cloth under different washing circumstances. The findings of this experiment will help determine which detergent composition is the most effective, as well as advise customers and producers about the best product to use or develop.

Objective: The objectives of this experiment are as below:

a. The main goal of this experiment is to evaluate the cleansing performance of detergent with varying combinations. The combinations will be compared to see if it offers a similar or better cleansing performance. This goal is critical because it will determine whether the time-consuming combination can be used as a more effective option than the other combination.

b. Determine whether the difference in cleansing efficiency between the different combinations is constant across all temperatures, agitation levels, and washing times, or whether the difference is contingent on the particular washing conditions.
This goal is to see if the difference in cleaning efficiency between the two combinations is constant across various washing conditions, such as temperature, agitation intensity, and washing duration. This is significant because it will help determine whether the performance difference is due to particular washing circumstances or if the time-taking combination is routinely less effective than the less agitation combination under all conditions.

c. Determine the temperatures, agitation levels, and washing periods that produce the largest variation in cleansing efficiency between the two combinations. Determine the circumstances that produce the smallest disparity. Determine whether there are any circumstances where there is no difference or where the new combination works worse.
The goal of this experiment is to determine which washing circumstances result in the largest and least variation in cleansing efficiency between the 3 different combinations. The researchers will also see if there are any circumstances in which the time-consuming version outperforms the other combinations or if there is no change in performance. This goal is critical because it will aid in determining the best cleaning circumstances for each combination, allowing for time-effective laundering.

In summation, the fundamental goals of this experiment are to compare the cleaning performance of detergent, find the effect of washing conditions on cleaning performance, and determine the optimum washing conditions for each combination. The experimenters will determine whether the time-consuming combination is a feasible alternative to the other combination while also offering time-effective cleaning performance by accomplishing these goals.

2. Selection of the response variable

Response variables are variables that provide important information about the study process. In many cases, the average and standard deviation of the experimental values represent the response variable. The experiment is carried out by cleaning different types of stains with different types of detergents. Each experiment will consist of cleaning clothes with different types of stains. This will be measured by a brightness sensor. All data will be recorded based on the brightness of the clothes. In this case, measurement error is crucial; if the sensor's capacity is insufficient, the experiment will likely only be able to detect a somewhat large factor impact, or possibly further replication will be needed. When a sensor's performance is subpar, we can test the experimental unit many times and utilize the average of those readings. Find out which particular washing conditions—such as temperatures, agitation levels, and times—lead to the biggest differences in the efficiency of the two cleaning formulas. Find the circumstances that cause the smallest difference. If there are any circumstances in which the new formula performs worse, you can find out.

Response variable(s)
1. Stain types
2. Washing time
3. Washing temperature

3. Choice of factors, levels, and ranges

Here are the factors, levels, and ranges for your investigation of the cleaning power of detergents:

3.1 Design Factors

1. ***Washing time***: Two levels
a. 10 minutes
b. 20 minutes

2. ***Water temperature***: Three levels
a. Cold
b. Warm
c. Hot

3. ***Level of agitation***: Three levels
a. Low
b. Medium
c. High

Low

Medium

High

4. *Replicate each experimental condition*: Three levels
a. 1 replicate
b. 2 replicates

3.2 Held Constant Factors

1. *Stain type*: One level
a. Dirt

2. *Brightness*: One-factor
a. The percentage rise in the brightness of the sub-specimen rinsed with the inexpensive detergent combination versus the costly combination. This factor's range will be determined by the experimental setup and technique and should be selected appropriately.

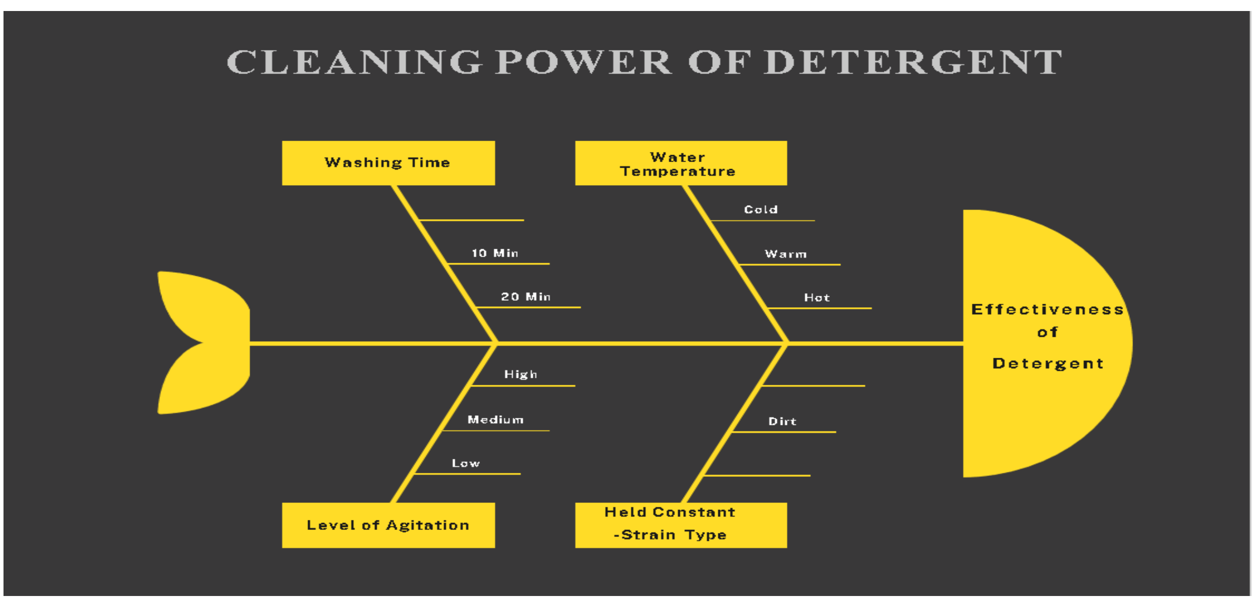


Fig: Fishbone Diagram

4. Choice of Experimental Design

During this experiment, we have identified five crucial factors that have a significant impact. To carry out this investigation, we selected three design factors: washing time, Water temperature, Level of agitation, and Replication of each experimental condition (Three levels).

We decided to work with three different types of agitation. Moreover, we subjected each of the samples to two levels of washing time -10 and 20 minutes, three levels of water temperature - cold, warm, and hot. This gave us a total of 18 experimental treatment combinations (3 x 2 x 3)

In order to reduce errors in the experimental design, we replicated each treatment combination for each fabric, washing time, water temperature, and level of agitation. This resulted in a total of 36 runs, since (3 x 2 x 3) x 2 = 36. It was important to take such measures to ensure the accuracy and reliability of our results.

Overall, our experiment was broad in scope and covered various factors that could potentially impact the washing of clothes. Through our meticulous experimental design and implementation, we have obtained valuable insights that can aid in improving the washing process and enhancing the quality of fabrics.

Deteregnt Quantity

Type of Deteregnt

Dirt Strain

5. Performing the Experiment

To ensure a rigorous experiment, we selected cotton types of fabric specimen. It was uniformly soiled with a dirt-based substance and then divided into two sub-specimens. One sub-specimen was washed in a cheap combination while the other was washed in a costly combination. To test the effect of different variables on the washing process, we subjected each sub-specimen to two levels of washing time (10 and 20 minutes), three levels of water temperature (cold, warm, and hot), and three levels of agitation (low, medium, and high). This resulted in a total of 18 experimental treatment combinations.

To minimize errors and ensure reliable results, we replicated each experiment three times, resulting in a total of **36** runs. We performed each treatment combination, washing time, water temperature, and level of agitation thrice.

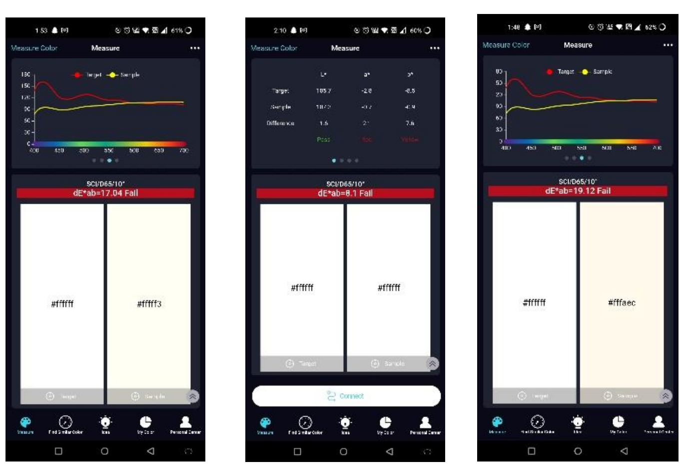
To conduct the experiment, we used a ZENY Portable Mini Washing Machine. We washed each sub-specimen according to the appropriate factor and then measured its brightness using a VEYKOLOR PRO Mini Colorimeter. To obtain accurate values, we measured the brightness in darkness. The device works on the principle of reflection, with the sub-specimen placed on a transparent glass and a light source located beneath it. The device reflects UV light, which is then absorbed by an absorber, and the value is determined.

Spectrocolrimeter

Portable Washing Machine

Cloth Washing

Randomization, one of the fundamental principles of experimental design, is accomplished in JMP for the experiments in full factorial design by plugging in the factors we have considered. Three replicas have been considered. JMP Pro is used to randomize the data to reduce some of the variability that causes errors. The randomized table associated with this experiment is shown below.



Data from Specrocolorimeter

6. Analysis of Data

6.1 JMP Table

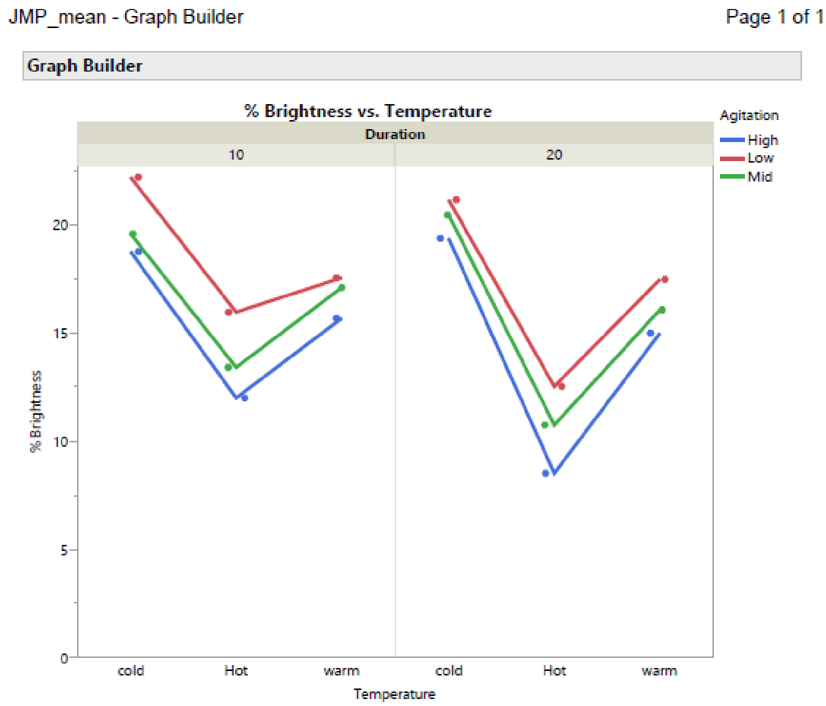
	Temperature	Duration	Agitation	Brightness (Trial 1)	Brightness (Trial 2)
1	cold	10	Low	22.43	21.95
2	cold	10	Mid	19.12	20.04
3	cold	10	High	18.57	18.96
4	cold	20	Low	21.25	21.04
5	cold	20	Mid	20.87	20
6	cold	20	High	19.68	19.05
7	warm	10	Low	18.06	17.04
8	warm	10	Mid	17.16	16.85
9	warm	10	High	16	15.35
10	warm	20	Low	17.87	17.08
11	warm	20	Mid	16.37	15.78
12	warm	20	High	14.98	15
13	Hot	10	Low	15.88	16.04
14	Hot	10	Mid	13.06	13.75
15	Hot	10	High	11.92	12.08
16	Hot	20	Low	12.07	13
17	Hot	20	Mid	10.48	11.02
18	Hot	20	High	8.91	8.13

JMP Table with repetition

	Temperature	Duration	Agitation	% Brightness
1	cold	10	Low	22.19
2	cold	10	Mid	19.58
3	cold	10	High	18.76
4	cold	20	Low	21.15
5	cold	20	Mid	20.45
6	cold	20	High	19.37
7	warm	10	Low	17.55
8	warm	10	Mid	17.1
9	warm	10	High	15.68
10	warm	20	Low	17.47
11	warm	20	Mid	16.07
12	warm	20	High	14.99
13	Hot	10	Low	15.96
14	Hot	10	Mid	13.41
15	Hot	10	High	12
16	Hot	20	Low	12.53
17	Hot	20	Mid	10.75
18	Hot	20	High	8.52

JMP Table

We start by visualizing the data. Graph shows the %Brightness values for all of the 2X3X3 = 18 various experimental settings (colored dots) as well as the average values for the two replicates (represented in colored lines).



The graph shows a few traits. The Low Agitation level has the greatest %Brightness values, while High Agitation has the lowest. The Mid Agitation results are in the middle of the two, although closer to High Agitation. When compared to the Warm and Hot Temp values, the Cold Temp values have the highest% Brightness values. For a 10-minute wash time, the %Brightness numbers are likewise greater. It is critical to delay making definitive conclusions until further formal statistical studies have been completed. Some of the changes in the graph might be due to random experimental variances rather than statistical significance.

6.2 ANOVA Table

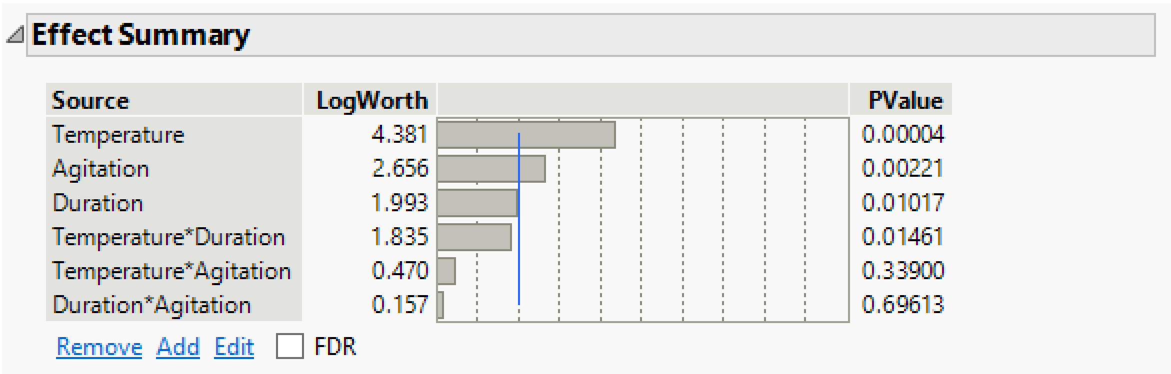
We used two-way ANOVA for analysis. Then, during analyzing, we utilize the fit model, in which we preserved '% Brightness' as the Pick Role Variable and the remaining Temperature, Duration, and Agitation as Construct model Effects, and we performed their complete factorial. This has resulted in a number of tables and graphs, which are detailed further below.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	13	238.63247	18.3563	58.0489
Error	4	1.26489	0.3162	Prob > F
C. Total	17	239.89736		0.0007*

ANOVA Table

The Effects Summary table shows the p-values associated with statistical tests evaluating the hypothesis that each of the six components we added to the model is truly useful in explaining the data. In other words, the table shows if there is sufficient information to establish that a term is statistically distinct from zero and hence should be included in the model. Log Worth is equal to -log10(p-value). This modification modifies the p-values to offer a more suitable graphing scale. At the 0.01 level, a number greater than 2 is significant because -log10(0.01)=2.



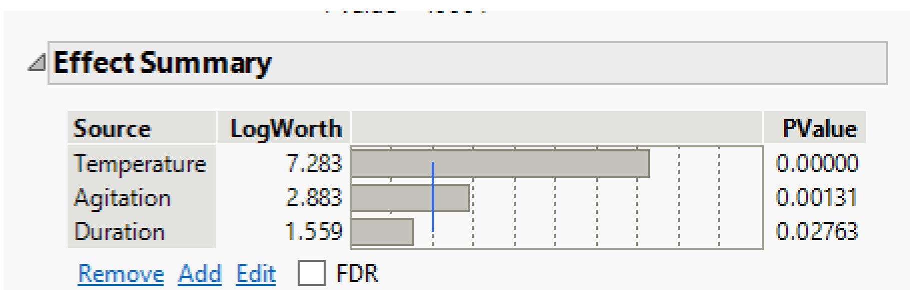
Effect Summary

Source	LogWorth	PValue
Temperature	4.381	0.00004
Agitation	2.656	0.00221
Duration	1.993	0.01017
Temperature*Duration	1.835	0.01461
Temperature*Agitation	0.470	0.33900
Duration*Agitation	0.157	0.69613

Remove Add Edit FDR

Effect Summary

The conventional method for developing an ANOVA model is to simplify the model such that it only includes statistically significant words, i.e. terms that are useful in explaining the data characteristics. The process of lowering a model starts with the most difficult terms. In this situation, it entails investigating the three two-way interactions. Temperature*Duration has a p-value of 0.01461; Duration*Agitation has a p-value of 0.69613; and Temperature*Agitation has a p-value of 0.69613. They are all significantly greater than any usual significance threshold employed (e.g., 0.01, 0.05, 0.10), indicating that these interaction terms are not useful in defining the data characteristics. An ANOVA model without interaction terms can be interpreted as the effect that each one of the three experimental factors has on the response is similar across the levels of the other factors.



Effect Summary

Source	LogWorth	PValue
Temperature	7.283	0.00000
Agitation	2.883	0.00131
Duration	1.559	0.02763

Remove Add Edit FDR

Effect Summary

The p-values for the two main impacts are all extremely significant (0.01). This illustrates that there is a substantial quantity of statistically significant data to suggest that the mean% Brightness values are not equal across the various levels of each element.

6.3 Multiple Comparison

The graph depicts the outcomes of repeated comparisons for Temp using the Student's t method.

Multiple Comparisons for Temperature

Least Squares Means Estimates

Student's t All Pairwise Comparisons

Quantile = 2.17881, DF = 12.0

All Pairwise Differences

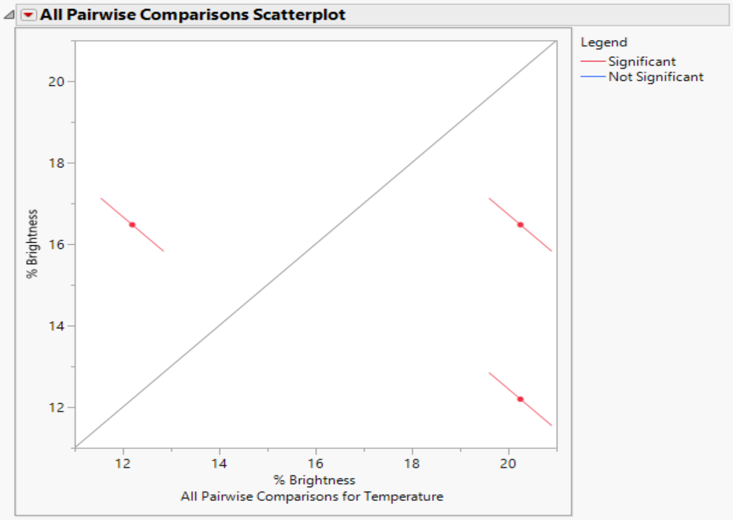
Temperature	-Temperature	Difference	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
cold	Hot	8.05500	0.5936266	13.57	<.0001*	6.76160	9.34840
cold	warm	3.77333	0.5936266	6.36	<.0001*	2.47993	5.06673
Hot	warm	-4.28167	0.5936266	-7.21	<.0001*	-5.57507	-2.98827

All Pairwise Differences Connecting Letters

Temperature				Least Squares Mean
cold	A			20.250000
warm		B		16.476667
Hot			C	12.195000

Levels not connected by same letter are significantly different.

All Pairwise Comparisons Scatterplot



Multiple Comparison

The All Pairwise Comparison scatterplot visualizes the outcomes of various comparisons. The coordinates of each pair of means are used to plot the points. For example, the point in the lower right (20.1, 12.05) represents the X-axis mean value for Cold Temp and the Y-axis mean value for Hot Temp. Hovering the cursor over the point reveals the label for each. The diagonal line depicts the point at which all of the means are equal. The red line extending from each point represents the confidence range for each pairwise comparison. If the confidence interval crosses the diagonal line, the pair under consideration is not statistically significant and is colored blue. If the CI does not cross the diagonal, as shown below, the pair under consideration is statistically distinct and is color-coded red. The CI for the comparison of Cold vs. Hot Temp is furthest from that diagonal line, which is consistent with the CI for that difference being farthest from 0. The CI for the comparison of Warm vs. Hot Temp is closest to the diagonal line.

Custom Comparison

A statistical comparison of certain experimental settings of interest might be instructive. The table, for example, shows an analysis of the hypothesis test as well as a confidence interval estimate for the difference between the two experimental conditions that yielded the greatest and lowest expected response.

Multiple Comparisons for User-Defined Estimates

User-Defined Estimates

Duration = 15, Agitation = High

Temperature	Estimate	Std Error	DF	Lower 95%	Upper 95%
cold	18.829444	0.54190451	12	17.648736	20.010153
Hot	10.774444	0.54190451	12	9.593736	11.955153

Student's t All Pairwise Comparisons

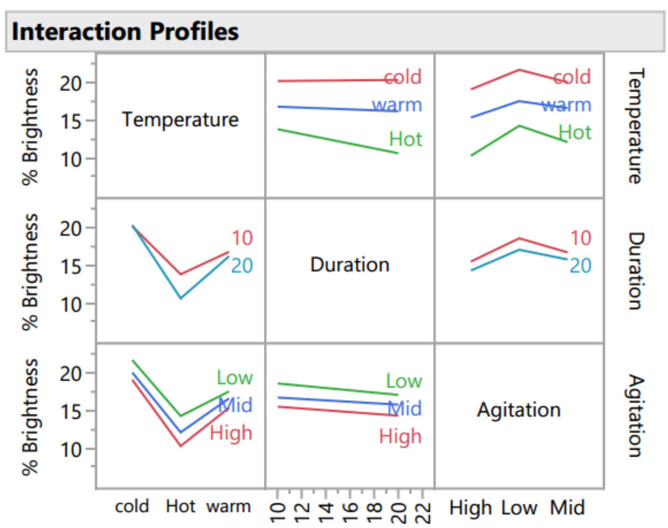
Duration = 15, Agitation = High
Quantile = 2.17881, DF = 12.0

All Pairwise Differences

Temperature	-Temperature	Difference	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
cold	Hot	8.055000	0.5936266	13.57	<.0001*	6.761599	9.348401

Multiple Comparison

6.4 Interaction Profile

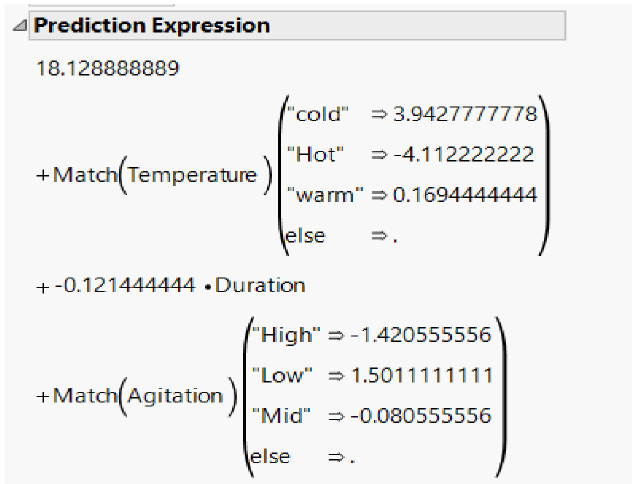


Interaction Profile

We can see that the maximum percentage change is observed when Temperature is cold and agitation is low.

6.5 Profile Prediction

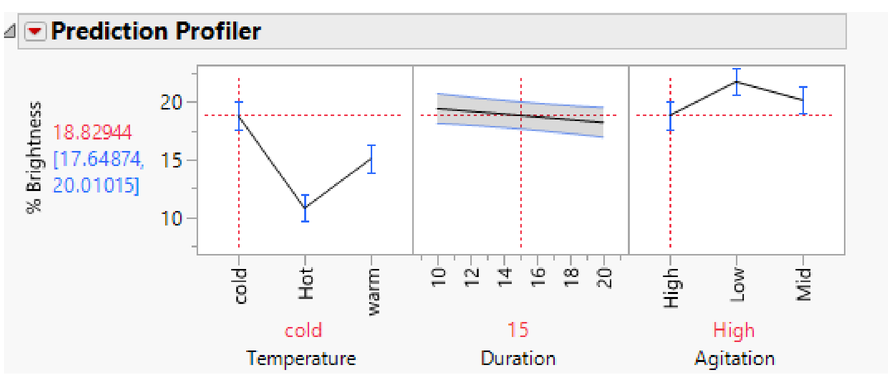
To have a better grasp of the ANOVA model that we've fitted to these data, we may look at the model's equation, as illustrated in the graphic below.



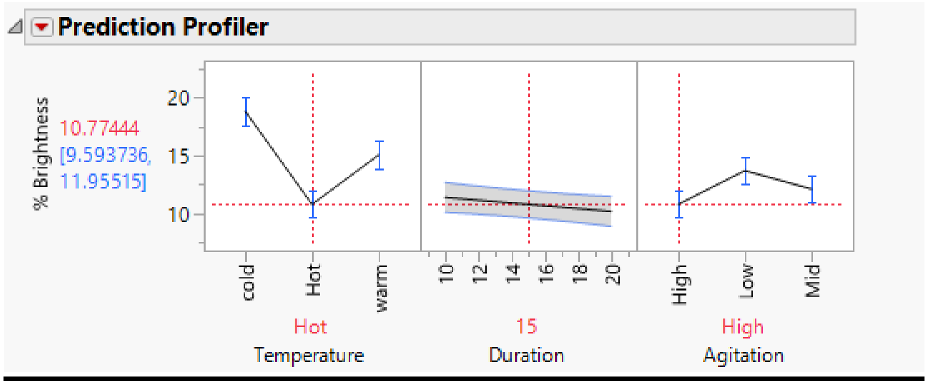
This equation yields the anticipated value for each treatment combination.

A visual representation of the model is usually the most effective method to "see" what the fitted model is. Exhibit 9 depicts visualization with the highest expected reaction in the first presentation and the lowest projected response in the second.

Prediction Profiler



The maximum projected value for the Cold Temp, 15-minute Time, and High Agitation is 18.83, with a 95% CI for the mean reaction of [17.65, 20.01].
The mean projection for the Hot Temp, 15-minute Time, and High Agitation is 10.77 (the lowest expected value), with a 95% CI of [9.59, 11.96].

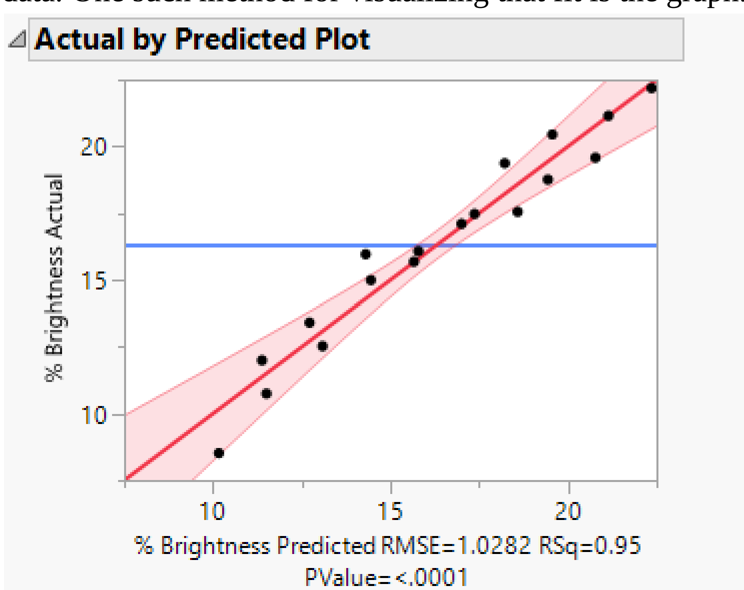


Profile Predictor

It is critical to note that the variable under consideration, % Brightness, is a measure of the percent increase in brightness between one sub-specimen washed with the new formulation and the other washed with the present formulation. Our investigation revealed that the Cold Temp, 15-minute Time, and High Agitation are the circumstances under which the new formulation outperforms the present formulation the most.

6.6 Model Performance

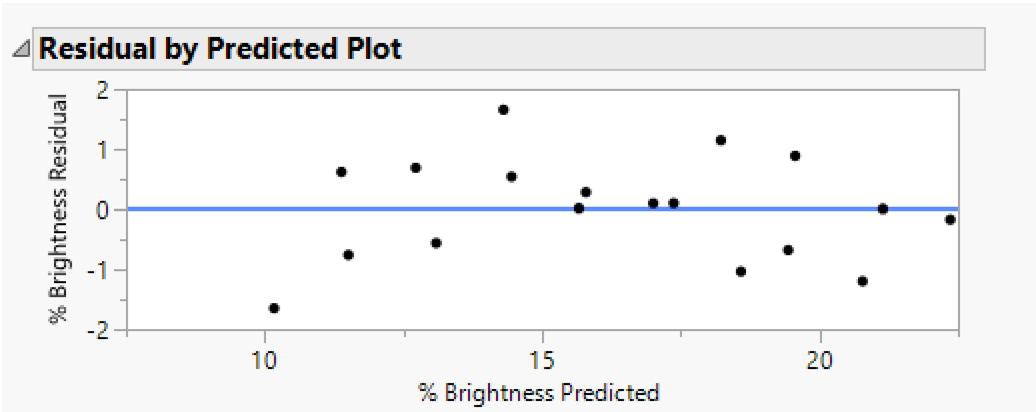
When developing a statistical model, like we have done here, it is critical to assess how well the model matches the data. One such method for visualizing that fit is the graph.



Actual by predicted plot

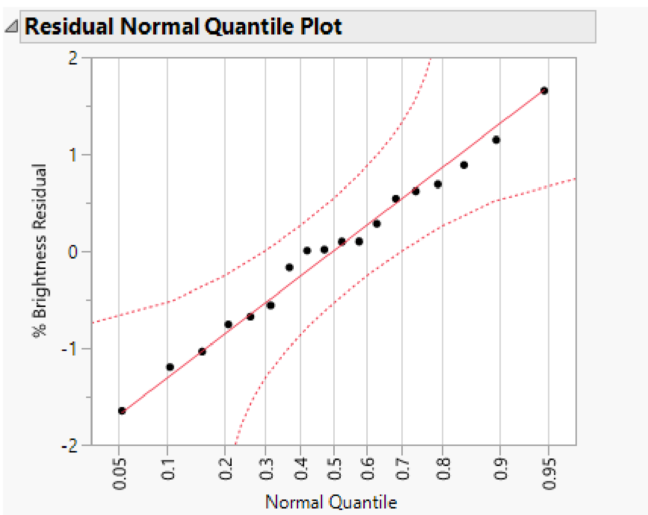
Actual% Brightness values are displayed on the Y axis, while predicted% Brightness values are plotted on the X axis. The red line indicates that the actual values are equal to the expected values. The fluctuation around that line represents the extra variation in the data that exists beyond the fitted model. The R-squared value quantifies how well the fitted model reflects the observed variance.

The graphic below is another approach to display the data variety that remains after the model has been applied.



Residual by predicted plot

On the X axis, the predicted% Brightness values are displayed, and on the Y axis, the residuals (Actual% Brightness/Predicted% Brightness). Data points on the horizontal line at 0 represent instances in which the expected and actual values are the same. Data points above the line represent observations in which the real% Brightness value exceeds the expected value, while data points below the line represent observations in which the actual value is less than the projected value.



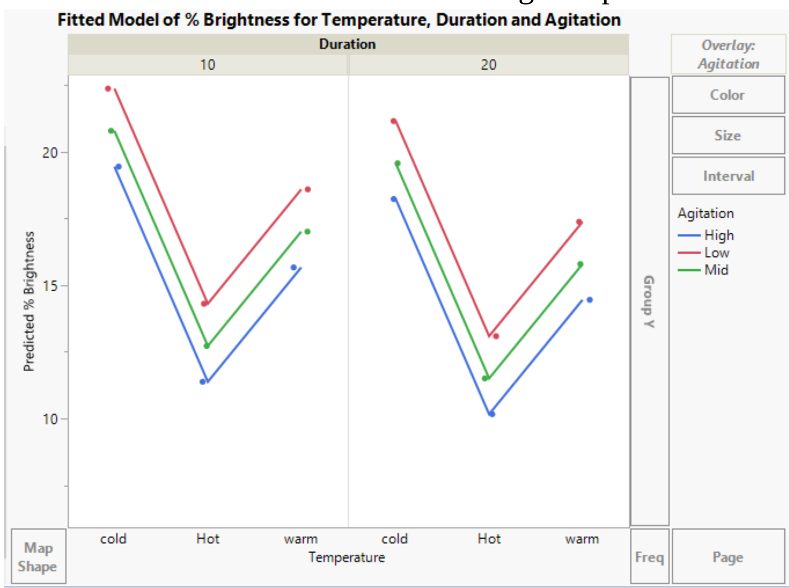
Residual Normal quantile plot

This graphic demonstrates that the residuals' normality assumption is fairly realistic.

We have no worries about the statistical tests and confidence interval estimations we got before since the assumptions of normality and homogeneity of variance in the residuals are adequate.

6.7 Fitted Model

When a statistical model is fitted to experimental data, as was done here, it might be useful to construct a visualization of that model. Two such renderings are provided in the graph.



Fitted model

These graphics depict the impact of each element on %Brightness. Because there are no interaction variables in the model, the effect of each component is the same across all levels of the other factors. This impact can be confirmed by calculating the difference between anticipated values for various experimental situations. For every combination of Temp and Agitation, the difference in expected values between 10 minutes Time and 20 minutes Time is 2.59.

7. Conclusion

Our results showed a substantial amount of statistical data suggesting that the new combination was superior. The statistical model that we created as a consequence gives an equation that we utilized to depict the improvement both visually and numerically. We discovered that this improvement varied depending on the washing circumstances (Temperature, Time, and Agitation). For example, the model assisted us in identifying the circumstances with the greatest improvement (cold temperature, 20 minutes time, and low agitation).

8. References

1. Design and Analysis of Experiments, 10th edition, by D.C. Montgomery

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