

MA548 Reliability and Quality Control  
Project:  
Olive Oil's Effect on Condom Burst Strength

Erik Erhardt

April 25, 2003

## Contents

<b>1</b>	<b>Executive Summary</b>	<b>4</b>
<b>2</b>	<b>Problem Description</b>	<b>5</b>
<b>3</b>	<b>Data Generation</b>	<b>6</b>
<b>4</b>	<b>Materials and Methods</b>	<b>9</b>
<b>5</b>	<b>Results</b>	<b>10</b>
5.1	Bottle Fill times . . . . .	10
5.2	Descriptive Statistic Analysis . . . . .	13
5.3	Distribution Verification Analysis . . . . .	16
5.4	Survival plots . . . . .	21
5.5	Kaplan-Meier Graphical Analysis . . . . .	23
5.6	Treatment Effect Analysis . . . . .	26
5.7	Nonparametric Methods Treatment Effect Analysis . . . . .	27
5.7.1	Wilcoxon and Log-Rank Nonparametric tests . . . . .	27
5.8	Normal Assumption Treatment Effect Analysis . . . . .	30
5.8.1	Homogeneity of Variance test . . . . .	30
5.8.2	Two-sample T tests . . . . .	33
5.8.3	Model equation and residual analysis (Time=Treatment) . . . . .	34

5.8.4	Model equation and residual analysis (Time=Treatment WhoHeld) . . . . .	34
5.8.5	Normal Assumption Analysis Conclusion . . . . .	36
5.9	Weibull Assumption Treatment Effect Analysis . . . . .	38
5.9.1	Log-likelihood ratio tests . . . . .	38
5.9.2	Model equation and residual analysis . . . . .	38
5.9.3	Weibull Assumption Analysis Conclusion . . . . .	40
5.10	Model Comparison . . . . .	41
<b>6</b>	<b>Conclusions</b>	<b>42</b>
<b>7</b>	<b>Appendix</b>	<b>43</b>

## List of Figures

1	Bottle Fill times are normal, though slightly autocorrelated . . .	11
2	IR Control Chart for Bottle Fill times, process in statistical control . . . . .	12
3	Fill times by treatment . . . . .	14
4	Fill times by Who Held condom . . . . .	15
5	Normal Probability Plots by Treatment with 95% Confidence Limits . . . . .	17
6	Weibull Probability Plots by Treatment with 95% Confidence Limits . . . . .	18
7	Normal Probability Plots by Who Held with 95% Confidence Limits . . . . .	19
8	Weibull Probability Plots by Who Held with 95% Confidence Limits . . . . .	20
9	Survival Plots by Treatment and by Who Held . . . . .	22
10	Kaplan-Meier Fitted Distributions by Treatment . . . . .	24
11	Kaplan-Meier Fitted Distributions by Treatment and Who Held	25
12	Control condom burst times are normal and independent . . . .	31
13	Treated condom burst times are normal and independent . . . .	32
14	Studentized Residuals Normal Quantile Plots . . . . .	35
15	Studentized Residuals Normal Quantile Plots, second fit . . . .	37
16	Standardized Residuals Smallest Extreme Value Quantile Plot	39

## 1 Executive Summary

In this report we investigate the effect of olive oil on condom burst strength using a timed destructive Water Burst Test, in which a condom is treated with olive oil then hung vertically and filled with water until it bursts. Data were collected using the Randomized Complete Block design model to control for variation in treatment and other experimental factors. Analysis of bottle fill times, as a control for consistent water flow rate, using Statistical Quality Control methods, namely Shewhart IR charts, found the water flow rate to be in statistical control.

Descriptive Statistics and Graphical methods suggested that the olive oil treatment and who held the condom effected burst times.

Distribution analysis found that the burst times were roughly normal or Weibull.

Significant difference from effects caused by treatment and who held were found using Nonparametric, Normal and Weibull analysis of the burst data. A roughly 30% decrease in the time to burst was attributed to the application of olive oil, from a median 68 to 46 seconds.

## 2 Problem Description

Sex is an important and enjoyable part of life. And it's best when worries of STD transmission and unwanted pregnancy are minimized. Condoms are the key factor for minimizing these worries in my life and the lives of many of my friends.

Condoms can be weakened by exposure to many environmental factors, however, condom breakage is rare. According to Consumer Reports (May 1995) most condom breakage is due to human error, not defective condoms. Studies have found that some condom users think products that wash off easily with water are water-based and therefore acceptable to use with condoms. However, several of the lotions that clients believed to be water-based contained mineral oil as a main ingredient<sup>1</sup>.

Only water-based lubricants should be used with latex condoms. Oil-based lubricants such as Vaseline, mineral oil, baby oil, vegetable oil, cold creams and most hand creams have oil in them that react with latex. Mineral oil, a common ingredient of hand lotions, can cause a 90 percent decrease in condom strength after as little as 60 seconds of exposure, dramatically increasing the chance of leakage or breakage<sup>2</sup>.

In this project I want to investigate this reported decrease in condom strength. I will use olive oil as my oil-based lubricant and use a timed destructive Water Burst Test as a measure of the condom burst strength<sup>3</sup>. Statistical Quality Control Methods will be employed to ensure consistency during experimentation. Reliability methods for destructive failure-time life testing and regression will be used to determine the treatment effect between oil treated condoms and out-of-the-package control condoms.

---

<sup>1</sup><http://www.jhuccp.org/pr/j44/j44chap11.c.shtml>

<sup>2</sup><http://www.globalprotection.com>

<sup>3</sup>A comprehensive series of tests with explanations and pictures can be found at Mayer Labs' Condom Production and Quality Testing website, <http://www.mayerlabs.com/consumer/quality.asp>

### 3 Data Generation

A best effort was made to replicate the customary ISO Water Burst Test. In this test, a condom is tested to see how much water it is able to hold. The condom is hung vertically and filled with water. The water fills and stretches the tip of the condom and weighs it down. Its ability to contain the water and withstand the forces on it is evaluated. The open rim of a condom is fitted over the opening of a shower hose, and the condom is filled at a constant rate until the condom bursts. Burst time is measured in seconds (s), burst weight in pounds (lbs) and burst volume in fluid ounces (oz).

Durex Natural Feeling Non-lubricated condoms (black foil with blue writing), with common expiration date 12/2005, were aquired from a common source to avoid differences in age and handling. These condoms were foil wrapped and rolled, allowing us to test condoms as they are most commonly aquired and used.

Preliminary tests were done to obtain water flow rates and consistent experimental procedure. The water flow rate was set that balanced both the need for longer times to help allow the distinction between treatment effects, and the need for shorter times to reduce fatigue on the experimenters. Surprisingly, a condom can hold up to three gallons when hanging. We had to hold the water hose and condom as it filled with a few gallons of water over an average time of 60 seconds.

In these tests, water flow was set at the beginning and untampered with. An intermediate flow switch allowed controlled stop and start of water flow so the condom could be secured on the water hose. For treated condoms, the outer surface is individually wetted by immersion in a beaker of test fluid (olive oil) to roughly two-thirds of its length (measured from the closed tip of the condom) for a designated time interval (about 90 seconds). All treatment operations were conducted at room temperature. Near the end of the interval, it is patted with paper towel to remove excess fluid. The condom is then tested on the Water Burst instrument for burst time, volume and weight. Burst times were carefully measured from the synchronized start of water flow into the condom, by use of the intermediate flow switch, until the visual detection of the burst. Immediately after the burst, the water was allowed to continue to flow, and a 30 oz bottle was filled as a control for constant water flow rate.

The Randomized Complete Block design (RCB) is used to control for variation in the experiment by accounting for spatial effects, specifically for

variation in the sequence of experimentation due to small changes in the water flow rate. Condoms are assigned at random to blocks. Treatments are assigned at random to the condoms in the blocks, each block consisting of a control and a treatment condom. The treatment fluid used is Whole Food's Extra Virgin Olive Oil. Untreated controls are taken directly from the package. There are thirty blocks or replications.

The effect of who secured and held the condom on the water hose is tested to evaluate whether the physical manipulations involved in securing the test condom on the water hose effected test results. The experimenters, Erik and Gretchen, each held fifteen blocks of condoms.

Table 1 on page 8 provides the experimental data. The column descriptions are as follows:

**Run** gives the ordered sample number.

**Treat** indicates whether the condom had the olive oil treatment, or was a control.

**Time** indicates the time until burst.

**Break** indicates whether the break occurred at the top of the condom, where it was held, or at the bottom or middle where the treatment was applied.

**Bottle** indicates the time to fill the 30 fluid ounce bottle immediately after each burst experiment.

**Holder** indicates who held the condom for that experiment.

**Vol** indicates the water volume, calculated as  $\text{Time} \times (30/\text{Bottle})$  fluid ounces.

**Wgt** indicates the water weight, calculated as  $\text{Vol}/16$  pounds.

Refer to the SAS Data step in the appendix for other variables considered.

Table 1: Experimental Data

Run	Treat	Time (s)	Break	Bottle	Holder	Vol (oz)	Wgt (lbs)
1	control	38.17	top	6.29	Gretchen	182.051	11.3782
2	oliveoil	34.67	top	6.18	Gretchen	168.301	10.5188
3	control	57.50	top	6.14	Gretchen	280.945	17.5590
4	oliveoil	41.17	bottom	6.13	Gretchen	201.485	12.5928
5	control	60.57	top	6.21	Gretchen	292.609	18.2880
6	oliveoil	48.70	bottom	6.05	Gretchen	241.488	15.0930
7	control	59.56	top	6.27	Gretchen	284.976	17.8110
8	oliveoil	38.34	bottom	5.96	Gretchen	192.987	12.0617
9	control	48.96	top	6.14	Gretchen	239.218	14.9511
10	oliveoil	44.80	bottom	5.95	Gretchen	225.882	14.1176
11	control	56.88	top	6.21	Gretchen	274.783	17.1739
12	oliveoil	37.95	bottom	6.43	Gretchen	177.061	11.0663
13	control	55.76	top	6.19	Gretchen	270.242	16.8901
14	oliveoil	38.21	bottom	6.08	Gretchen	188.536	11.7835
15	control	42.71	top	6.23	Gretchen	205.666	12.8541
16	oliveoil	40.76	top	6.33	Gretchen	193.175	12.0735
17	control	81.98	top	6.08	Gretchen	404.507	25.2817
18	oliveoil	42.20	bottom	6.20	Gretchen	204.194	12.7621
19	control	34.42	top	5.98	Gretchen	172.676	10.7922
20	oliveoil	48.73	bottom	5.94	Gretchen	246.111	15.3819
21	control	41.75	top	5.94	Erik	210.859	13.1787
22	oliveoil	59.65	bottom	6.09	Erik	293.842	18.3651
23	control	76.73	bottom	6.14	Erik	374.902	23.4314
24	oliveoil	42.40	bottom	6.11	Erik	208.183	13.0115
25	control	64.85	top	6.28	Erik	309.793	19.3621
26	oliveoil	45.77	bottom	6.11	Erik	224.730	14.0456
27	control	74.70	bottom	6.04	Erik	371.026	23.1892
28	oliveoil	45.63	bottom	6.03	Erik	227.015	14.1884
29	control	77.67	top	6.19	Erik	376.430	23.5269
30	oliveoil	44.63	bottom	6.30	Erik	212.524	13.2827
31	control	68.16	bottom	6.12	Erik	334.118	20.8824
32	oliveoil	50.06	bottom	5.99	Erik	250.718	15.6699
33	control	86.61	bottom	6.25	Erik	415.728	25.9830
34	oliveoil	49.47	bottom	6.05	Erik	245.306	15.3316
35	control	67.91	bottom	6.05	Erik	336.744	21.0465
36	oliveoil	43.38	bottom	6.04	Erik	215.464	13.4665
37	control	81.17	bottom	6.03	Erik	403.831	25.2394
38	oliveoil	42.94	bottom	6.10	Erik	211.180	13.1988
39	control	71.50	top	6.34	Erik	338.328	21.1455
40	oliveoil	52.47	bottom	6.00	Erik	262.350	16.3969
41	control	80.52	bottom	6.20	Gretchen	389.613	24.3508
42	oliveoil	44.34	bottom	5.89	Gretchen	225.840	14.1150
43	control	84.99	bottom	6.07	Gretchen	420.049	26.2531
44	oliveoil	48.30	bottom	5.91	Gretchen	245.178	15.3236
45	control	72.17	top	6.06	Gretchen	357.277	22.3298
46	oliveoil	46.32	bottom	6.03	Gretchen	230.448	14.4030
47	control	59.85	top	6.03	Gretchen	297.761	18.6101
48	oliveoil	49.86	bottom	5.99	Gretchen	249.716	15.6073
49	control	54.86	top	6.06	Gretchen	271.584	16.9740
50	oliveoil	50.17	bottom	6.01	Gretchen	250.433	15.6520
51	control	77.20	bottom	5.91	Erik	391.878	24.4924
52	oliveoil	47.33	bottom	5.90	Erik	240.661	15.0413
53	control	69.92	top	6.06	Erik	346.139	21.6337
54	oliveoil	48.37	bottom	5.93	Erik	244.705	15.2941
55	control	72.47	bottom	6.07	Erik	358.171	22.3857
56	oliveoil	46.14	bottom	5.88	Erik	235.408	14.7130
57	control	72.58	bottom	5.89	Erik	369.677	23.1048
58	oliveoil	48.78	bottom	5.85	Erik	250.154	15.6346
59	control	62.43	top	6.15	Erik	304.537	19.0335
60	oliveoil	45.57	bottom	6.05	Erik	225.967	14.1229

## 4 Materials and Methods

This project employed methods from both halves of the course, Quality Control and Reliability. In the first part of the project, we assess the experiment for consistence using Quality Control methods. In the remaining parts of the project, we use Reliability methods to determine distributions to fit our data, create survival plots, and perform treatment effect analysis. Below is a brief discussion of the methods used for this project.

Statistical Quality Control methods, namely Shewhart IR charts, we used to determine whether the water flow rate was in statistical control. QQ-plots, ACF plots and the Shapiro-Wilk test were used to assess model assumptions of normality and independence.

Descriptive Statistics (mean, standard deviation, quantiles) and Graphical methods (box plots and histograms) were used to assess differences in condom burst times by treatment and by who held the condom.

Probability plots were used to determine models for the data. Survival plots were used to see visually the probability of surviving beyond time  $t$ . Kaplan-Meier Graphical Analysis was used, again, to determine models for the data.

Treatment effect Analysis was performed using nonparametric methods, where no distribution is assumed, and under Normal and Weibull assumption models. Tests for location for all methods and scale for Normal was done. The nonparametric Wilcoxon test was used to check for equal medians between treatment types. Using the normal model, a Log Likelihood test and Levene's test were used to check for homogeneity of variance. Two-sample T tests were used to test for equal means between treatments and who held. ANOVA was used to assess model fit and parameter estimates. Analysis of studentized residuals were used to check model assumptions. Using the Weibull model, a Log Likelihood test was used to determine which regressors to use, and standardized residuals were used to check model assumptions.

## 5 Results

### 5.1 Bottle Fill times

During our experiment, we took flow rate measurements after every trial. Therefore, it makes sense to first assess whether these flow times are in statistical control.

First we check the assumptions of normality and independence by use of QQ and ACF plots. The plots in Figure 1 on page 11 do not strongly suggest individual Bottle Fill times do not have a normal distribution, additionally, the Shapiro-Wilk Test for Normality gives a p-value of 0.3701, which provides insufficient evidence to reject the assumption of normality. However, the plots do suggest that there is a slight autocorrelation. It has been considered that if water pressure rises slightly while the intermediate flow switch halts water flow, and if water pressure drops slightly while water runs, then for the runs that took longer (control condoms), the bottle fill time might be longer. This might explain the oscillating ACF. In fact, we find the means of the Bottle Fill times by Treatment to be different in Table 2 on page 10. The difference is not large, but is significant at the 95% level, based on the confidence limits.

Table 2: Bottle Fill times by Treatment

Parameter	Control			Treated		
	Estimate	LCL	UCL	Estimate	LCL	UCL
Mean	6.1207	6.0778	6.1636	6.0503	5.9995	6.1011
Std Dev	0.1149	0.0915	0.1544	0.1360	0.1083	0.1829
Variance	0.0132	0.0084	0.0239	0.0185	0.0117	0.0334

The Shewhart IR plots in Figure 2 on page 12 demonstrates the Bottle Fill times are in statistical control. At  $3\sigma$  control limits, the charts can be summarized in this way:

**I-chart:** LCL=5.73672, CL=6.0855, UCL=6.43428

**R-chart:** LCL=0, CL=0.13119, UCL=0.42852

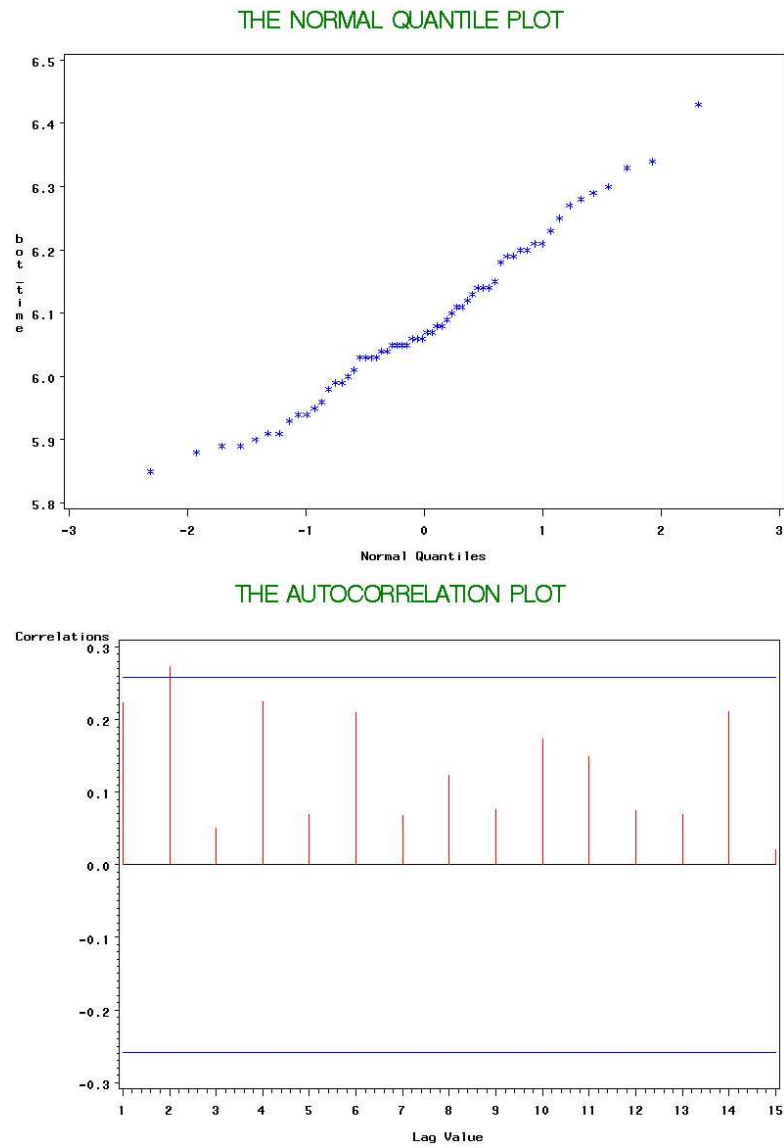


Figure 1: Bottle Fill times are normal, though slightly autocorrelated

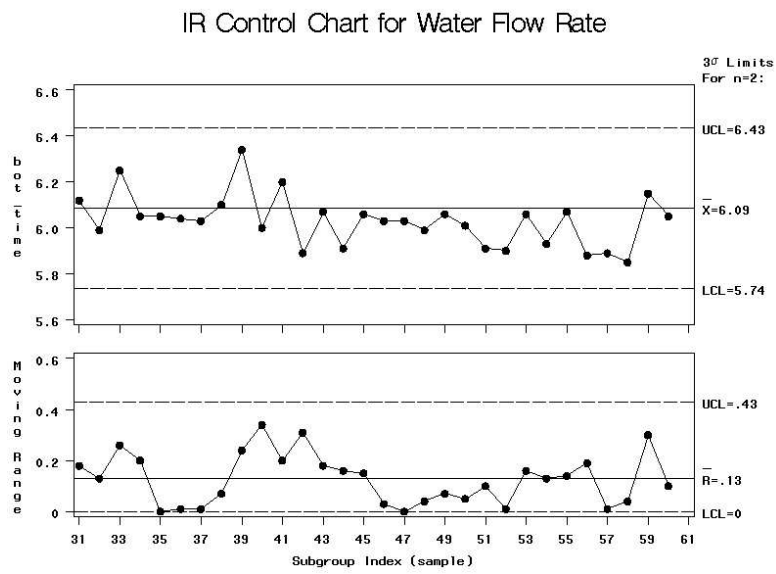
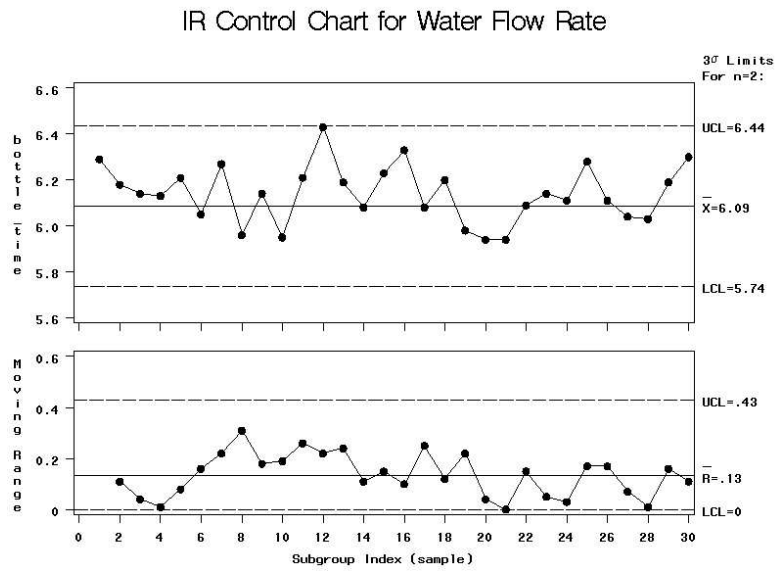


Figure 2: IR Control Chart for Bottle Fill times, process in statistical control

## 5.2 Descriptive Statistic Analysis

Table 3 on page 13 gives the moments and quantiles for the time to burst for control and treatment condoms. The mean time to burst was roughly 65 seconds for the control and 46 seconds for the treated condoms. The Shapiro-Wilk tests for normality gives a p-value of 0.2202 for the control and p-value of 0.5130 for the treated condoms, providing insufficient evidence to reject the assumption of normality for either population.

Table 3: Moments and Quantiles for Time by Treatment and by Who Held

		Treatment		Who Held	
		Control	Treatment	Erik	Gretchen
<i>Moments</i>	N	30	30	30	30
	Mean	65.1517	45.5703	59.2747	51.4473
	Std Dev	14.1295	5.0245	14.2531	13.7249
<i>Quantiles</i>	100% Max	86.6100	59.6500	86.6100	84.9900
	75% Q3	76.7300	48.7300	72.4700	57.5000
	50% Med	68.0350	45.7000	56.0600	48.7150
	25% Q1	56.8800	42.4000	45.7700	41.1700
	0% Min	34.4200	34.6700	41.7500	34.4200
	Range	52.1900	24.9800	44.8600	50.5700
	Q3-Q1	19.8500	6.3300	26.7000	16.3300

The Box plot and Histograms in Figure 3 on page 14 show the large difference in location and scale for the fill times by treatment. The Box plot and Histograms in Figure 4 on page 15 show a small difference in location and scale for the fill times by who held the condom. The bimodality is from the dominant treatment effect. Details for both of these are in Table 3 on page 13.

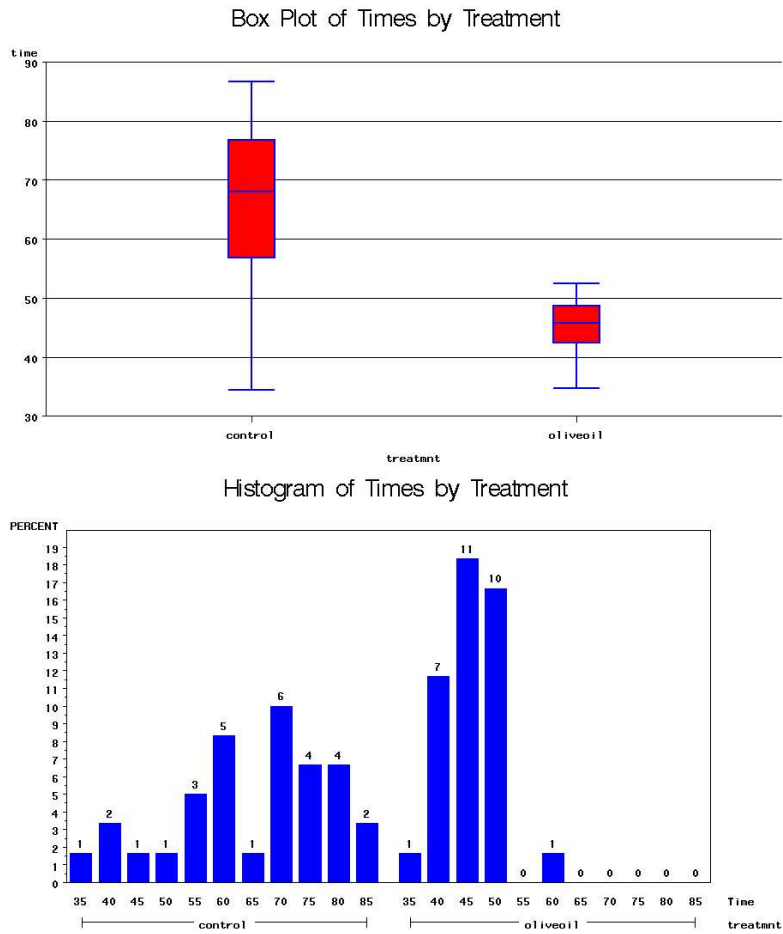


Figure 3: Fill times by treatment

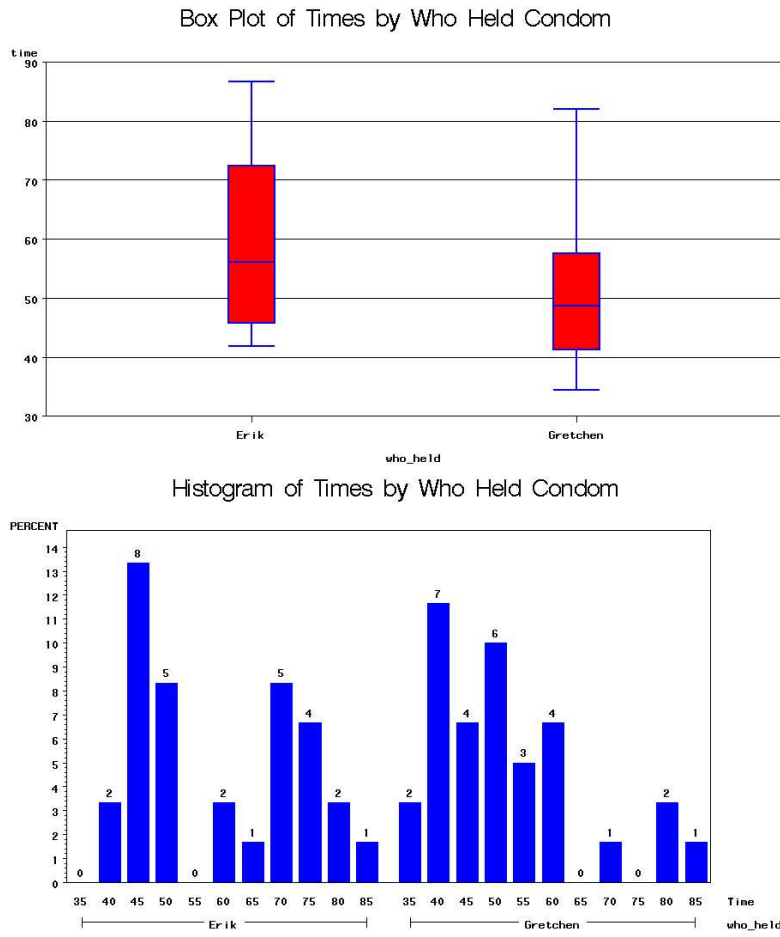


Figure 4: Fill times by Who Held condom

### 5.3 Distribution Verification Analysis

The probability plots of the data were used to analyze model fit. Normal plots by treatment appear in Figure 5 on page 17. Weibull plots by treatment appear in Figure 6 on page 18. The data does not deviate from the assumptions of either the normal or the Weibull distribution. The normal distribution does seem to fit the data by treatment better than the Weibull. For the normal distribution, for the control and treated condoms there is only one point outside the 95% confidence limits for each probability plot. For the Weibull distribution, for the control condoms there are no points outside the 95% confidence limits, but for the treated condoms there are four (maybe five) points outside.

Normal plots by who held appear in Figure 7 on page 19. Weibull plots by who held appear in Figure 8 on page 20. The data by Who Held does deviate from the assumptions of both the normal and the Weibull distribution. In fact, because the treatment effect is dominant, no common distribution would fit the data strictly by Who Held. Again, the histograms in Figure 4 on page 15 indicate bimodality from the treatment effect.

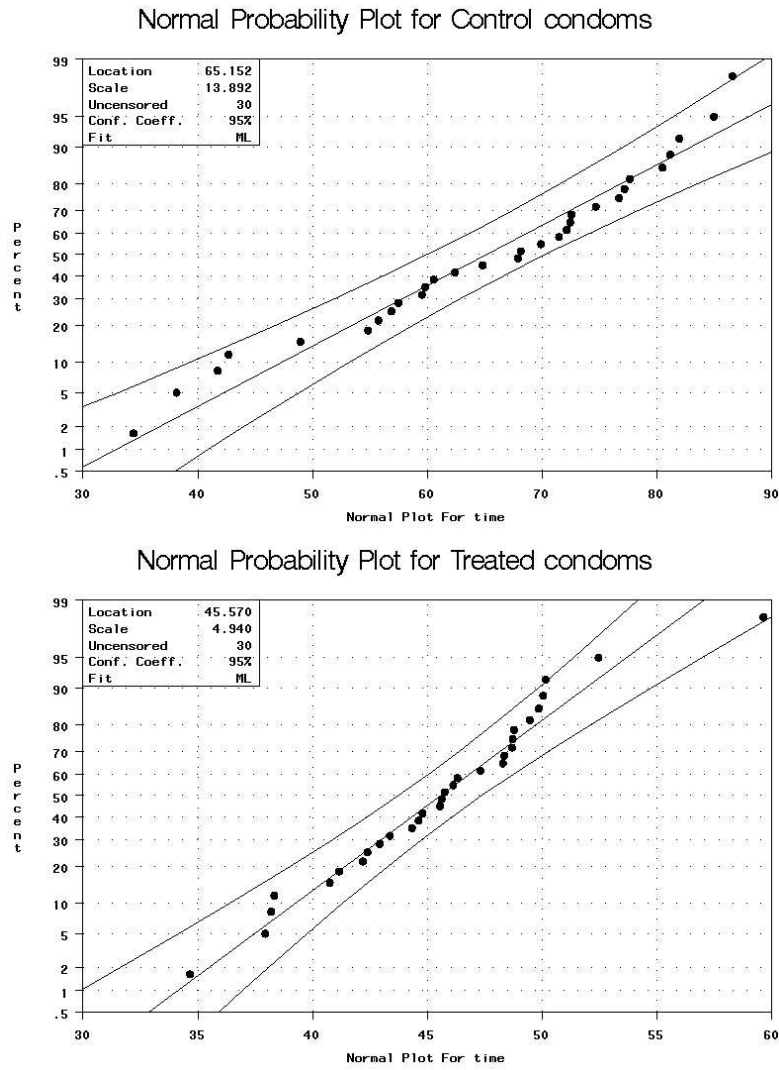


Figure 5: Normal Probability Plots by Treatment with 95% Confidence Limits

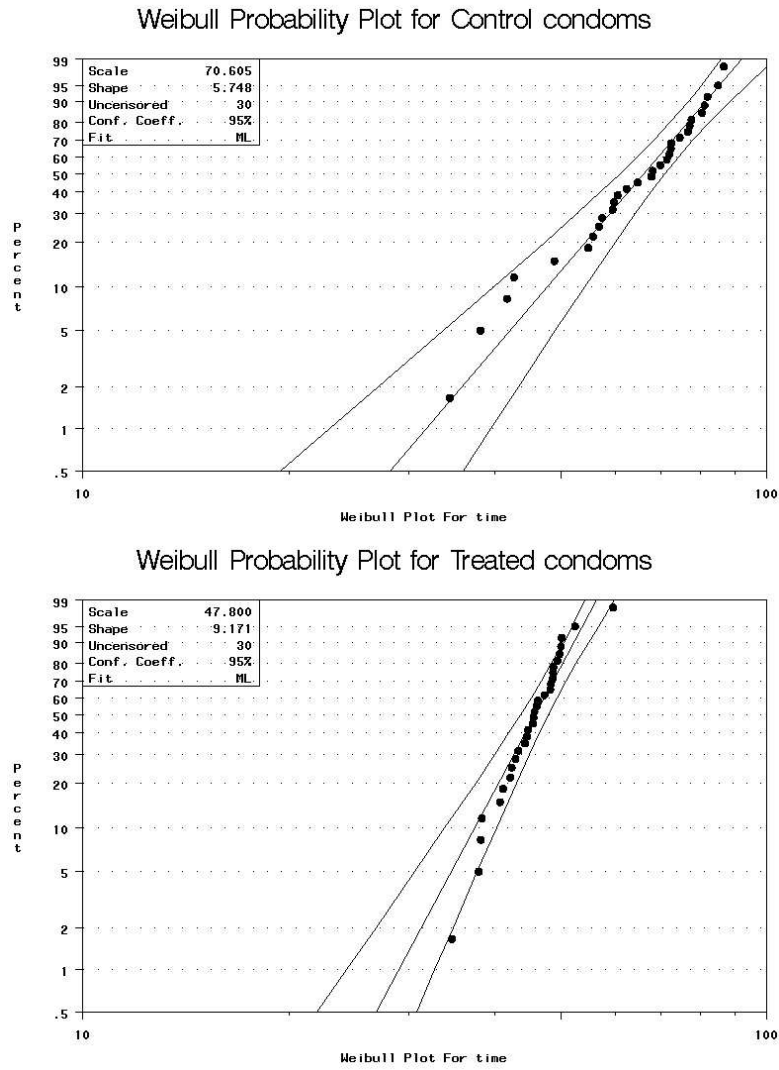


Figure 6: Weibull Probability Plots by Treatment with 95% Confidence Limits

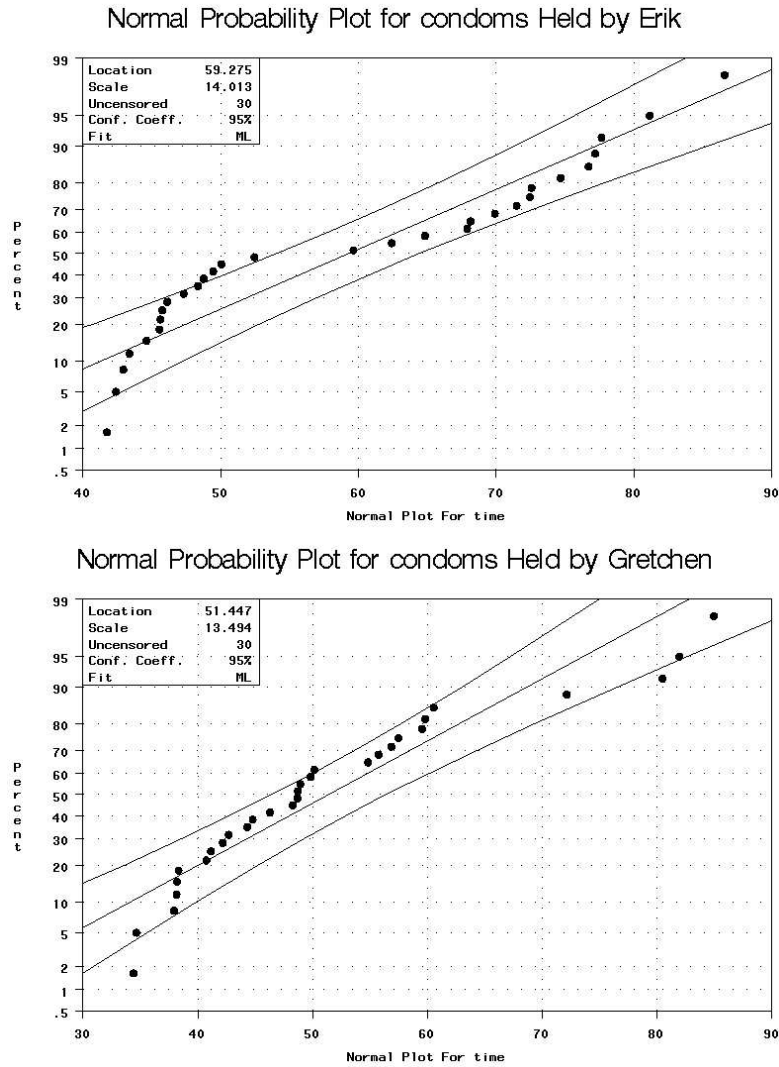


Figure 7: Normal Probability Plots by Who Held with 95% Confidence Limits

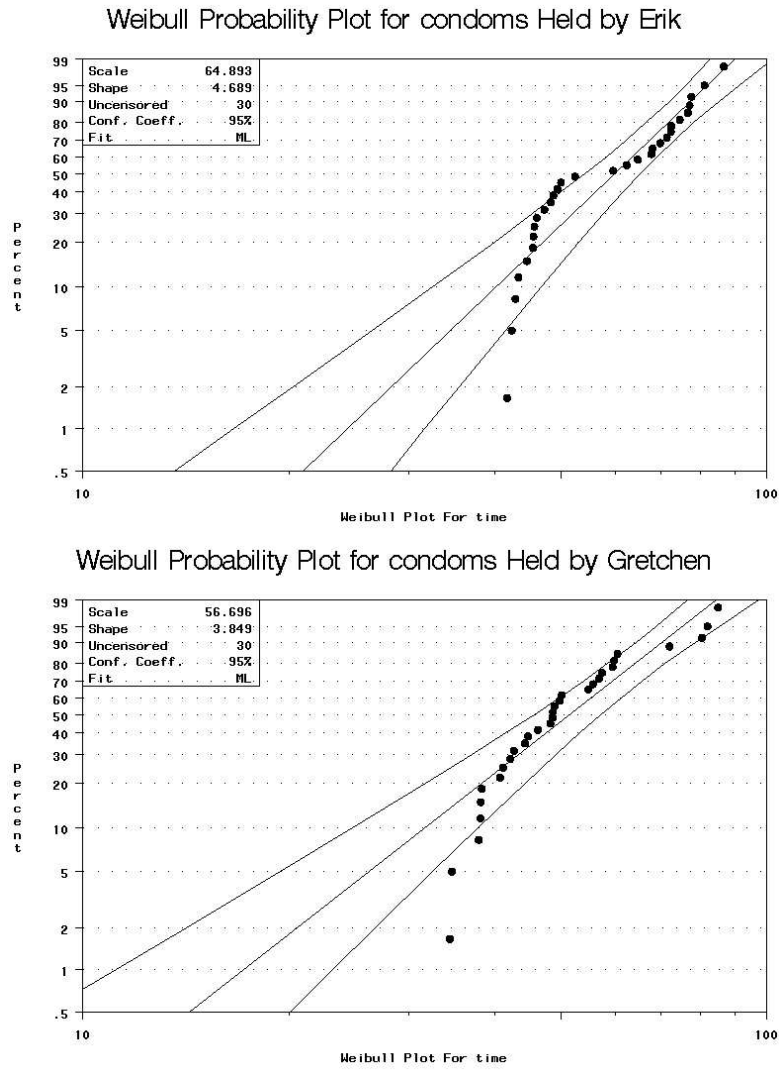


Figure 8: Weibull Probability Plots by Who Held with 95% Confidence Limits

## 5.4 Survival plots

Survival plots by Treatment and by Who Held are shown in Figure 9 on page 22. The first condom failures occurred at 35 seconds. In the Survival plot by treatment, at 50 seconds, more than 90% of the treated condoms had failed when less than 20% of the control condoms had failed. The two survival functions have very different slopes, the treated condoms having an extremely steep descent, while the control condoms descend much more slowly. In the Survival plot by who held, the condoms held by Erik tended to take longer to fail. This difference is not nearly as drastic as the treatment effect, however. Note that you can see in this plot the separate slopes in each Survival function due to the treatment effect, first the steep descent from the treated condoms, then the gradual descent from the control condoms.

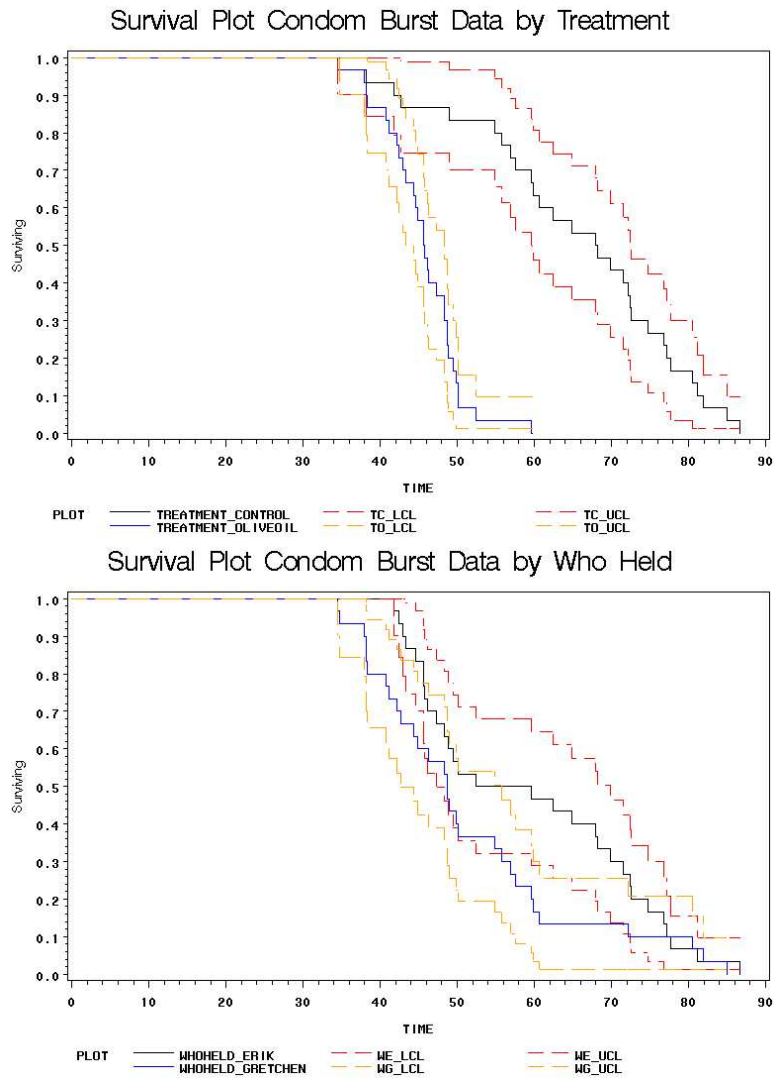


Figure 9: Survival Plots by Treatment and by Who Held

## 5.5 Kaplan-Meier Graphical Analysis

The Weibull and Exponential distributions were considered in fitting the data shown in Figure 10 on page 24. It appears the Weibull distribution characterizes the data appropriately, as the data appear to fall along a straight line. I did not expect the Exponential distribution to fit, but included it here as an example of a poor fit, for contrast. In the Weibull Plot, the early failures do not properly fit, five for the control and four for the treated groups. When who held is included in the model, shown in Figure 11 on page 25, it appears again that the Weibull distribution characterizes the data appropriately, as the data appear to fall along a straight line.

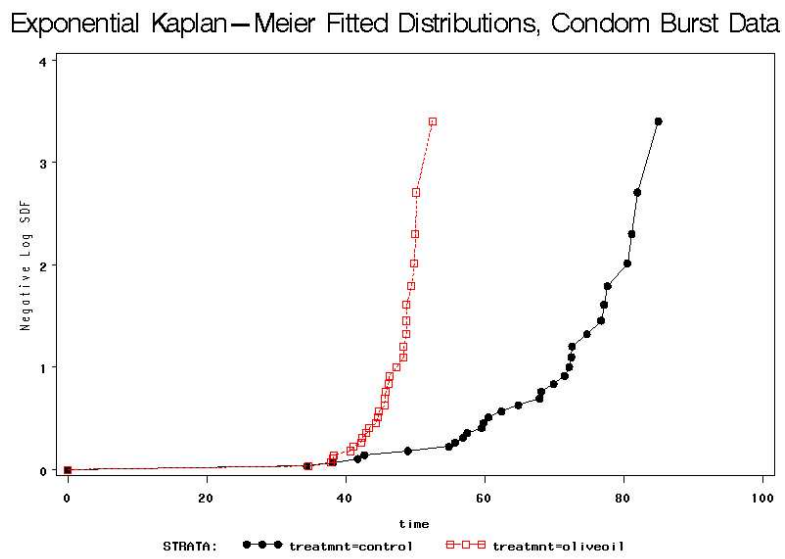
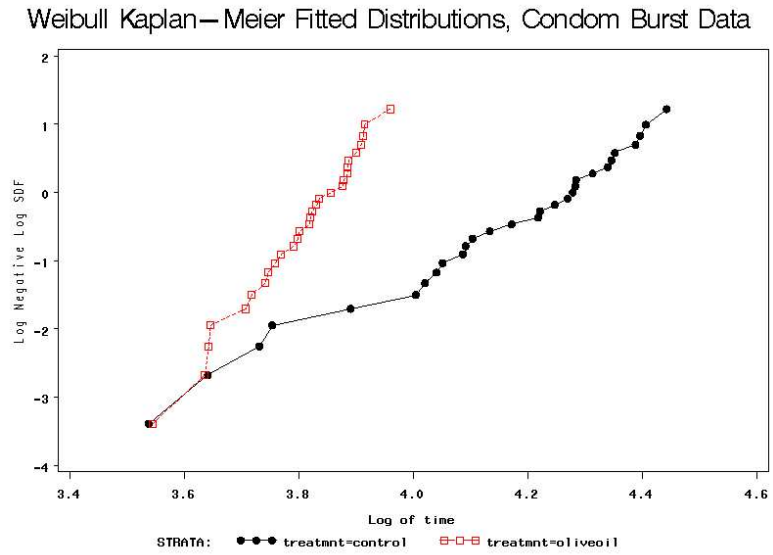


Figure 10: Kaplan-Meier Fitted Distributions by Treatment

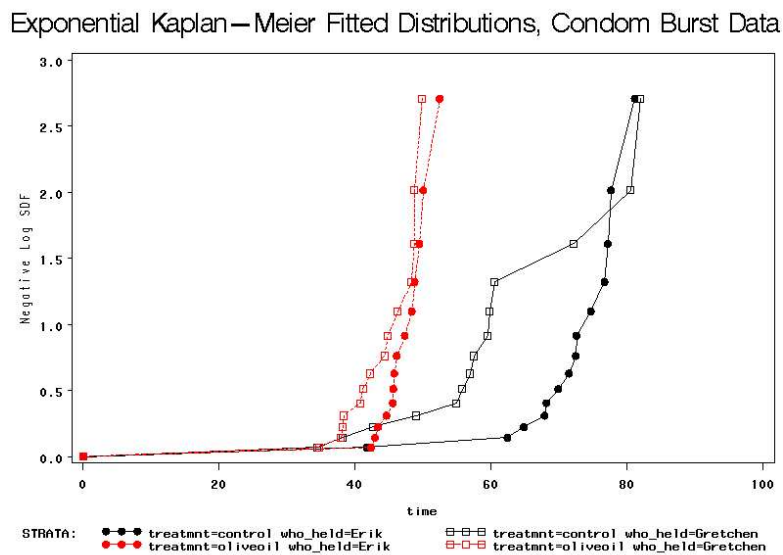
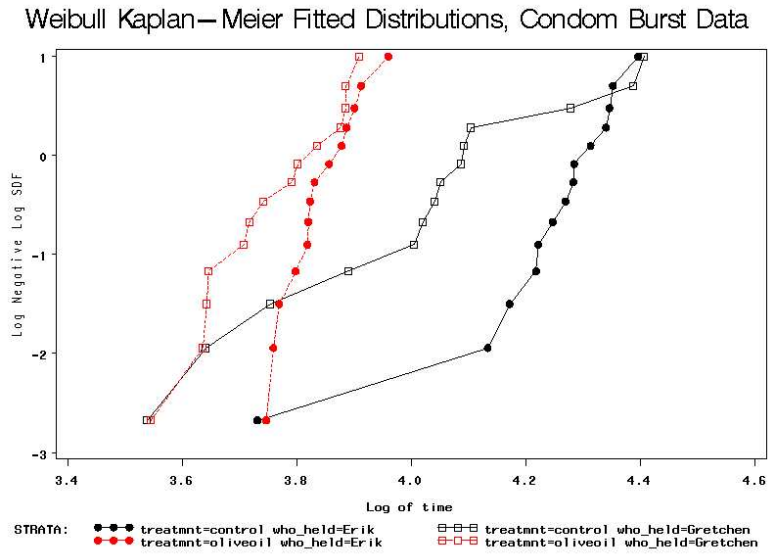


Figure 11: Kaplan-Meier Fitted Distributions by Treatment and Who Held

## 5.6 Treatment Effect Analysis

The data does not deviate from assumptions of either the Normal or Weibull Distributions. Three testing methods are used to analyze the data.

1. Nonparametric Methods Analysis (no distribution assumed)
  - Wilcoxon test
  - Log-Rank test
2. Normality Assumption Analysis
  - Homogeneity of Variance test
  - two-sample T test
  - Model equation and residual analysis
3. Weibull Assumption Analysis
  - Log-likelihood ratio tests
  - Model equation and residual analysis

## 5.7 Nonparametric Methods Treatment Effect Analysis

### 5.7.1 Wilcoxon and Log-Rank Nonparametric tests

Results of the homogeneity tests across treatment types are given in Table 4 on page 27. The log-rank and Wilcoxon statistics and their corresponding covariance matrices are displayed. Also given is a table that consists of the approximate chi-square statistics, degrees of freedom, and p-values for the log-rank, Wilcoxon, and likelihood ratio tests. The log-rank and Wilcoxon tests indicate strong evidence of a significant difference among the survival curves for the two treatment types ( $p < 0.0001$ ). That is, there is a difference between the median control condom burst time of 68.0350 and the median treated condom burst time of 45.7000, and is in fact longer.

Table 4: Nonparametric homogeneity tests across treatment types

Rank Statistics		
treatmnt	Log-Rank	Wilcoxon
control	-17.499	-670.00
oliveoil	17.499	670.00

Covariance Matrix for the Log-Rank Statistics		
treatmnt	control	oliveoil
control	7.51534	-7.51534
oliveoil	-7.51534	7.51534

Covariance Matrix for the Wilcoxon Statistics		
treatmnt	control	oliveoil
control	15749.0	-15749.0
oliveoil	-15749.0	15749.0

Test of Equality over Strata			
Test	Chi-Square	DF	p-value
Log-Rank	40.7473	1	< .0001
Wilcoxon	28.5034	1	< .0001
-2Log(LR)	1.9066	1	0.1673

If we include Who Held in the model, we obtain similar results. Results of the homogeneity tests across treatment types and who held are given in Table 5 on page 29. The log-rank and Wilcoxon statistics and their corresponding covariance matrices are displayed. Also given is a table that consists of the approximate chi-square statistics, degrees of freedom, and p-values for the log-rank, Wilcoxon, and likelihood ratio tests. The log-rank and Wilcoxon tests indicate strong evidence of a significant difference among the survival curves for the two treatment types ( $p < 0.0001$ ). That is, there is at least one difference between the medians for the control condom burst time for Erik of 72.4700 and Gretchen of 57.5000 and the treated condom burst time for Erik of 46.1400 and Gretchen of 44.3400.

Table 5: Nonparametric homogeneity tests across stratum: treatment and who held

Legend for Strata			Rank Statistics		
Stratum	treatmnt	who held	Stratum	Log-Rank	Wilcoxon
1	control	Erik	1	-13.371	-513.00
2	control	Gretchen	2	-4.129	-157.00
3	oliveoil	Erik	3	7.451	227.00
4	oliveoil	Gretchen	4	10.048	443.00

Covariance Matrix for the Log-Rank Statistics				
Stratum	1	2	3	4
1	13.0088	-8.9711	-2.4919	-1.5457
2	-8.9711	12.4488	-2.1237	-1.3540
3	-2.4919	-2.1237	5.8071	-1.1916
4	-1.5457	-1.3540	-1.1916	4.0913

Covariance Matrix for the Wilcoxon Statistics				
Stratum	1	2	3	4
1	15657.0	-7290.0	-4951.0	-3416.0
2	-7290.0	14672.0	-4347.0	-3035.0
3	-4951.0	-4347.0	12249.0	-2951.0
4	-3416.0	-3035.0	-2951.0	9402.0

Test of Equality over Strata			
Test	Chi-Square	DF	p-value
Log-Rank	45.8649	3	< .0001
Wilcoxon	34.9143	3	< .0001
-2Log(LR)	2.2071	3	0.5306

## 5.8 Normal Assumption Treatment Effect Analysis

First we check the assumptions of normality and independence by use of QQ and ACF plots. The plots for control condoms in Figure 12 on page 31 do not strongly suggest the burst times do not have a normal distribution, or are not independent. Additionally, the Shapiro-Wilk Test for Normality gives a p-value of 0.2202, which provides insufficient evidence to reject the assumption of normality. The plots for treated condoms in Figure 13 on page 32 do not strongly suggest the burst time do not have a normal distribution, or are not independent. Additionally, the Shapiro-Wilk Test for Normality gives a p-value of 0.5130, which provides insufficient evidence to reject the assumption of normality.

### 5.8.1 Homogeneity of Variance test

We test the equal variance hypothesis  $H_0 : \sigma_{control} = \sigma_{oliveoil}$  versus  $H_1 : \sigma_{control} \neq \sigma_{oliveoil}$ . Under the null hypothesis, the common, pooled, estimate of the residual (co)variance is 112.44. The Restricted Log Likelihood is  $-222.7$ . Under the alternative hypothesis, the estimated variance for control condoms is 199.64 and for the treated condoms 25.2455. The Restricted Log Likelihood is  $-209.3$ . The two models that we have just fitted differ only in the 1 extra variance component in the second model. To determine if the ‘goodness of fit’ of the model has improved, we use the Restricted Log Likelihoods. Standard Maximum Likelihood theory tells us that negative twice the difference in the Log Likelihoods of our models has a chi-squared distribution. Thus since the models differ only in the second model having 1 extra variance parameter there will be 1 degree of freedom difference. Thus,  $-2(-222.7 - -209.3) = -2(-13.4) = 26.8$ .

At the  $\alpha = 0.05$  significance level we find from statistical tables that 1 degree of freedom chi-squared has a critical value of 3.84; that is to say that a chi-squared value of greater than 3.84 is statistically significant. Therefore we reject  $H_0$  and conclude that there was significant improvement in the model by including the extra variance component since the variance components by treatment are different.

We can also use Levene’s Test for Homogeneity of Variance given in Table 6 on page 33, which rejects the same null hypothesis.

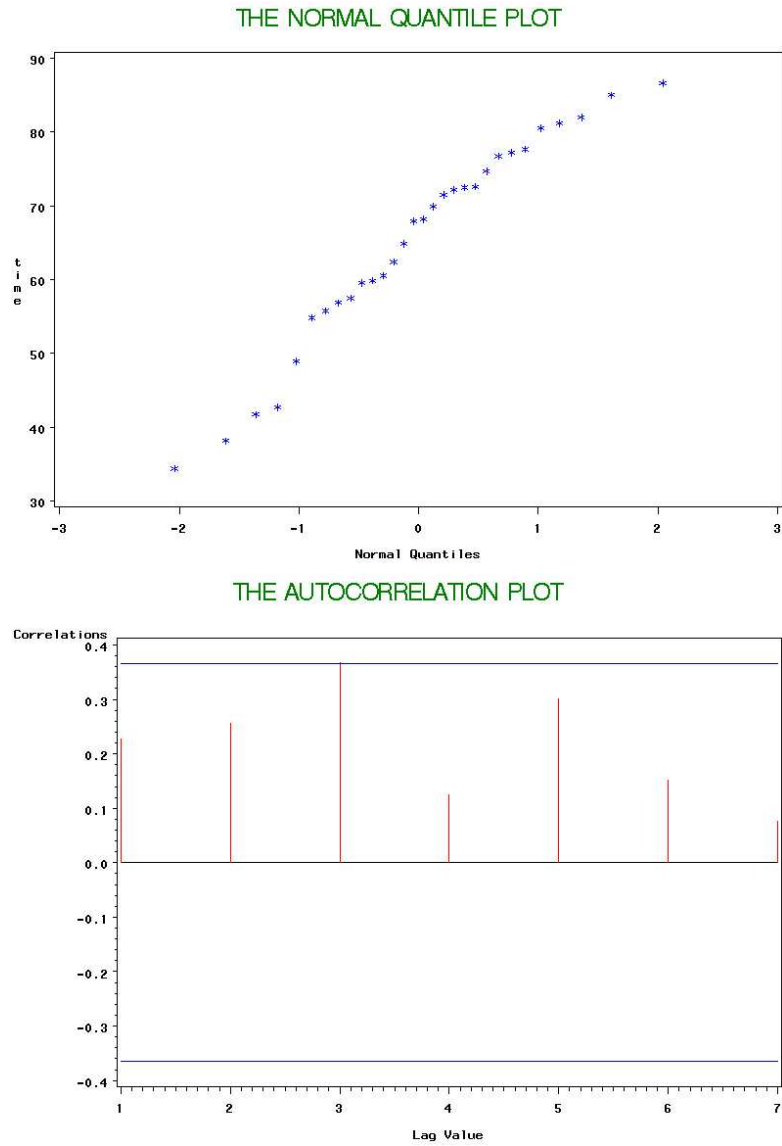


Figure 12: Control condom burst times are normal and independent

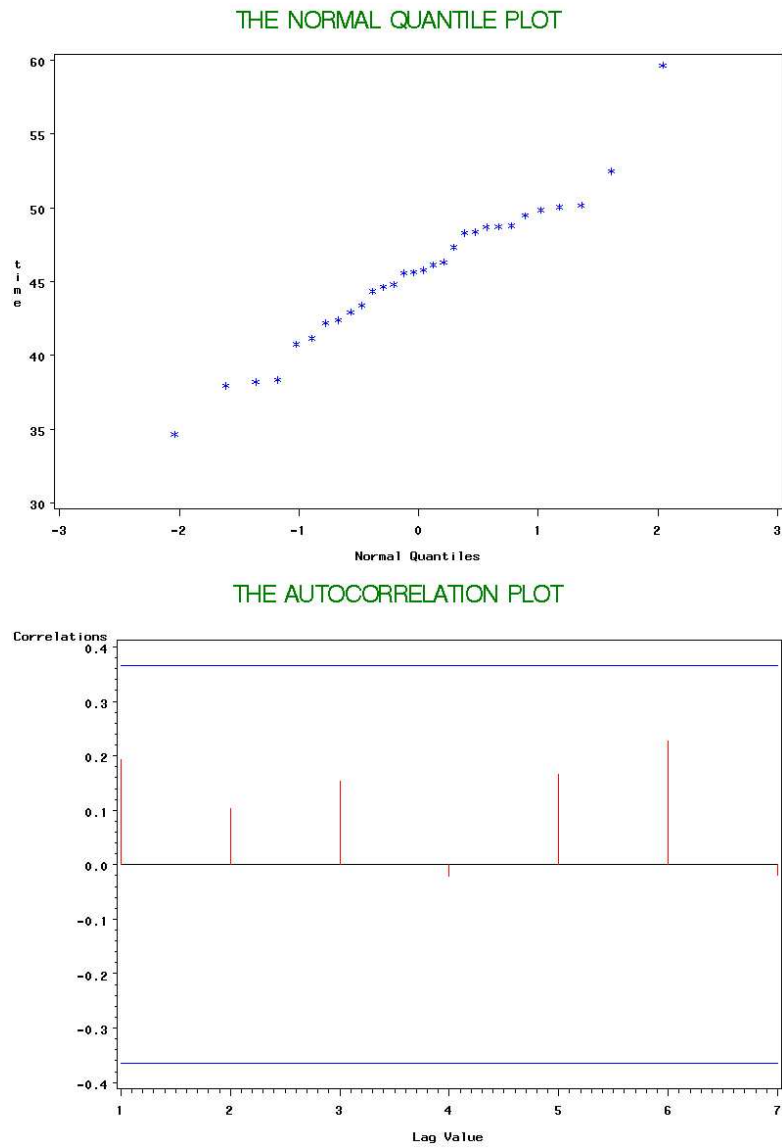


Figure 13: Treated condom burst times are normal and independent

Table 6: Levene's Test for Homogeneity of time Variance

ANOVA of Squared Deviations from Group Means					
Source	DF	SS	MS	F Value	p-value
treatmnt	1	426304	426304	14.92	0.0003
Error	58	1657477	28577.2		

### 5.8.2 Two-sample T tests

We test the equal Treatment mean hypothesis  $H_0 : \mu_{control} - \mu_{oliveoil} = 0$  versus  $H_1 : \mu_{control} - \mu_{oliveoil} \neq 0$ . Under the null hypothesis, the difference in means are 0. Table 7 on page 33 shows the result of a Two-sample T test used to compare the average burst times for the two treatment groups. We find that the difference between  $\mu_{control} = 65.152$  and  $\mu_{oliveoil} = 45.570$  is significant (p-value < 0.0001), indicating there is a treatment effect. Since the estimate is positive, we can also conclude that the mean for control is greater than the mean for the olive oil treatment.

We test the equal Who Held mean hypothesis  $H_0 : \mu_{Erik} - \mu_{Gretchen} = 0$  versus  $H_1 : \mu_{Erik} - \mu_{Gretchen} \neq 0$ . Under the null hypothesis, the difference in means are 0. Table 7 on page 33 shows the result of a Two-sample T test used to compare the average burst times for who held. We find that the difference between  $\mu_{Erik} = 59.275$  and  $\mu_{Gretchen} = 51.447$  is significant (p-value=0.0034), indicating there is a effect of who held. Since the estimate is positive, we can also conclude that the mean for Erik is greater than the mean for Gretchen.

Table 7: Two-sample T test to compare average burst times for the two treatment types

Label	Estimate	Std.Error	DF	t Value	p-value
control - olive oil	19.5813	2.7379	58	7.15	< .0001
Erik - Gretchen	7.8273	2.5599	58	3.06	0.0034

### 5.8.3 Model equation and residual analysis (Time=Treatment)

Using Analysis of Variance, we find the model to be significant, as shown in Table 8 on page 34, with model equation

$$\text{Burst Time} = 45.57 + 19.58 \times \text{Treatment}$$

where Treatment=1 for control condoms and Treatment=0 for condoms treated with olive oil.

Table 8: Analysis of Variance

Source	DF	SS	MS	F Value	p-value
Model	1	5751.4292	5751.4292	51.15	< .0001
Error	58	6521.7333	112.4437		
Corrected Total	59	12273.1625			
Parameter	Estimate	Std Error	t Value	p-value	
Intercept	45.5703	1.9360	23.54	< .0001	
control=1,oliveoil=0	19.5813	2.7379	7.15	< .0001	

The Studentized Residuals plotted versus the Normal Quantiles and by treatment are shown in Figure 14 on page 35. Except for a handful of outliers in the lower tail, the studentized residuals appear reasonably normal. However, the Shapiro-Wilk tests for normality gives a p-value of 0.0191, which provides sufficient evidence to reject the assumption of normality. The residuals by treatment appear slightly more dense above than below for the control condoms.

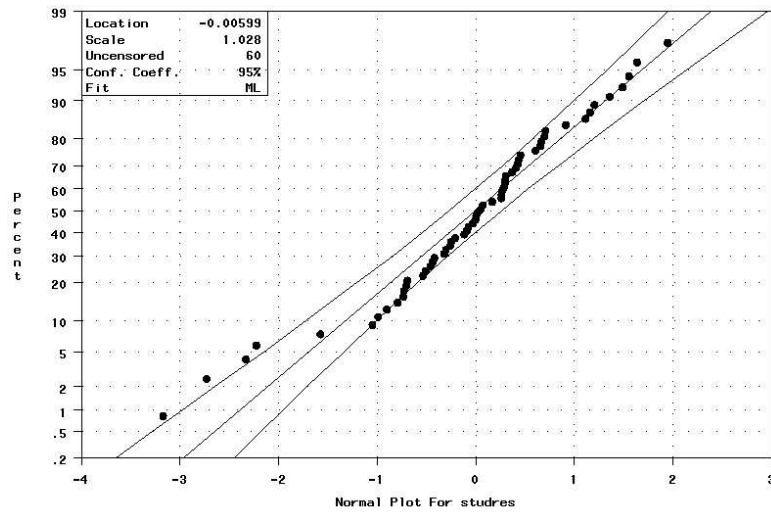
### 5.8.4 Model equation and residual analysis (Time=Treatment WhoHeld)

First an interaction model was fit, and it was found the interaction was not significant, so the additive model is used. Using Analysis of Variance, we find the model to be significant, as shown in Table 9 on page 36, with model equation

$$\text{Burst Time} = 41.66 + 19.58 \times \text{Treatment} + 7.83 \times \text{WhoHeld}$$

where Treatment=1 for control condoms and Treatment=0 for condoms treated with olive oil and where WhoHeld=1 for when Erik held the condom and

Studentized Residuals Normal Quantile Plot, Condom Burst Data



Studentized Residuals vs Treatment, Condom Burst Data

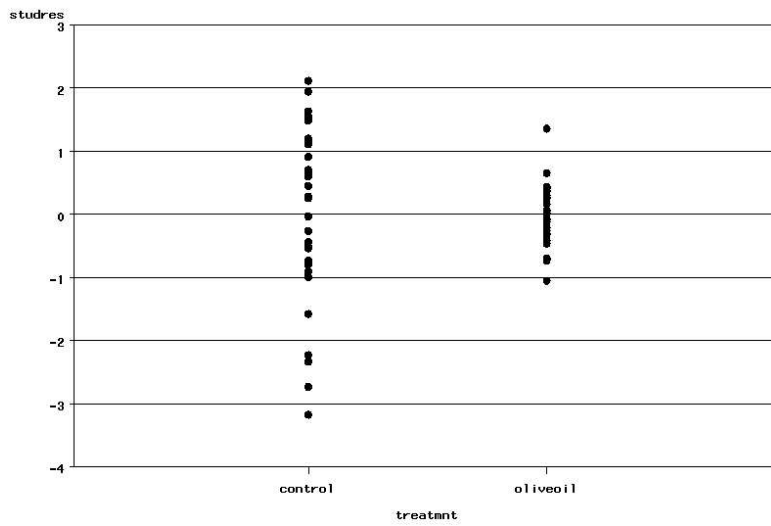


Figure 14: Studentized Residuals Normal Quantile Plots

WhoHeld=0 for when Gretchen held the condom. The Likelihood Ratio 95% Confidence Limits for the intercept is (37.3529, 45.9604), for the Treatment coefficient is (14.6118, 24.5509), for the WhoHeld coefficient is (2.8578, 12.7969), and the Scale parameter on the residuals is 9.6633 with Confidence Limits (8.1619, 11.6883).

Table 9: Normal Parameter Estimates and Analysis of Variance

Source	DF	SS	MS	F Value	p-value
Model	2	6670.43643	3335.21822	33.93	< .0001
Error	57	5602.72611	98.29344		
Corrected Total	59	12273.16254			
Parameter	Estimate	Std Error	t Value	p-value	
Intercept	41.6567	2.1608	18.79	< .0001	
control=1,oliveoil=0	19.5813	2.4950	7.65	< .0001	
Erik=1 ,Gretchen=0	7.8273	2.4950	3.06	0.0034	

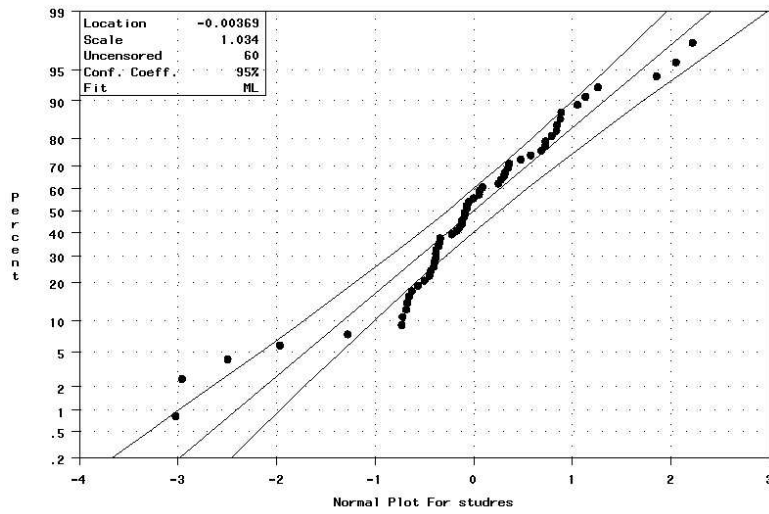
The Studentized Residuals plotted versus the Normal Quantiles and by treatment and who held are shown in Figure 15 on page 37. There appears to be a problem with the assumptions of these residuals. The first quantile of the studentized residuals do not appear normal. Additionally, the Shapiro-Wilk tests for normality gives a p-value of 0.0019, which provides sufficient evidence to reject the assumption of normality. The residuals by treatment appear slightly more dense above than below for the control condoms.

### 5.8.5 Normal Assumption Analysis Conclusion

After fitting the model, because the assumptions of these studentized residuals are not met, it appears the normal model is not appropriate for the full data set. It is possible that after removing several of the extreme times (outliers) that the assumption of normality will be met. This may be worth further investigation.

Our model suggests that the olive oil treatment reduces the condom burst time by roughly one third.

Studentized Residuals Normal Quantile Plot, Condom Burst Data



Studentized Residuals vs Treatment and Who Held, Condom Burst Data

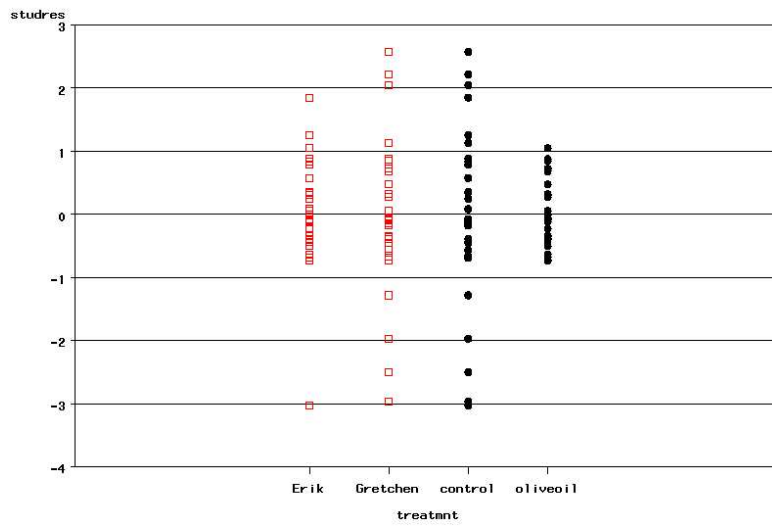


Figure 15: Studentized Residuals Normal Quantile Plots, second fit

## 5.9 Weibull Assumption Treatment Effect Analysis

### 5.9.1 Log-likelihood ratio tests

Models are fit for both

$$\log(\text{Burst Time}) = \beta_0 + \beta_1 \times \text{Treatment} \quad \text{and}$$

$$\log(\text{Burst Time}) = \beta_0 + \beta_1 \times \text{Treatment} + \beta_2 \times \text{WhoHeld}.$$

We use Weibull log-likelihood ratio testing to test the hypothesis  $H_0 : \beta_2 = 0$  versus  $H_1 : \beta_2 \neq 0$ . The log likelihood for the full model is 25.380726 and for the reduced model is 23.01103. Twice the difference is 4.739392. At the  $\alpha = 0.05$  significance level we find from statistical tables that 1 degree of freedom chi-squared has a critical value of 3.84; that is to say that a chi-squared value of greater than 3.84 is statistically significant. Therefore we reject  $H_0$  and conclude that there was significant improvement in using the full model.

### 5.9.2 Model equation and residual analysis

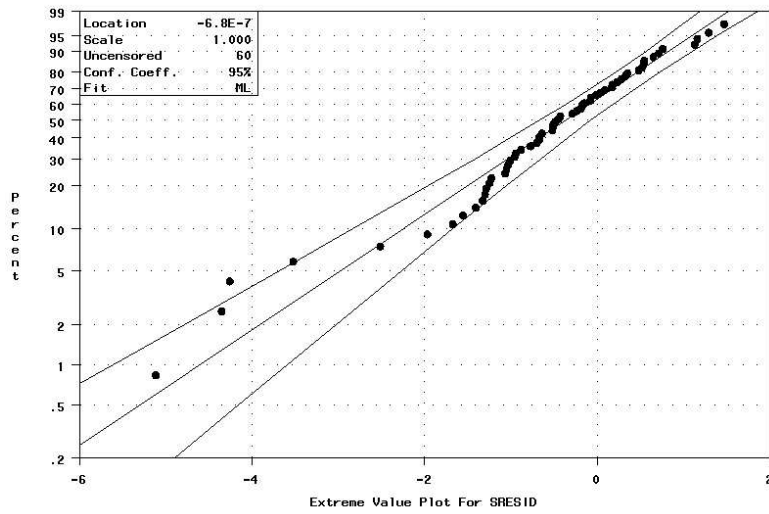
First an interaction model was fit, and it was found the interaction was not significant, so the additive model is used. The parameter estimates, standard errors and the Likelihood Ratio 95% Confidence Limits are given in Table 10 on page 40, with model equation

$$\log(\text{Burst Time}) = 3.81 + 0.42 \times \text{Treatment} + 0.08 \times \text{WhoHeld}$$

where Treatment=1 for control condoms and Treatment=0 for condoms treated with olive oil and where WhoHeld=1 for when Erik held the condom and WhoHeld=0 for when Gretchen held the condom. Because the 95% Confidence limits do not include 0, all parameters are significant at the 95% confidence level.

The Standardized Residuals plotted versus the Smallest Extreme Value Quantiles and by treatment and who held are shown in Figure 16 on page 39. There appears to be little problem with the assumptions of these residuals, only two points in the lower tail plot outside the confidence limits. The residuals plotted by treatment and who held appear distributed evenly about zero, except for five negative outliers.

Standardized Residuals vs Treatment and Who Held, Condom Burst Data



Standardized Residuals vs Treatment and Who Held, Condom Burst Data

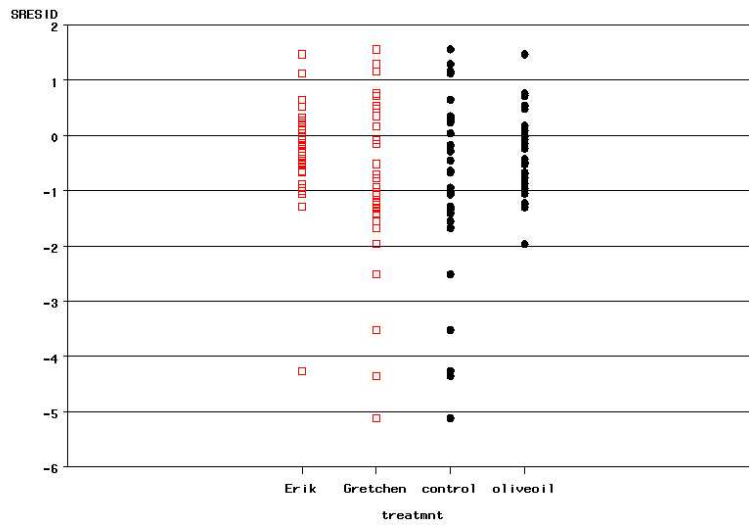


Figure 16: Standardized Residuals Smallest Extreme Value Quantile Plot

Table 10: Weibull Parameter Estimates

Parameter	Estimate	Std Error	95% Confidence Limits	
			Lower	Upper
Intercept	3.8119	0.0309	3.7514	3.8751
control=1,oliveoil=0	0.4190	0.0352	0.3468	0.4882
Erik=1 ,Gretchen=0	0.0771	0.0352	0.0079	0.1492

### 5.9.3 Weibull Assumption Analysis Conclusion

After fitting the model, because the assumptions of these studentized residuals are reasonably met, it appears the Weibull model is appropriate for the data set. Again, it is worth investigating removal of several of the extreme times (outliers) to assess the effect these outliers have on the model fit.

Our model suggests that the olive oil treatment reduces the condom burst time by roughly one third.

## 5.10 Model Comparison

The Table 11 on page 41 summarizes the parameter estimates from earlier, and gives the Burst Time model estimates at each value of treatment and who held for comparison. We find in the lower table that the Weibull puts more weight on the treatment effect than the who held effect.

Normal: Burst Time =  $41.66 + 19.58 \times \text{Treatment} + 7.83 \times \text{WhoHeld}$

Weibull:  $\log(\text{Burst Time}) = 3.81 + 0.42 \times \text{Treatment} + 0.08 \times \text{WhoHeld}$

Table 11: Parameter Estimates Comparison

Parameter	Estimate	Std Error	95% Confidence Limits	
			Lower	Upper
<b>Normal</b> Intercept	41.6567	2.1608	37.3529	45.9604
control=1,oliveoil=0	19.5813	2.4950	14.6118	24.5509
Erik=1 ,Gretchen=0	7.8273	2.4950	2.8578	12.7969
<b>Weibull</b> Intercept	3.8119	0.0309	3.7514	3.8751
control=1,oliveoil=0	0.4190	0.0352	0.3468	0.4882
Erik=1 ,Gretchen=0	0.0771	0.0352	0.0079	0.1492

Burst Time			
Normal	Weibull	Treatment	Who Held
69.0653	74.2918	control	Erik
61.2380	68.7791	control	Gretchen
49.4840	48.8620	oliveoil	Erik
41.6567	45.2363	oliveoil	Gretchen

## 6 Conclusions

In this project we found that in a controlled water burst test, applying olive oil to a condom has a significant effect in decreasing the time to burst, roughly one third the time of a control condom. In light of this evidence, we recommend not using olive oil with condoms under conditions of stress.

An effect was also found due to who held the condom during the experiment. Erik's time to burst tended to be slightly longer than Gretchen's. We suspect this had to do with the slight difference in grip we used to secure the condom to the shower hose.

Burst times appear normal or Weibull by probability plots. They are modeled well by the Weibull distribution, but normal assumptions regarding the residuals are not met. Investigating the outliers and removal may help the normality assumptions.

Further studies of interest could include many types of water-based and oil-based lubricants, as well as condoms of different brands and thickness for comparison. Further variation reducing techniques would be helpful, such as an apparatus to hold the condom and a device for controlling the water flow rate more accurately and precisely.

This project was an enjoyable experience.

## 7 Appendix

### SAS/S-Plus/MatLab Code

```

/*****
* Condom Burst data;
*
*      type: 1 -Durex Natural Feeling Non-lubricated (blue) exp 12/2005;
*           1a -Durex Natural Feeling Non-lubricated (blue) exp 01/2005;
*           2 -Torjan Non-lubricated (red) exp 12/2005;
*           3 -Durex Non-lubricated (green) exp 10/2003;
*      exp_date: expiration date printed on foil wrapper;
*      treatmnt: control - out of the package, as is;
*               oliveoil - olive oil applied to condom for at least one minute;
*      time: time in seconds from when water flow begins until condom bursts;
*      loc_brak: top - break occurs near or at where condom is held;
*               bottom - break occurs at center or bottom of condom;
*      bot_time: time to fill a bottle (3.75 cups/30 oz) in the seconds
*               following a burst test to help determine if flow is constant;
*      who_held: Gretchen - if Gretchen held the condom while Erik timed;
*               Erik - if Erik held the condom while Gretchen timed;
*      trial_dt: date when sampes were taken;
*
*      notes: any comments about a particular run, these are rare, may explain outliers;
options ls=75 ps=75 nocenter;
data burst;
input sample type exp_date date. treatmnt $ time
      loc_brak $ bot_time who_held $ trial_dt date.;
format exp_date date7.;
format trial_dt date7.;
burstvol=time*(30/bot_time); * oz;
burstwt=burstvol/16; * lbs;
cards;
1 1 01DEC05 control 38.17 top 6.29 Gretchen 05APR03
2 1 01DEC05 oliveoil 34.67 top 6.18 Gretchen 05APR03
3 1 01DEC05 control 57.50 top 6.14 Gretchen 05APR03
4 1 01DEC05 oliveoil 41.17 bottom 6.13 Gretchen 05APR03
5 1 01DEC05 control 60.57 top 6.21 Gretchen 05APR03
6 1 01DEC05 oliveoil 48.70 bottom 6.05 Gretchen 05APR03
7 1 01DEC05 control 59.56 top 6.27 Gretchen 05APR03
8 1 01DEC05 oliveoil 38.34 bottom 5.96 Gretchen 05APR03
9 1 01DEC05 control 48.96 top 6.14 Gretchen 05APR03
10 1 01DEC05 oliveoil 44.80 bottom 5.95 Gretchen 05APR03
11 1 01DEC05 control 56.88 top 6.21 Gretchen 05APR03
12 1 01DEC05 oliveoil 37.95 bottom 6.43 Gretchen 05APR03
13 1 01DEC05 control 55.76 top 6.19 Gretchen 05APR03
14 1 01DEC05 oliveoil 38.21 bottom 6.08 Gretchen 05APR03
15 1 01DEC05 control 42.71 top 6.23 Gretchen 05APR03
16 1 01DEC05 oliveoil 40.76 top 6.33 Gretchen 05APR03
17 1 01DEC05 control 81.98 top 6.08 Gretchen 05APR03
18 1 01DEC05 oliveoil 42.20 bottom 6.20 Gretchen 05APR03
19 1 01DEC05 control 34.42 top 5.98 Gretchen 05APR03
20 1 01DEC05 oliveoil 48.73 bottom 5.94 Gretchen 05APR03
21 1 01DEC05 control 41.75 top 5.94 Erik 05APR03
22 1 01DEC05 oliveoil 59.65 bottom 6.09 Erik 05APR03
23 1 01DEC05 control 76.73 bottom 6.14 Erik 05APR03
24 1 01DEC05 oliveoil 42.40 bottom 6.11 Erik 05APR03
25 1 01DEC05 control 64.85 top 6.28 Erik 05APR03
26 1 01DEC05 oliveoil 45.77 bottom 6.11 Erik 05APR03
27 1 01DEC05 control 74.70 bottom 6.04 Erik 05APR03
28 1 01DEC05 oliveoil 45.63 bottom 6.03 Erik 05APR03
29 1 01DEC05 control 77.67 top 6.19 Erik 05APR03
30 1 01DEC05 oliveoil 44.63 bottom 6.30 Erik 05APR03
31 1 01DEC05 control 68.16 bottom 6.12 Erik 05APR03
32 1 01DEC05 oliveoil 50.06 bottom 5.99 Erik 05APR03
33 1 01DEC05 control 86.61 bottom 6.25 Erik 05APR03
34 1 01DEC05 oliveoil 49.47 bottom 6.05 Erik 05APR03
35 1 01DEC05 control 67.91 bottom 6.05 Erik 05APR03
36 1 01DEC05 oliveoil 43.38 bottom 6.04 Erik 05APR03
37 1 01DEC05 control 81.17 bottom 6.03 Erik 05APR03
38 1 01DEC05 oliveoil 42.94 bottom 6.10 Erik 05APR03
39 1 01DEC05 control 71.50 top 6.34 Erik 05APR03
40 1 01DEC05 oliveoil 52.47 bottom 6.00 Erik 05APR03
41 1 01DEC05 control 80.52 bottom 6.20 Gretchen 05APR03
42 1 01DEC05 oliveoil 44.34 bottom 5.89 Gretchen 05APR03
43 1 01DEC05 control 84.99 bottom 6.07 Gretchen 05APR03
44 1 01DEC05 oliveoil 48.30 bottom 5.91 Gretchen 05APR03
45 1 01DEC05 control 72.17 top 6.06 Gretchen 05APR03

```

```

46 1 01DEC05 oliveoil 46.32 bottom 6.03 Gretchen 05APRO3
47 1 01DEC05 control 59.85 top 6.03 Gretchen 05APRO3
48 1 01DEC05 oliveoil 49.86 bottom 5.99 Gretchen 05APRO3
49 1 01DEC05 control 54.86 top 6.06 Gretchen 05APRO3
50 1 01DEC05 oliveoil 50.17 bottom 6.01 Gretchen 05APRO3
51 1 01DEC05 control 77.20 bottom 5.91 Erik 05APRO3
52 1 01DEC05 oliveoil 47.33 bottom 5.90 Erik 05APRO3
53 1 01DEC05 control 69.92 top 6.06 Erik 05APRO3
54 1 01DEC05 oliveoil 48.37 bottom 5.93 Erik 05APRO3
55 1 01DEC05 control 72.47 bottom 6.07 Erik 05APRO3
56 1 01DEC05 oliveoil 46.14 bottom 5.88 Erik 05APRO3
57 1 01DEC05 control 72.58 bottom 5.89 Erik 05APRO3
58 1 01DEC05 oliveoil 48.78 bottom 5.85 Erik 05APRO3
59 1 01DEC05 control 62.43 top 6.15 Erik 05APRO3
60 1 01DEC05 oliveoil 45.57 bottom 6.05 Erik 05APRO3
;run;

/*****
Check statistical control of water flow rate.
*****/
symbol v=dot;
title 'IR Control Chart for Water Flow Rate';
proc shewhart data=burst;
  irchart bot_time*sample/outhistory=outha outlimits=burstl;
run;
*proc print data=outha; run;
proc print data=burstl; run;

*proc print data=burst; run;
proc insight data=burst;run;

/* TREATMENT */
/* BOX PLOTS */
title1 'Box Plot of Times by Treatment';
/* use the BWIDTH= option to specify the width of the box */
symbol1 i=boxft bwidth=8 width=2 cv=red co=blue;
axis1 minor=none offset=(0,0);
axis2 minor=none offset=(30,30);
proc gplot data=burst;
  plot time*treatmnt / vaxis=axis1 haxis=axis2 noframe autovref;
run;
/* HISTOGRAM PLOTS */
title1 'Histogram of Times by Treatment';
proc gchart data=burst;
  pattern value=solid color=blue;
  axis label=('Time');
  vbar time / group=treatmnt type=pct frame freq maxis=axis midpoints=35 to 85 by 5;
*goptions device=xcolor;
run;

/* WHO HELD */
/* BOX PLOTS */
title1 'Box Plot of Times by Who Held Condom';
/* use the BWIDTH= option to specify the width of the box */
symbol1 i=boxft bwidth=8 width=2 cv=red co=blue;
axis1 minor=none offset=(0,0);
axis2 minor=none offset=(30,30);
proc gplot data=burst;
  plot time*who_held / vaxis=axis1 haxis=axis2 noframe autovref;
run;
/* HISTOGRAM PLOTS */
title1 'Histogram of Times by Who Held Condom';
proc gchart data=burst;
  pattern value=solid color=blue;
  axis label=('Time');
  vbar time / group=who_held type=pct frame freq maxis=axis midpoints=35 to 85 by 5;
*goptions device=xcolor;
run;

/** SPLIT DATA **/
/* BURSTT_C is just the treatmnt=control */
data burstt_c;
  set burst;
  if treatmnt='oliveoil' then delete;
run;
/* BURSTT_O is just the treatmnt=oliveoil */
data burstt_o;

```

```

set burst;
if treatmnt='control' then delete;
run;

/* BURSTW_E is just the who_held=Erik */
data burstw_e;
set burst;
if who_held='Gretchen' then delete;
run;
/* BURSTW_G is just the who_held=Gretchen */
data burstw_g;
set burst;
if who_held='Erik' then delete;
run;
*proc print data=burstt_c; run;
*proc print data=burstt_o; run;
*proc print data=burstw_e; run;
*proc print data=burstw_g; run;

/**** fit different distributions to the data ****/
title 'Normal Probability Plot for Control condoms';
*title 'Normal Probability Plot for Treated condoms';
*title 'Normal Probability Plot for condoms Held by Erik';
*title 'Normal Probability Plot for condoms Held by Gretchen';
*title 'Weibull Probability Plot for Control condoms';
*title 'Weibull Probability Plot for Treated condoms';
*title 'Weibull Probability Plot for condoms Held by Erik';
*title 'Weibull Probability Plot for condoms Held by Gretchen';
data burst2;
*set burst;
set burstt_c;
*set burstt_o;
*set burstw_e;
*set burstw_g;
run;
* fit different distributions to the data;
symbol v=dot;
proc reliability data=burst2;
class treatmnt who_held;
*distribution BINOMIAL;
*distribution EXPONENTIAL;
*distribution EXTREME;
*distribution GAMMA;
*distribution LOGISTIC;
*distribution LLOGISTIC;
*distribution LOGNORMAL;
*distribution LOGNORMAL10;
*distribution NORMAL;
*distribution POISSON;
*distribution WEIBULL;
*probplot time/ppout;
**The lrcl and lrclper options request likelihood ratio CIs for parameters and distribution percentiles.;
probplot time/lrcl lrclper;
model time=treatmnt who_held/covb corrb obstats;
run;

/**** PLOT SURVIVAL FUNCTION WITH ERROR BARS ****/
data burst1;
set burstt_c; * TREATMENT: CONTROL;
run;
title 'Product Limit Analysis, Condom Burst Data';
proc lifetest data=burst1 outsurv=burstout;
time time;
run;
data burstout1;
set burstout;
if sdf_lcl=. then sdf_lcl=0;
if sdf_ucl=. then sdf_ucl=0;
run;
proc iml;
use burstout1;
read all var{time survival sdf_lcl sdf_ucl} into z;
*nobs=nrow(z);do i=2 to nrow(z); if z[i,3]=0 then z[i,3]=z[i-1,3]; if z[i,4]=0 then z[i,4]=z[i-1,4];end;
colnames={time Treatment_Control TC_lcl TC_ucl};create burstout2 from z [colname=colnames];append from z;
quit;
/**** plot survival function with error bars ****/

```

```

data burst1;
  set burstt_o;      * TREATMENT: OLIVE OIL;
run;
title 'Product Limit Analysis, Condom Burst Data';
proc lifetest data=burst1 outsurv=burstout;
  time time;
run;
data burstout1;
  set burstout;
  if sdf_lcl=. then sdf_lcl=0;
  if sdf_ucl=. then sdf_ucl=0;
run;
proc iml;
use burstout1;
read all var{time survival sdf_lcl sdf_ucl} into z;
*nobs=nrow(z);do i=2 to nrow(z); if z[i,3]=0 then z[i,3]=z[i-1,3]; if z[i,4]=0 then z[i,4]=z[i-1,4];end;
colnames={time2 Treatment_OliveOil TO_lcl TO_ucl};create burstout22 from z [colname=colnames];append from z;
quit;
title 'Survival Plot Condom Burst Data by Treatment';
data burstout3;
  set burstout2;
  set burstout22;
run;
symbol1 i=stepj c=black l=1;symbol2 i=stepj c=red l=2;symbol3 i=stepj c=red l=2;
symbol4 i=stepj c=blue l=1; symbol5 i=stepj c=orange l=2;symbol6 i=stepj c=orange l=2;
axis1 label=(a=90 font=swiss 'Surviving');
proc gplot data=burstout3;
  plot (Treatment_Control TC_lcl TC_ucl)*time (Treatment_OliveOil TO_lcl TO_ucl)*time2/overlay vaxis=axis1 legend;
run;
title ' ';

/**** PLOT SURVIVAL FUNCTION WITH ERROR BARS ****/
data burst1;
  set burstw_e;      * WHO HELD: ERIK;
run;
title 'Product Limit Analysis, Condom Burst Data';
proc lifetest data=burst1 outsurv=burstout;
  time time;
run;
data burstout1;
  set burstout;
  if sdf_lcl=. then sdf_lcl=0;
  if sdf_ucl=. then sdf_ucl=0;
run;
proc iml;
use burstout1;
read all var{time survival sdf_lcl sdf_ucl} into z;
*nobs=nrow(z);do i=2 to nrow(z); if z[i,3]=0 then z[i,3]=z[i-1,3]; if z[i,4]=0 then z[i,4]=z[i-1,4];end;
colnames={time WhoHeld_Erik WE_lcl WE_ucl};create burstout2 from z [colname=colnames];append from z;
quit;
/**** plot survival function with error bars ****/
data burst1;
  set burstw_g;      * WHO HELD: GRETCHEN;
run;
title 'Product Limit Analysis, Condom Burst Data';
proc lifetest data=burst1 outsurv=burstout;
  time time;
run;
data burstout1;
  set burstout;
  if sdf_lcl=. then sdf_lcl=0;
  if sdf_ucl=. then sdf_ucl=0;
run;
proc iml;
use burstout1;
read all var{time survival sdf_lcl sdf_ucl} into z;
*nobs=nrow(z);do i=2 to nrow(z); if z[i,3]=0 then z[i,3]=z[i-1,3]; if z[i,4]=0 then z[i,4]=z[i-1,4];end;
colnames={time2 WhoHeld_Gretchen WG_lcl WG_ucl};create burstout22 from z [colname=colnames];append from z;
quit;
title 'Survival Plot Condom Burst Data by Who Held';
data burstout3;
  set burstout2;
  set burstout22;
run;
symbol1 i=stepj c=black l=1;symbol2 i=stepj c=red l=2;symbol3 i=stepj c=red l=2;
symbol4 i=stepj c=blue l=1; symbol5 i=stepj c=orange l=2;symbol6 i=stepj c=orange l=2;
axis1 label=(a=90 font=swiss 'Surviving');

```

```

proc gplot data=burstout3;
  plot (WhoHeld_Erik WE_lcl WE_ucl)*time (WhoHeld_Gretchen WG_lcl WG_ucl)*time2/overlay vaxis=axis1 legend;
run;
title ' ';

/**** PLOT KAPLAN-MEIER FITTED DISTRIBUTIONS ****/
data burst1;
set burst;
run;
/*****
(3) Requested plots are:
      s:  shat(t) vs. t           SURVIVAL
      ls: -log[shat(t)] vs. t     EXPONENTIAL
      lls: log(-log[shat(t)]) vs. t WEIBULL
      h:  hhat(t) vs. t          HAZARD
*****/
title 'Exponential Kaplan-Meier Fitted Distributions, Condom Burst Data'; * FOR FIRST ONE;
title 'Weibull Kaplan-Meier Fitted Distributions, Condom Burst Data'; * FOR SECOND ONE;
symbol1 v=dot color=black line=1;
symbol2 v=square color=black line=1;
symbol3 v=dot color=red line=2;
symbol4 v=square color=red line=2;
proc lifetest data=burst1 plots=(s,ls,lls,h,p) graphics outsurv=burstout method=km;
  time time;
  strata treatmnt;* who_held;
run;

/* WHO HELD DOES NOT MAKE SENSE IN THIS CASE SINCE TREATMNT IS DOMINANT */

/**** TREATMENT EFFECT ANALYSIS ****/
/** NPAR **/
/** Use proc lifetest output in the Kaplan-meier for NPAR results **/
/** Normal **/
* NACF macro on burstt_c and burstt_o with variable time ;
* Do LRT H0: equal var, H1: not equal var ;
proc mixed data=burst;
  classes treatmnt;
  model time = treatmnt;
  *repeated /group=treatmnt; * for seperate variances ;
run;
proc mixed data=burst;
  classes treatmnt;
  model time = treatmnt;
  repeated /group=treatmnt; * for seperate variances ;
run;
* Use -2 (resloglike1st - resloglike2nd) is chi^2 ;
/**** TIME = TREATMENT only ****/
* Two-sample T test;
proc glm data=burst;
  class treatmnt;
  model time = treatmnt /solution ;
  random treatmnt ;
  means treatmnt /t hovtest;
  estimate 'control - olive oil' treatmnt 1 -1;
  estimate 'Erik - Gretchen ' who_held 1 -1;
  output out=burstres p=yhat r=resid stdr=eresid rstudent=studres;
run;

symbol1 v=dot color=black line=1;
symbol2 v=square color=red line=2;
title 'Studentized Residuals Normal Quantile Plot, Condom Burst Data';
* And this fits the model to the residuals;
proc reliability data=burstres;
  distribution normal;
  model studres;
  probplot studres/lrcl lrclper;
run;

symbol1 v=dot color=black line=1;
symbol2 v=square color=red line=2;
title 'Studentized Residuals vs Treatment, Condom Burst Data';
axis1 minor=none offset=(0,0);
axis2 minor=none offset=(30,30);

```

```

proc gplot data=burstres;
  plot studres*treatmnt / vaxis=axis1 haxis=axis2 noframe autovref;
  plot studres*who_held / vaxis=axis1 haxis=axis2 noframe autovref;
run;

/** TIME = TREATMENT + WHO_HELD **/
proc glm data=burst;
  class treatmnt who_held;
  model time = treatmnt who_held /solution ;
  random treatmnt who_held ;
  means treatmnt who_held /t hovtest;
  *estimate 'control - olive oil' treatmnt 1 -1;
  *estimate 'Erik - Gretchen ' who_held 1 -1;
  output out=burstres p=yhat r=resid stdr=eresid rstudent=studres;
run;
symbol1 v=dot color=black line=1;
symbol2 v=square color=red line=2;
title 'Studentized Residuals Normal Quantile Plot, Condom Burst Data';
* And this fits the model to the residuals;
proc reliability data=burstres;
  distribution normal;
  model studres ;
  probplot studres /lrcl lrclper;
run;
symbol1 v=dot color=black line=1;
symbol2 v=square color=red line=2;
title 'Studentized Residuals vs Treatment and Who Held, Condom Burst Data';
axis1 minor=none offset=(0,0);
axis2 minor=none offset=(30,30);
proc gplot data=burstres;
  plot studres*(treatmnt who_held)/ vaxis=axis1 haxis=axis2 noframe autovref overlay;
  *plot studres*treatmnt / vaxis=axis1 haxis=axis2 noframe autovref;
  *plot studres*who_held / vaxis=axis1 haxis=axis2 noframe autovref;
run;

/** Or use this **/
ods output modobstats=burstres;
proc reliability data=burst;
  class treatmnt who_held;
  distribution normal;
  model time=treatmnt who_held/lrcl covb corrb obstats;
  pplot time;
run;
proc reliability data=burstres;
  distribution normal;
  pplot resid;
  pplot sresid;
  pplot aresid;
run;
symbol1 v=dot color=black line=1;
symbol2 v=square color=red line=2;
title 'Standardized Residuals vs Treatment and Who Held, Condom Burst Data';
axis1 minor=none offset=(0,0);
axis2 minor=none offset=(30,30);
proc gplot data=burstres;
  plot sresid*(treatmnt who_held)/ vaxis=axis1 haxis=axis2 noframe autovref overlay;
run;

/** Weibull **/
/** TIME = TREATMENT only **/
ods output modobstats=burstres;
proc reliability data=burst;
  class treatmnt ;
  distribution weibull;
  model time=treatmnt /lrcl lrclper covb corrb obstats;
  pplot time;
run;

/** TIME = TREATMENT + WHO_HELD **/
ods output modobstats=burstres;
proc reliability data=burst;
  class treatmnt who_held;

```

```
      distribution weibull;
      model time=treatmnt who_held/lrcl covb corrb obstats;
run;
/**
Compare the likelihood ratios against a  $\chi^2_1=3.84$  to choose model
-2*(23.01103 -25.380726)=4.739392
***/

* use smallest extreme value distribution because of negative values;
proc reliability data=burstres;
      distribution ev;
      pplot sresid;
run;
symbol1 v=dot color=black line=1;
symbol2 v=square color=red line=2;
title 'Standardized Residuals vs Treatment and Who Held, Condom Burst Data';
axis1 minor=none offset=(0,0);
axis2 minor=none offset=(30,30);
proc gplot data=burstres;
      plot sresid*(treatmnt who_held)/ vaxis=axis1 haxis=axis2 noframe autovref overlay;
run;
```