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QUALITY IMPROVEMENT AND OPTIMIZATION OF A RESINA CAPPER ON A PACKAGING LINE: AN APPLICATION OF STATISTICS UTILIZING THE TAGUCHI LOSS FUNCTION

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Hugh E. Lockhart

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QUALITY IMPROVEMENT AND OPTIMIZATION OF A RESINA CAPPER ON A PACKAGING LINE: AN APPLICATION OF STATISTICS UTILIZING THE TAGUCHI LOSS FUNCTION

By

Christopher Andrew Ian Clarke

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ABSTRACT

QUALITY IMPROVEMENT AND OPTIMIZATION OF A RESINA CAPPER ON A PACKAGING LINE: AN APPLICATION OF STATISTICS UTILIZING THE TAGUCHI LOSS FUNCTION

By

Christopher Andrew Ian Clarke

The thesis reports an application of the Taguchi Loss Function to a Resina Capper on a packaging line in a major United States pharmaceutical company. It calculates the cost saving realized by reducing variability, improving the quality of removal torque, and ultimately reducing process costs.

The design and structure of the experiments followed these principles:

1. Statement of the Needs - Written statement of intended knowledge to be gained.
2. Conceptualizing the Design - Brainstorming, review of available data and literature.
3. Evaluation of the Measurement Process - Gain an understanding of the process, quality requirements, and operating characteristics.
4. Consider Potential Experimental Problems - Assess process inconsistencies.
5. Design the Experiment - Based on statistical and non-statistical methods.
6. Run the Experiment - Based on the design.
7. Analyze the Results - Utilizing statistical methods.
8. Taguchi Loss Function - Apply the Loss Function to the results to determine possible cost savings, improved quality, and increased productivity.

Improved quality, increased output and significant cost savings were realized as a direct result of the experiments that were conducted on the packaging line. By implementing the changes recommended, on all of the packaging lines utilizing Resina Cappers, overall improvement of quality and productivity can be achieved, resulting in significant cost savings.

In memory of my father,

IAN EDWARD CLARKE,

who has provided me with continual motivation to succeed.

ACKNOWLEDGMENTS

I would like to express my eternal gratitude to Dr. Hugh Lockhart, my major professor, for his keen interest, valuable advice, and guidance. I would also like to thank my committee members Dr. Bruce Harte, Dr. Julian Lee, and especially Dr. Dennis Gilliland for his invaluable statistical guidance. Without their help this paper could not have been written.

To my mother, Shirley Clarke, I gratefully thank you for continually encouraging me to reach for higher goals and providing me with the support, both financially and spiritually, to be able to attain those goals.

To my wife, Jane, thank you for providing me with your undying support, especially while being away from you during the research phase of this thesis.

To all those associated with this research project especially, Bill Gierke who made the project possible, Jeff Fluharty and James Edelman for their help and enthusiasm. A special thank you to all operators who assisted in the running of the experiments. Without your help the data could never have been collected.

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LIST OF SYMBOLS

MSD	= Mean Squared Deviation
θ(Classical)	= Classical Standard Deviation
θ(Taguchi)	= Taguchi Standard Deviation
M	= Deviation of Process Average from Target Value
K	= Taguchi Loss Constant
Loss	= Taguchi Loss Function
S/N-Ratio	= Signal-to-Noise Ratio
Cpk	= Process Capability Index
$\overline{X}$	= Process Average
T	= Target Value
LSL	= Lower Specification Limit
USL	= Upper Specification Limit

1. INTRODUCTION

In today's market, organizations compete in three main areas: quality, delivery, and price. An organization's reputation is directly tied to the quality of its products. Quality is often used to signify "excellence" and in some companies quality indicates that a product conforms to certain guidelines established by the company. These guidelines often overlook the customer who ultimately defines the meaning of quality. A company's definition of quality should be to *meet the requirements of the customer*. Traditionally American companies have not given quality the attention it requires. The quality control revolution in Japan has now forced American companies to adopt different manufacturing methods to enable them to compete in the same markets. Statistical Process Control (SPC) is one method that has been applied to American manufacturing processes. SPC addresses the area of on-line quality control and refers to the monitoring of current manufacturing processes to verify the quality levels produced. SPC is a method to help control processes [1]. Off-line quality control refers to the improvement of quality in the product and process development stages [10]. This step is not usually incorporated into traditional SPC methods and often excludes the customer's requirements.

Genichi Taguchi, a Japanese statistician, has developed a methodology that incorporates off-line and on-line quality control into the design and manufacturing processes. Taguchi methods have a positive impact on cost that is obtained by improving quality in the developmental phases of a product cycle. Taguchi emphasizes the importance of moving quality improvements upstream from the manufacturing process. The goal is to design quality into every product and the processes that build them. A key component of Taguchi's philosophy is reduction in variability, this incorporates three central ideas [13]:

1. Products and processes should be designed so that they are robust to external sources of variability.
2. Experimental design methods are an engineering tool to help accomplish this objective.
3. Operation on target is more important than conformance to specifications.

The ultimate goal of the Taguchi philosophy is to have a process that operates with minimal variation around a desired target value [12]. The Taguchi loss function generates minimal loss when a process has the least variation and is producing on target.

1.1 The American Pharmaceutical Industry

The American pharmaceutical industry is a world leader in the manufacturing of quality pharmaceutical products. Applications of the Taguchi philosophy fit perfectly into the industry because of the stringent manufacturing practices that are demanded by the U.S. Food and Drug Administration (FDA). These practices are known as current Good Manufacturing Practices (cGMP's). By incorporating Taguchi's philosophy and Statistical Process Control into the pharmaceutical industry, significant improvements in GMP's can be achieved. This not only satisfies the FDA's GMP requirements but also reduces variation in processes and lowers manufacturing costs. Currently the American pharmaceutical industry leads in quality. To maintain this position, the industry must adopt new manufacturing design and production methods to ensure that its quality is continuously improved. This is the fundamental basis of the Taguchi philosophy: reducing variation (improved quality) reduces the *"loss to society"*. The loss refers to the cost that is incurred by society when the consumer uses a product whose characteristics differ from the nominal [14]. Reducing this loss, in turn leads to the ultimate benefit of producing quality products for less money.

2. LITERATURE REVIEW

The quality revolution in today's "Global Economy" has emphasized quality as the major factor in deciding market share. Markets are no longer dominated by one particular product. Companies around the world can compete in almost any market in terms of cost and volumes of finished product. Supply often outweighs demand in most markets today. As a result, product cost and cost differentiation between competing products are minimized. One deciding factor that differentiates one product from another is that of quality. Dr. Genichi Taguchi, defines quality as *"the loss to society caused by a product after it is shipped"* [6,7]. A product with good quality will cause little loss to society and one with poor quality will cause greater loss to society. The Taguchi loss function recognizes the customer's desire to have products that are more consistent, and the producer's desire to make a low-cost product. The loss to society is composed of the costs incurred during the production process as well as the costs incurred during the use of a particular product by the customer i.e. repair, dissatisfaction, and lost business. Taguchi claims that minimal loss is incurred when a process is producing close to or at the set target. The further away a process is from the target, the higher the resulting loss, even when the process is within specification limits.

Traditional specification losses allow for a range of values that a process can operate within, generating zero loss within the specified range. In the traditional concept, the only time a loss is incurred, is when the specification limits are exceeded. The loss under the Taguchi philosophy is in part based on the Mean Squared Deviation (MSD) of a given process from its target. Any deviation from the process target and/or increase in variation within a process results in a proportional loss. This loss can be measured, even for a process operating within specification limits. Any process can be improved by reducing the variation within the process, and savings generated by improving the process are determined by comparing the Signal-to-Noise ratios (S/N Ratio) of the process before and after the change. This concept is presented in Figure 1 - Loss Functions: Specification vs. Taguchi.

2.1 Calculating the Taguchi Loss Function

2.1.1 Mean Squared Deviation (MSD)

The Loss Function is based on the MSD of a given process. The MSD is a measure of the amount of variation that a process contains and how far that process average deviates from the process target. A larger amount of variation within a given process, will generate a larger loss. The further a process average deviates from the target value, the larger the loss incurred. The MSD is calculated as follows [6,7,10]:

$$\mathrm{MSD} = (\vartheta(\mathrm{Taguchi}))^2 + (\mathrm{M})^2 \qquad (1)$$

Where:

$$\vartheta(\mathrm{Taguchi}) = \vartheta(\mathrm{Classical}) \Big/ \sqrt{\mathrm{N}/\mathrm{N}-1}$$

$$\mathrm{M} = \mathrm{Target} - \mathrm{Average}$$

2.1.2 Loss Constant (K)

The amount of loss determined by the Loss Function also depends on a constant value that represents the cost per unit, during production, in relation to the specified tolerance of a quality characteristic. To get an exact value for K, costs for the following factors are needed: Materials costs, Product costs, Research and Development costs, and Labor costs. The exact dollar value is difficult to obtain since most cost areas are usually

LOSS FUNCTIONS: SPECIFICATION VS. TAGUCHI

SPECIFICATION LOSS FUNCTION

TAGUCHI LOSS FUNCTION

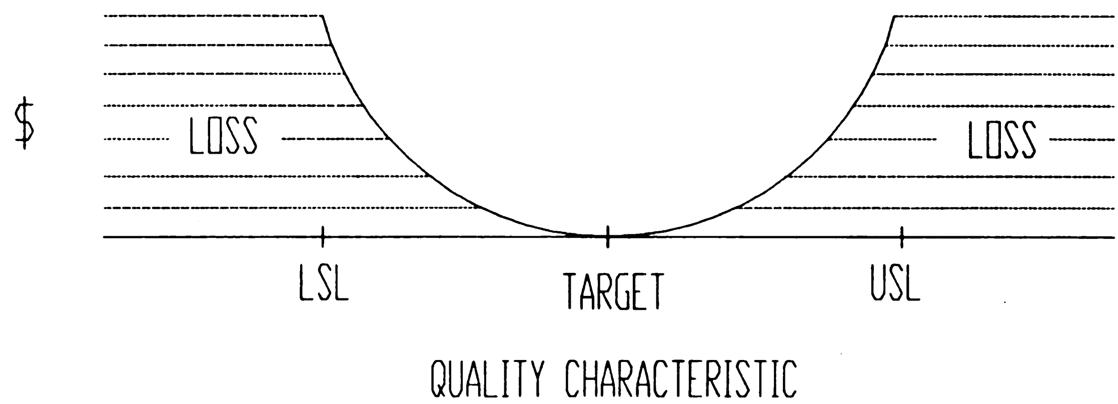

FIGURE 1

spread out over the life of the product. This would require knowledge of previous and future expected production volumes. The Loss Constant is calculated as follows [6,7,10,11]:

$$K = \frac{\text{Loss}/\text{Unit}}{(\text{Tolerance})^2} \qquad (2)$$

Where:

Tolerance = (USL - LSL)/2

2.1.3 The Taguchi Loss Function

The average loss per unit associated with a given distribution is calculated by multiplying the Loss Constant (Equation 2) by the MSD (Equation 1) of a given process. This Loss is calculated as follows [6,7,10]:

$$\text{Loss} = K(\text{MSD}) \qquad (3)$$

2.2 Calculating Savings Associated with Two Processes

2.2.1 Signal-to-Noise Ratio (S/N-Ratio)

The Taguchi method focuses on the reduction of noise factors that introduce greater variation into the performance of a given product. There are three sources of product performance variation: External factors, Internal factors, and Unit-to-Unit factors.

External factors encompass the environment in which the product is used or distributed. Internal factors encompass product deterioration with age or use. Unit-to-Unit factors encompass variations in the manufacturing process [14]. To minimize the amount of variation associated with a given product, all three of these noise factors must be considered during the design phase of a product. Product and production processes should be designed so that they are less sensitive to noise factors. A useful calculation for this is the signal to noise ratio (S/N).

The S/N ratio is the reciprocal of the variance of the measurement error. This value is maximized when process parameters have a minimum error in their variance [6]. The S/N ratio consolidates several repetitions (at least two data points) into one value which reflects the amount of variation present. The optimum process design will have a S/N ratio that is smaller than the S/N ratio of a process that one is trying to improve. The S/N-Ratio is calculated as follows [10,11]:

$$S/N\ Ratio = -10\log(MSD)^{*} \qquad (4)$$

* This equation is used in the calculation for S/N ratio based on the variance only.

2.2.2 Savings

The savings associated with an improved process can be calculated by comparing the Signal-to-Noise Ratios of each process. The savings are calculated as a percent cost improvement of one process over another, according to the following equation [11]:

$$\text{Savings} = (1 - 10^{\{-(S/N_2 - S/N_1)/10\}}) * 100\%$$
$$= (\frac{MSD_1 - MSD_2}{MSD_1}) * 100\% \quad (5)$$

2.3 Calculating the Process Capability Index

The process capability index (Cpk) is based on the centering of a frequency distribution and the ratio of the spread of the distribution within the width of the specification [12]. The frequency distribution and the Cpk will reflect control within a process and the actual performance of a process after process modification has occurred. The Cpk compares the centrality of the process mean within the tolerance spread, and how capable the given process is of operating within the specified limits. A Cpk value of less than one indicates that a process is not capable of producing within specified limits. A Cpk value one indicates that a process is just capable of producing within the specified limits. A Cpk value of greater than one indicates that a process is capable of producing within specified limits. This latter case provides the most desirable situation. The Cpk is calculated as follows [12]:

$$Cpk = \frac{|\text{Nearer Specification Limit} - \overline{X}|}{3\sigma(\text{Classical})} \quad (6)$$

Where:

$\overline{X}$ = Process Average

3. COMPANY BACKGROUND

3.1 Company Introduction

The research phase of the thesis was conducted at a major United States pharmaceutical company located in the Midwest. The company produces prescription, non-prescription, and animal healthcare products. The main emphasis is placed on the prescription side of the pharmaceutical business. Products are packaged in a variety of different packages: blisters, vials, glass bottles, and plastic bottles. The bottles are sealed with a number of different closure styles made from metal and plastic components. The Child Resistant Closure (CRC) is the most commonly used closure on both plastic and glass bottles. The cap is made up of three components, an inner shell, an outer shell, and the liner system. The inner component is made from a polypropylene resin and the outer shell is made from a high density polyethylene resin. The liner system is a laminate composed of four separate layers: coating, facing, backing, and the glassine liner. The caps are supplied to the company by an outside supplier.

The CRC is applied to the bottle utilizing a Resina Capper. The Resina is an in-line capper which has consecutive pairs of rollers that spin the cap onto the bottle and apply torque to the cap. The Resina Capper that this thesis evaluates, has four pairs of consecutive rollers that apply the torque successively. The first set of rollers spins three times as fast as the next three pairs of rollers. The function of these rollers is to spin the cap until the liner is seated on the land of the bottle finish. The first pair of rollers do not actually apply any torque to the closure system. The next three pairs of rollers apply the torque in succession, to the desired level. The separation between the two rollers in each of the four pairs of rollers and the setting of the clutches on the individual spindles is crucial. These two variables have the most pronounced effect on application torque.

There is a large number of variables associated with the torque application process and each variable was studied to evaluate its effect on the removal torque of the CRC.

Areas of study include: the performance characteristics of the Resina capper, set-up of the capper, and the variation caused by materials (caps and bottles).

The Food and Drug Administration (FDA) has instituted very strict regulations governing closure removal torques. Effectively, if one CRC is found to be loose in the field, an entire lot will have to be automatically recalled. A loose cap may lead to leaking and deterioration of the contents of the package. A loose cap may also provide evidence that a closure system has been tampered with. A recall can prove to be very costly and careful consideration for the application process has to be taken into account. The variability of the process has to be controlled to reduce the probability that a closure system might fail in the field.

3.2 Statement of the Needs

3.2.1 What are we trying to learn?

Historically the capping operation has not performed consistently to ensure that there are no loose caps out in the field. This has resulted in a recall and increased process costs. All the variables associated with the capper were studied to "learn" how each variable affects the output (removal torque) of the process. Once the effects were evaluated, those having the most significant effect were targeted to improve quality (consistent removal torques) and reduce process costs.

The effects of supplier inconsistencies were also investigated to find out whether the closure system contributes to machine down-time and decreased quality. Supplier quality has been suspected as a probable cause for creating defects during production runs.

3.2.2 What are the aims of the research?

1. To improve the consistency of quality (removal torque) of the Resina Capping process.
2. To lower costs by reducing the probability of a recall occurring, by increasing the

output of the machine, and by reducing down-time associated with defective supplier materials.

3. To evaluate the performance characteristics of the Resina Capper:

   a) Mechanical Performance - Evaluate the variables associated with the setup and operation of the Resina Capper.

   b) Operator Performance - Evaluate the effects of operator variability.

4. To evaluate the supplier's materials for inconsistencies and defective components.

5. To evaluate the variability of torque measuring methods and devices to ensure that consistent and valid data are collected.

6. To predict possible cost savings by applying the Taguchi Loss function to the collected data.

4. EVALUATION OF THE MEASUREMENT DEVICE

4.1 Qualification of the Measurement Device

The measurement device that was used to collect the data was a Sure Torque Torque Tester Model number NEBT33 manufactured by the New England Machinery company. The method of measuring removal torque is automated and requires little human interaction while measuring removal torque. The Sure Torque has a constant velocity rotating head. The torque (force) measuring system is calibrated against a known mass and provides an accurate and repeatable method for measuring removal torque. Operator variability is significantly reduced by the torque tester. The Sure Torque measurement device was compared to the current removal torque tester being utilized. This device is known as the SecurePak torque tester (Hand method) and when compared to the Sure Torque it was found to be less precise.

An experiment was designed to evaluate the two torque measuring devices against each other. A comparison of operator variability was conducted for each device and a comparison of torque tester variability between the two devices was also conducted. The operator variability test on each device was conducted by two operators on each of the torque testers. Two hundred caps were applied to two hundred glass bottles at 22 Torque Inch Pounds (TIP) by the Sure Torque tester. Each operator then measured the removal torques of fifty bottles on each of the measuring devices.

The evaluation of the two measuring devices was made up of the combined sample of the two operators on the same measuring device compared to the combined sample of the two operators on the other measuring device. The raw data is listed in Table 1, Table 2, and Table 3 in Appendix A. A summary of the data is listed below.

Table 1 - Operator Variability Secure Pak (Hand Method)

VARIABLE	OPERATOR 1	OPERATOR 2
SAMPLE SIZE	50	50
AVERAGE	16.2	13.3
VARIANCE	2.44	1.32
STD. DEV.	1.56	1.15
MINIMUM	12.1	10.3
MAXIMUM	19.7	15.5
RANGE	7.6	5.2

Table 2 - Operator Variability Sure Torque

VARIABLE	OPERATOR 1	OPERATOR 2
SAMPLE SIZE	48	50
AVERAGE	12.3	11.4
VARIANCE	2.50	1.18
STD. DEV.	1.58	1.09
MINIMUM	8.2	9.5
MAXIMUM	15.6	14.5
RANGE	7.4	5.0

Table 3 - Torque Tester Variability: Secure Pak vs. Sure Torque

VARIABLE	SECURE PAK	SURE TORQUE
SAMPLE SIZE	100	98
AVERAGE	14.8	11.9
VARIANCE	3.97	1.98
STD. DEV.	1.99	1.41
MINIMUM	10.3	8.2
MAXIMUM	19.7	15.6
RANGE	9.4	7.4
KURTOSIS	-0.460	-0.096

4.2 Results

The results of the operator variability test on the SecurePak torque tester show that the average for Operator 1 is 16.2 TIP and the average for Operator 2 is 13.3 TIP. A t-test was conducted to see whether there is a significant statistical difference in means. The t-test showed that the difference between means is highly significant at an Alpha level of 0.001. A further test was conducted to see whether the ratio of the variances of the two operators was equal to one. A ninety five percent confidence interval for the ratio of the variances does not include one, therefore the variances of the two operators are not equal. The multiple Box-and Whisker Plot in Figure 2 shows graphically the difference in medians represented by a visible separation of the center lines of each box. The presence of no overlap between each of the boxes reveals that there is a difference in variances between each of the operators.

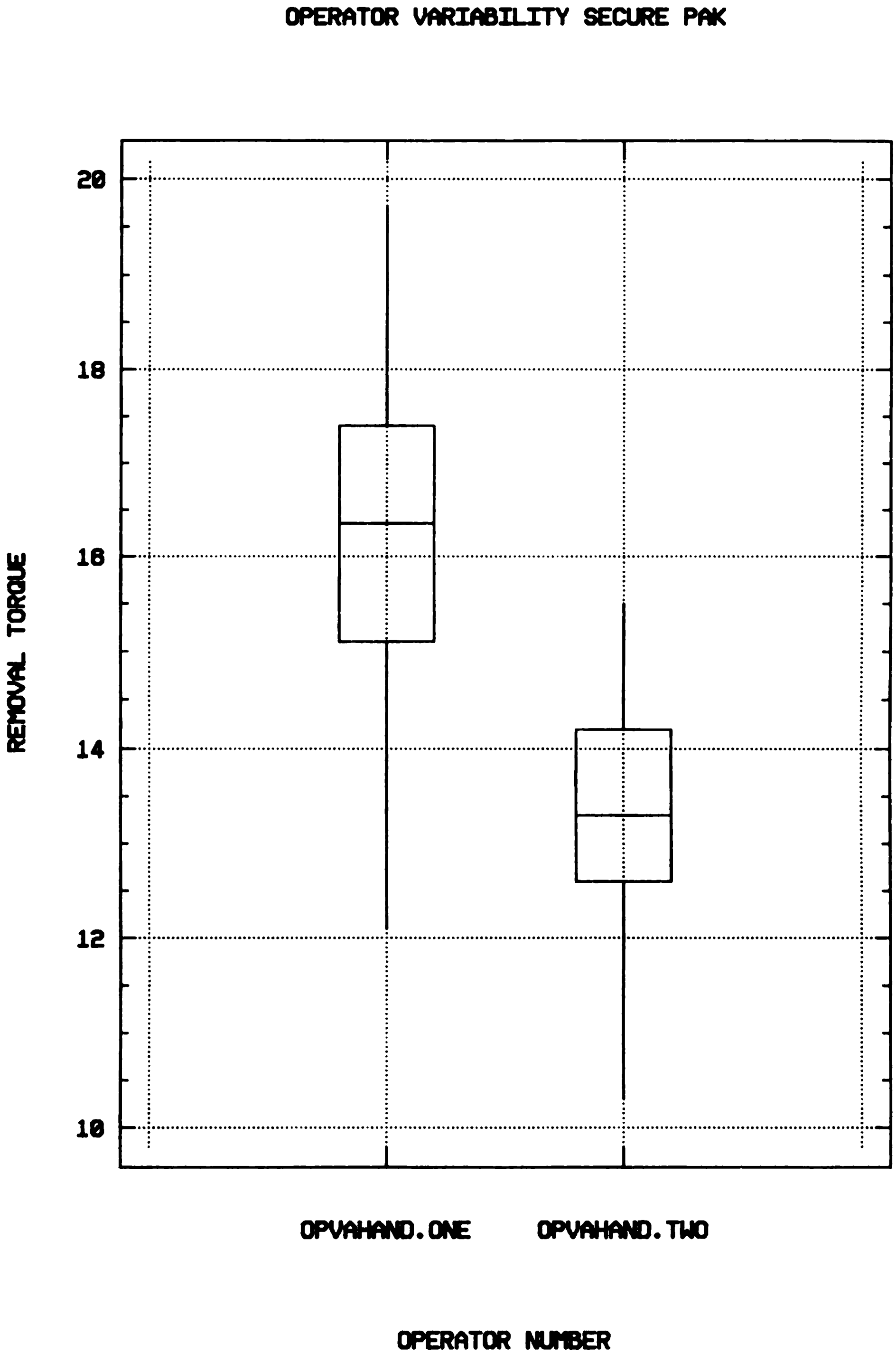
OPERATOR VARIABILITY SECURE PAK
REMOVAL TORQUE
20
18
16
14
12
10
OPVAHAND.ONE
OPVAHAND.TWO
OPERATOR NUMBER

FIGURE 2

The results of the operator variability test on the Sure Torque torque tester show that the average for Operator 1 is 12.3 TIP and the average for Operator 2 is 11.4 TIP. A t-test was conducted to see whether there is a statistical difference in means. The t-test showed that the difference between means was not significant at an Alpha level of 0.001. A further test was conducted to see whether the ratio of the variances of the two operators was equal to one. A ninety five percent confidence interval for the ratio of the variances does not include one, therefore the variances of the two operators are not equal. The difference in variances can be attributed to the fact that the CRC cap must be engaged, or in the locked position before it is placed into the Sure Torque tester. Individual operators may accomplish this by utilizing different methods of engagement and this may result in the differences in variances. The multiple Box-and Whisker Plot in Figure 3 shows graphically that the difference in medians represented by the separation of the center lines of each box is not pronounced and not statistically significant. The presence of overlap between each of the boxes reveals a closer association between the two operator distributions. This is not reflected in the standard deviation for each operator on each measurement device. The standard deviation for each operator on the SecurePak are highly conservative estimates of a true production setting. The tests were conducted under controlled conditions and the results present a "best case" scenario. The Sure Torque test data reflect actual results that can be expected in a production setting. The latter part of the thesis provides further evidence by evaluating actual production processes utilizing the SecurePak and Sure Torque torque testers, and show the above to be true.

The results of the torque tester variability test show that the average of one hundred samples for the SecurePak torque tester was 14.8 TIP and the average for the ninety eight samples on the Sure Torque was 11.9 TIP. A t-test was conducted to see whether there is a statistical difference in means. The t-test showed that the difference between means was highly significant at an Alpha level of 0.001. A further test was

OPERATOR VARIABILITY SURE TORQUE

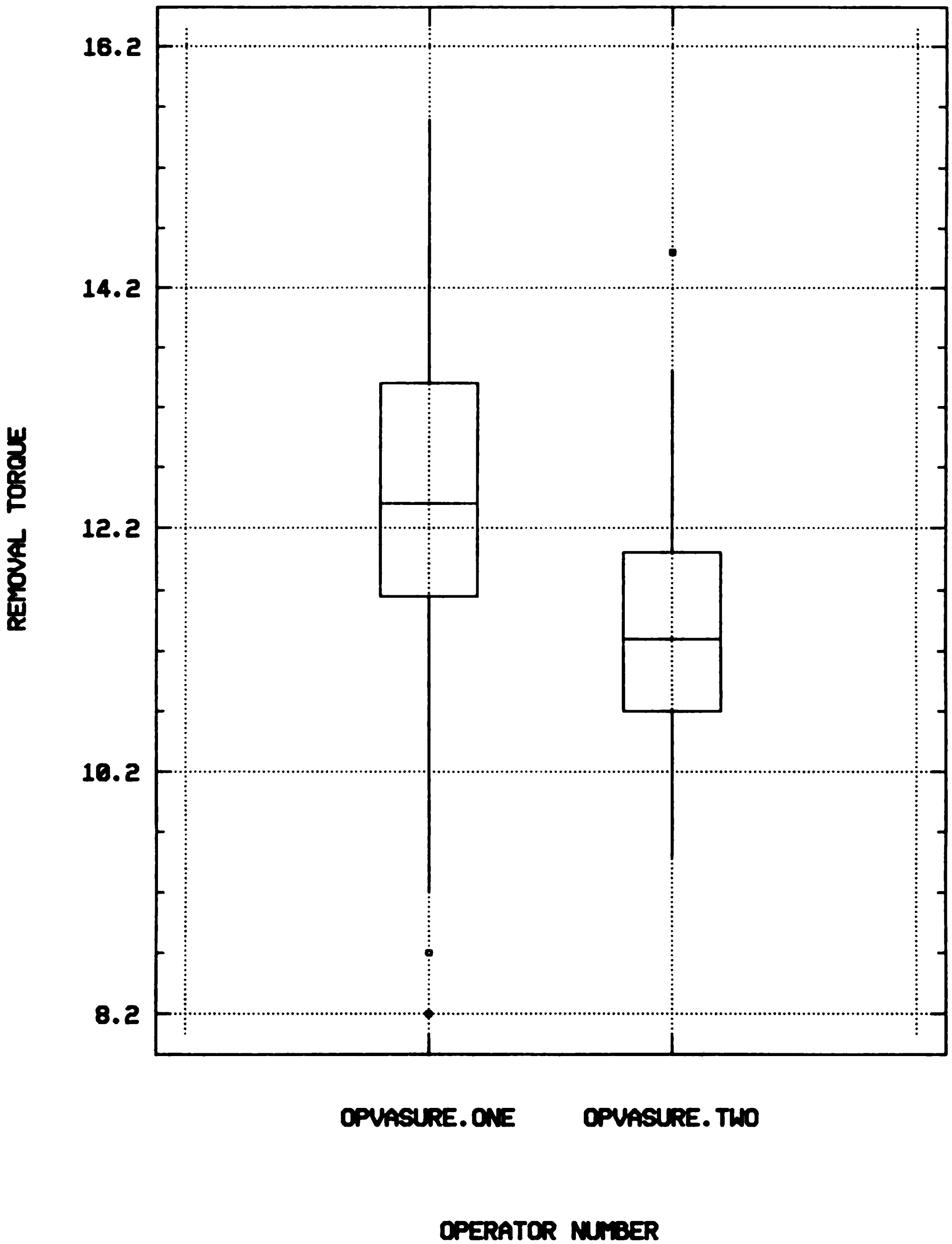

FIGURE 3

conducted to see whether the ratio of the variances of the two torque testers was equal to one. A ninety five percent confidence interval for the ratio of the variances does not include one, therefore the variances of the two torque testers are not equal. The multiple Box-and Whisker Plot in Figure 4 shows graphically the difference in medians represented by a visible separation of the center lines of each box. The presence of no overlap between each of the boxes reveals that there is a difference in variances between each of the torque testers. The box representing the SecurePak torque tester is much larger (larger variance) than the box for the Sure Torque tester (less variance). The test for normality or the Kurtosis for each of the measurement devices was also calculated and was -0.460 for the SecurePak and was -0.096 for the Sure Torque. A Kurtosis = 0 is representative of a "normal" distribution. The Kurtosis for the Sure Torque is closer to zero compared to the Kurtosis for the Secure Pak. This reflects that the Sure Torque approximates a normal distribution better than the Secure Pak. The Kurtosis value for each measurement device was negative, which shows that these distributions are flatter and have shorter tails than does a normal distribution.

4.3 Conclusions

1. Operator variability - the tests for operator variability show that the SecurePak removal torque tester has greater operator variability than the Sure Torque removal torque tester. There is more operator interaction associated with measuring removal torque by the hand method. This can be attributed to individual operators applying different vertical and lateral forces to the closure system while rotating the cap during the measuring process. The Sure Torque provides a fully automated method of measuring removal torque and significantly reduces the effects of operator variability. The presence of a constant velocity head and a constant downward pressure applied to the closure system on

TORQUE TESTER VARIABILITY

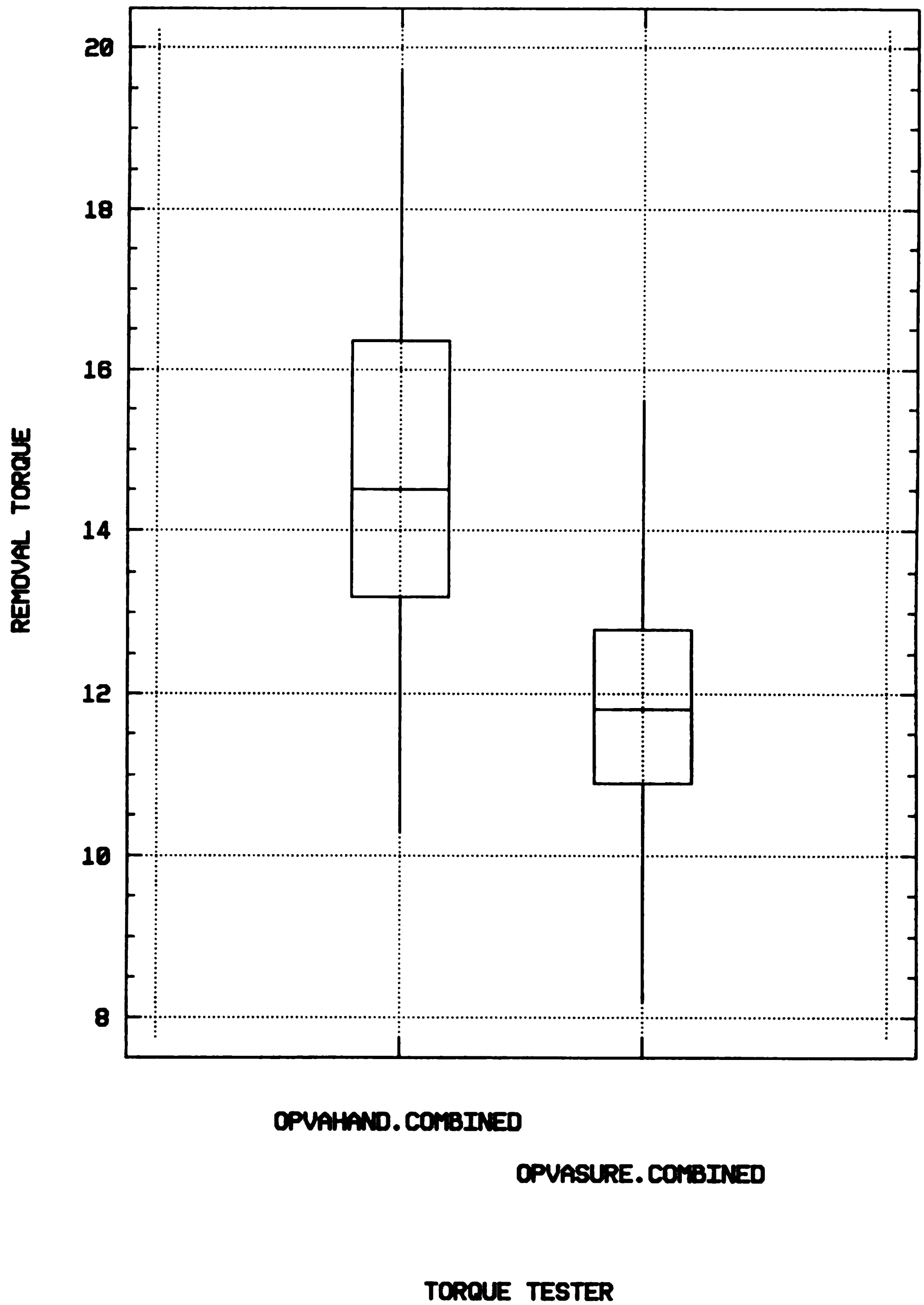

FIGURE 4

the Sure Torque, virtually eliminates the effect of vertical and lateral forces introduced by individual operators.

2. Torque tester variability - the tests for torque tester variability show that the Sure Torque provides a better method for measuring removal torques than does the SecurePak. The precision of the two torque testers is reflected in the standard deviations of each of the processes. The Sure Torque (standard deviation 1.4 TIP) has a lower standard deviation compared to the SecurePak (standard deviation 2.0 TIP) and is therefore more precise. The mean removal torque on the Sure Torque (11.9 TIP) is 2.9 TIP lower than the mean removal torque for the SecurePak (14.8 TIP). Further research should be conducted to reveal which measurement device produces a reading that approximates the "true" removal torque.

3. An evaluation of the measurement device methods for measuring removal torque shows the Sure Torque to be more consistent. The Sure Torque uses a fully automated method for measuring removal torque. A bottle is placed against a rubber guide block, by the operator, and then the Sure Torque is activated. A second rubber block then closes against the bottle, securing it in place and the base plate raises the bottle up to locate the cap in the cap chuck. The chuck clamps onto the cap and begins to rotate. A constant velocity rotating head removes the cap at a constant rate while measuring removal torque. The rotating head continues to measure removal torque until it senses a dramatic drop in removal torque force. Once this point is reached, the measurement process is complete.

The Secure Pak method is not automated and requires more operator interaction. A bottle is clamped between four rubber covered posts and the removal torque is then measured by an operator. The operator "grips" the cap and removes it by rotating counterclockwise. Each operator will perform this task differently and introduce various degrees of vertical and lateral forces. This results in greater variation in the measurements of removal torque. This is further reinforced by the test for "normality" or the Kurtosis for the Sure Torque (-0.096) being closer to zero than the Kurtosis for the SecurePak (-0.460). A Kurtosis value of zero reflects that a given process is normally distributed.

The Multiple Box-and-Whisker plots for Operator Variability Secure Pak (Figure 2) and Torque Tester Variability (Figure 4) are similar since they both show that there is no close relationship between the two population groups (no overlapping of the "Boxes"). The median value or the centerline of the individual "Boxes", in both cases, are separated from each other. This shows that there is a difference in medians which is reinforced by the t-test discussed earlier. The Multiple Box-and-Whisker plot for Operator Variability Sure Torque (Figure 3) shows a closer relationship between the two population groups (the "Boxes" overlap). The median value or the centerline of the individual "Boxes" are more closely related to each other. This shows that there is not a significant difference in medians which is reinforced by the t-test discussed earlier.

5. REDUCING MACHINE SET-UP VARIABILITY

The Resina capping machine is an effective tool for applying a cap to a bottle as long as it is set-up in the correct manner. There is a large number of different machine variables that influence application torque. An evaluation of which machine variable has the most influence on application torque was conducted. A two-to-the-three factorial experiment was conducted to evaluate three factors (variables), each at two levels. The three variables tested were: roller speed, belt speed, and roller separation. The roller speed refers to the speed of four sets of rubber rollers that apply torque to the CRC cap. The belt speed refers to the speed of the two belts that hold the bottle in place as it travels through the Resina capper. The tests revealed that roller speed and separation between rollers in a pair are the two most critical parameters that need to be targeted. Belt speed had negligible effect on the process.

Roller speed is relatively easy to control and is adjusted by simply turning a crank that alters the position of the motor in relation to the drive belt. The optimum roller speed is obtained at slow speed settings (3.3 RPM). The Resina should be set-up to run at this speed during production runs. Roller separation has the most influence on application torque and is more difficult to control than roller speed. The Resina has no dials or marked gauges that allow for a consistent roller pair set-up, so a set-up gauge was designed to enable a better setting of the distance between rollers in a pair.

Another variable that was found to be critical to the cap application process was the alignment of the roller pairs in the direction of travel (Figure 5). The way the Resina capper is designed makes it very difficult to set the roller separation correctly and consistently across all production runs. A high speed video of the process revealed that bottles would become laterally stressed if the roller pairs were not aligned. The objective

PAIRED ROLLER SET-UP

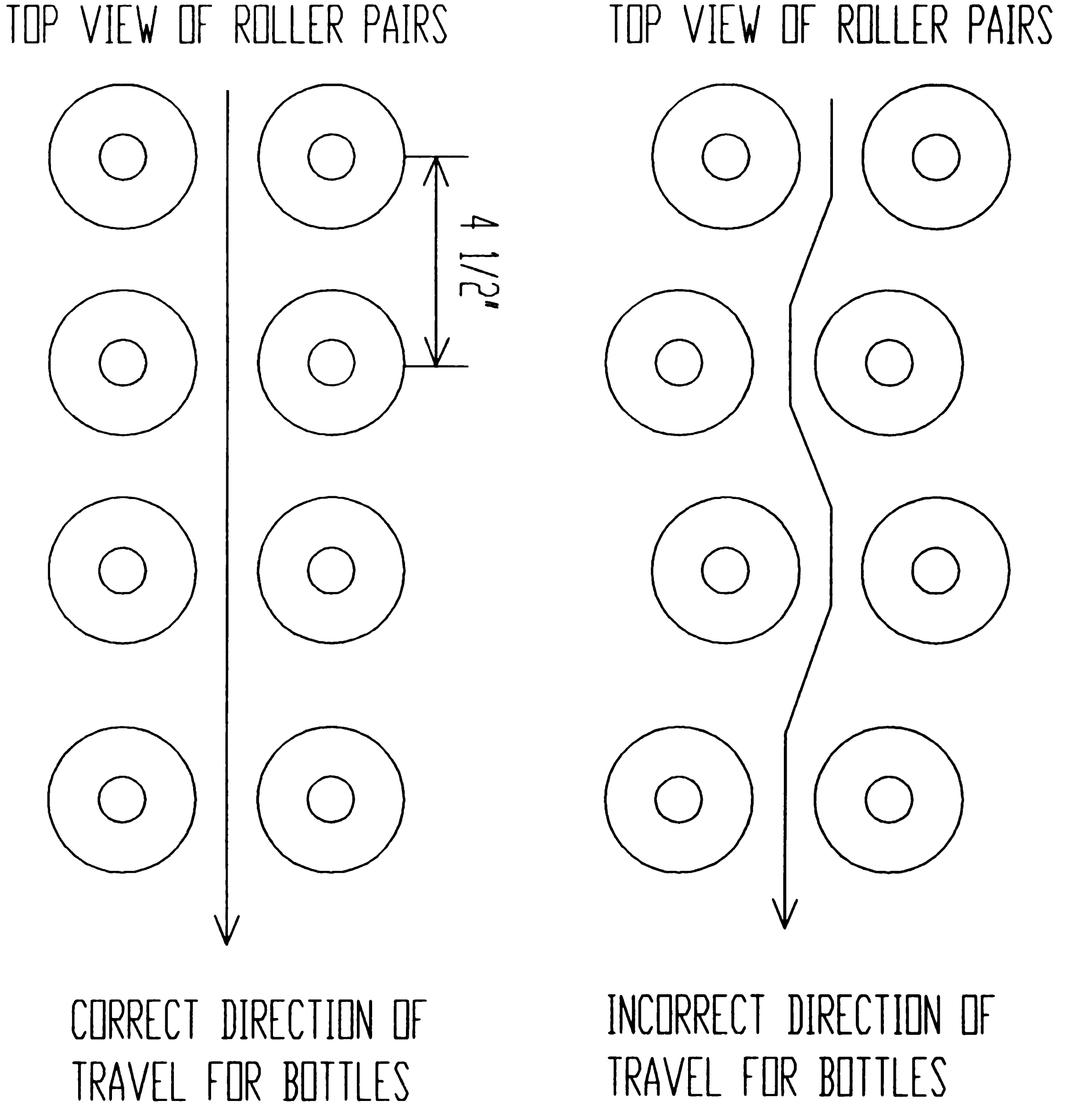

FIGURE 5

is to have both rollers of a pair strike the cap at exactly the same time. If the rollers do not strike at the same time the closure system will become stressed on one side and will cause the bottle and cap to move laterally within the belts. This will result in application torque variation as well as the possibility of broken bottles during production causing unnecessary down time.

5.1 Designing a set-up gauge

The current system for setting up the Resina is inconsistent and allows excessive variation to be introduced into the process. A single bottle is "jogged" into the machine until it is aligned with the center of the shaft on the first set of rollers. The separation between these rollers is then adjusted relative to the bottle/cap position by turning set screws. The bottle is then "jogged" onto the next pair of rollers. This is done until all four pairs of rollers are set. In this procedure there is no assurance that bottles will follow a straight line through the machine. Each individual operator will set the machine up differently every time. This variation should be reduced.

To eliminate machine set-up variability, a set-up gauge was designed to make setting up the Resina easier and more consistent. The gauge itself is comprised of a series of molded epoxy bottles that are attached to each other by two metal rods that run through the center of each bottle (Figure 6). The epoxy bottles were molded from glass bottles that are used in production and provide accurate facsimiles of the original glass bottles. The bottles are spaced 4 1/2" apart which is the distance between the centers of the spindle shafts on the Resina capper.

During a gauge set-up procedure, the gauge is "jogged" into the Resina so that the center of each of the bottles is directly aligned with the center of the spindle shafts. Once the gauge is in the machine each of the consecutive pairs of rollers are individually

RESINA SET-UP GAUGE

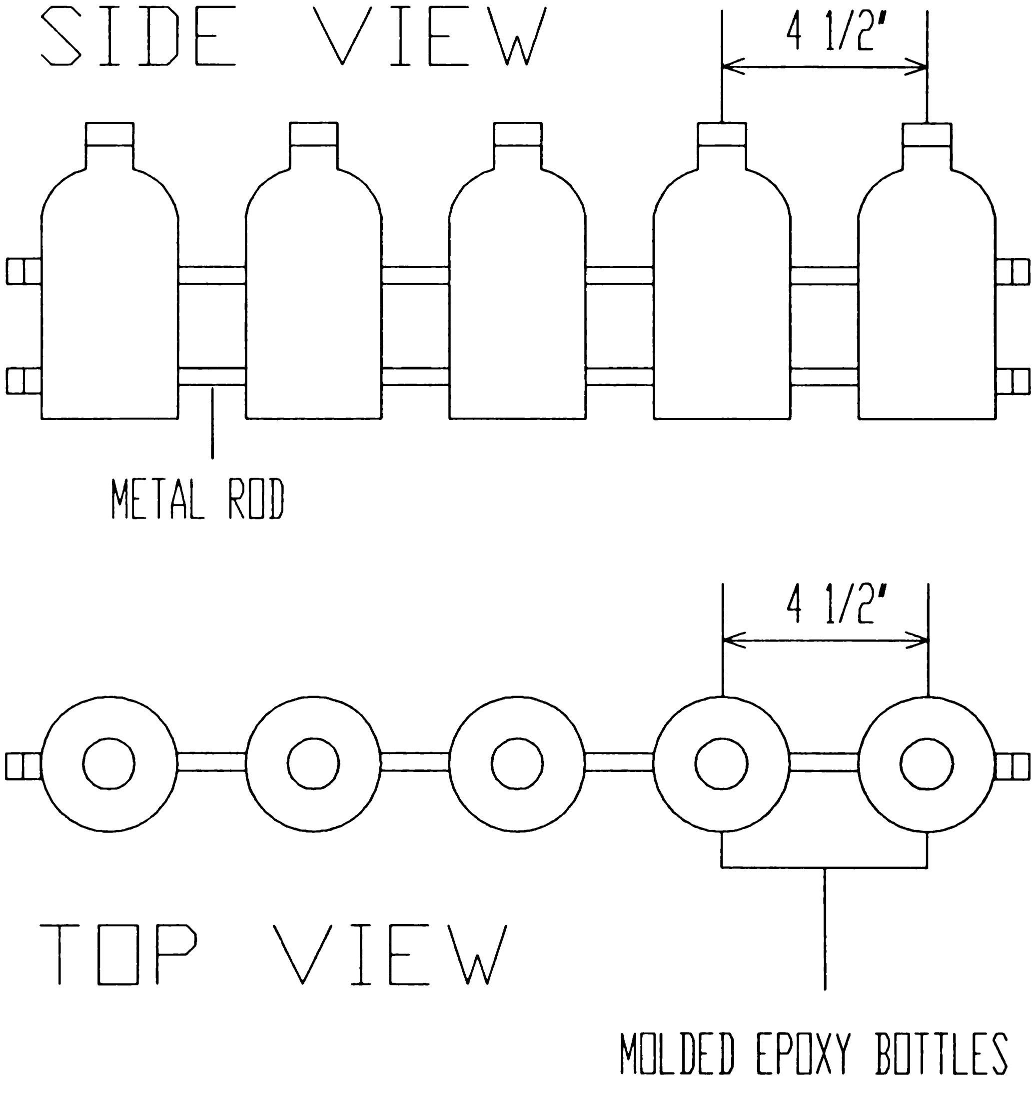

FIGURE 6

positioned according to the gauge. The gauge also provides the operator with the correct straight line path of travel that a bottle will take through the machine.

An in depth analysis of how the gauge performs on actual production runs was conducted and this analysis follows in the latter part of the thesis.

6. CRITICAL PARAMETER DESIGN

6.1 Evaluating The Closure System

To effectively reduce variation in a process, one needs to know what specific parameters control that process. In this case the process that needs to be controlled is that which produces application and removal torques. The variable of application torque is very difficult to measure in a production setting. Current capping equipment does not have the capability to provide an in-process application torque readout. Providing such a feature is cost prohibitive and may not be accurate at high speed production rates. As a result, removal torque during production runs was used as a surrogate for application torque. This evaluation of removal torque is specific to the type of closure, the size of the closure, the liner material, and the materials of the bottle and cap. The packaging system studied contains a liquid product.

The type of closure evaluated is a 28 mm Child Resistant Closure (CRC). The inner shell is made from polypropylene resin and the outer shell is made from high density polyethylene. The bottle that the CRC is applied to is made from type NP or better amber glass. The liner is a three layer laminated structure consisting of:

a) Backing - made from pulp board with thickness of 0.035 inches.

b) Facing - made from polyethylene that is extrusion coated to 30 pound white paper.

c) Coating - made from paraffin wax approximately 0.001 inches thick.

The manufacturer of the CRC cap suggests that application torques should range from a minimum of 13 TIP to a maximum of 19 TIP, for this particular closure system. The supplier also suggests that a minimum removal torque of 3 TIP is required for the closure system to be engaged and effective as a child resistant closure.

6.2 Determining Removal Torques: Target, Minimum, and Maximum

To determine the target, minimum, and maximum removal torques for this closure system an experiment was designed to evaluate a number of critical characteristics. The difference between application torque and immediate removal torque was studied, as was the effect that time has on removal torque.

The most critical parameter for the closure system is that of maintaining the removal torque above the three torque inch pounds that is required to maintain the Child Resistant feature. A safety factor will be incorporated into the evaluation to ensure that any experimental or material errors can be accounted for.

The experiment itself was comprised of applying a series of bottles and caps at three different torque levels (12 TIP, 15 TIP, and 18 TIP). Forty eight bottles were used at each level for a total of one hundred and forty four bottles and caps. The caps were applied to the water filled bottles utilizing the Sure Torque torque tester. The bottles could not be filled with the product itself due to Quality Control issues and cost constraints. Removal torques were then measured at different intervals to evaluate the effect of time. The intervals used were immediate removal torque (15 minutes or 0.01 Days), and removal torques after Day 1, Day 4, and Day 7. Each removal torque data point represents an average of twelve closures. The percent retention in Table 4 is the removal torque as a percentage of the application torque. The raw data is listed in Table 4 in Appendix A. A summary of the data is listed in Table 4:

Table 4 - Removal Torque Study vs. Time Showing Removal Torque Decay

12 TIP APPLIC.	DAY 0.01*	DAY 1	DAY 4	DAY 7
AVERAGE	7.3 TIP	5.8 TIP	5.7 TIP	5.6 TIP
STD. DEV.	0.53 TIP	0.56 TIP	0.41 TIP	0.35 TIP
% RETENTION	60.7%			
15 TIP APPLIC.	DAY 0.01*	DAY 1	DAY 4	DAY 7
AVERAGE	8.8 TIP	7.1 TIP	6.6 TIP	6.5 TIP
STD. DEV.	0.67 TIP	0.73 TIP	0.46 TIP	0.36 TIP
% RETENTION	58.7%			
18 TIP APPLIC.	DAY 0.01*	DAY 1	DAY 4	DAY 7
AVERAGE	10.1 TIP	8.2 TIP	8.0 TIP	7.9 TIP
STD. DEV.	0.50 TIP	0.54 TIP	0.63 TIP	0.63 TIP
% RETENTION	56.2%			

* DAY 0.01 represents immediate removal torque.

Immediate removal torques are significantly lower than application torques. As the application torque increases, the percent retention between immediate removal and application torque decreases. The average percent retention within the test parameters is 58.5%, or immediate removal torque is 0.585 * Application Torque (for this particular closure system). The effect of time is also very significant. The removal torques degrade over time but it should be noted that the first one to two day period results in the largest amount of removal torque decay. After the initial drop off, the removal torque degradation levels off to a very slow rate.

6.3 Predicting the Target Value (Application and Removal)

To fully evaluate the effect of decay over time, a regression analysis was conducted to try to predict removal torque after a given amount of time. The amount of time is determined by the shelf-life of the product that is being packaged. The shelf-life of this particular product has previously been determined (by stability testing) to be two years or seven hundred and thirty days. A multiplicative (logarithmic) model was used to predict the removal torques after seven hundred and thirty days, at each of the three application levels. Twelve closure systems were evaluated at each application level, for each time interval contained in the model. Previous removal torque studies conducted at other pharmaceutical companies have shown that, at room temperatures, the extent of relaxation of the closure system has taken full effect after seven to fourteen days. After the initial relaxation, removal torque decay subsides and the closure system assumes a constant removal torque value. Although there is a large error associated with making a prediction of removal torque after two years based on seven days, one can safely assume that once a constant removal torque is achieved, there will be little variation around the constant removal torque value. The prediction of removal after two years is therefore reasonably accurate. These values are tabulated below:

Table 5 - Predicted Removal Torques

APPLICATION TORQUE	REMOVAL TORQUE AFTER 730 DAYS	TORQUE ABOVE MINIMUM (3 TIP)
12 TIP	4.6 TIP	1.6 TIP
15 TIP	5.2 TIP	2.2 TIP
18 TIP	6.5 TIP	3.5 TIP

The predictions for all of the application torques are above the three torque inch pound minimum after two years. The desired safety factor to be built into the system would be two torque inch pounds above the minimum i.e. five torque inch pounds. This safety factor will provide adequate protection from defective materials, process inconsistencies, and harsh environmental conditions. The effects of vibration were studied and show that removal torques may decrease as much as two torque inch pounds after a vibration test. The current process has a safety factor that is considerably lower and inadequate. Although the 12 TIP prediction (R-squared 64.55%) is 1.6 TIP above the minimum of 3 TIP (after two years), this value is below the desired two torque inch pound safety factor. If a target application torque was aimed at twelve torque inch pounds, the process (assuming normality) will not guarantee that loose caps will not be found in the field before two years has elapsed. In fact, based on the model closures would have degraded to five torque inch pounds after only 12.4 weeks. After two years the predicted removal torques would be 4.6 TIP. The first seven days of removal torque degradation are represented in Figure 7 - 12 TIP Application.

The 15 TIP prediction (R-squared 71.90%) is 2.2 TIP above the minimum after two years. This value is also above the value that incorporates the two torque inch pound safety factor. Based on the model, it would take 4.75 years to reach five torque inch pounds. The two year shelf life of the product is well within this time frame. After two years the predicted removal torques would be 5.2 TIP. The first seven days of removal torque degradation are represented in Figure 8 - 15 TIP Application.

The 18 TIP prediction (R-squared 68.76%) is 3.5 TIP above the minimum (after two years). Based on the model, in practical terms, closures would not reach five torque inch pounds. Theoretically it would take almost 1500 years before these closures would degrade to five torque inch pounds. After two years the predicted removal torques would be 6.5 TIP. The first seven days of removal torque degradation are represented in Figure 9 - 18 TIP Application.

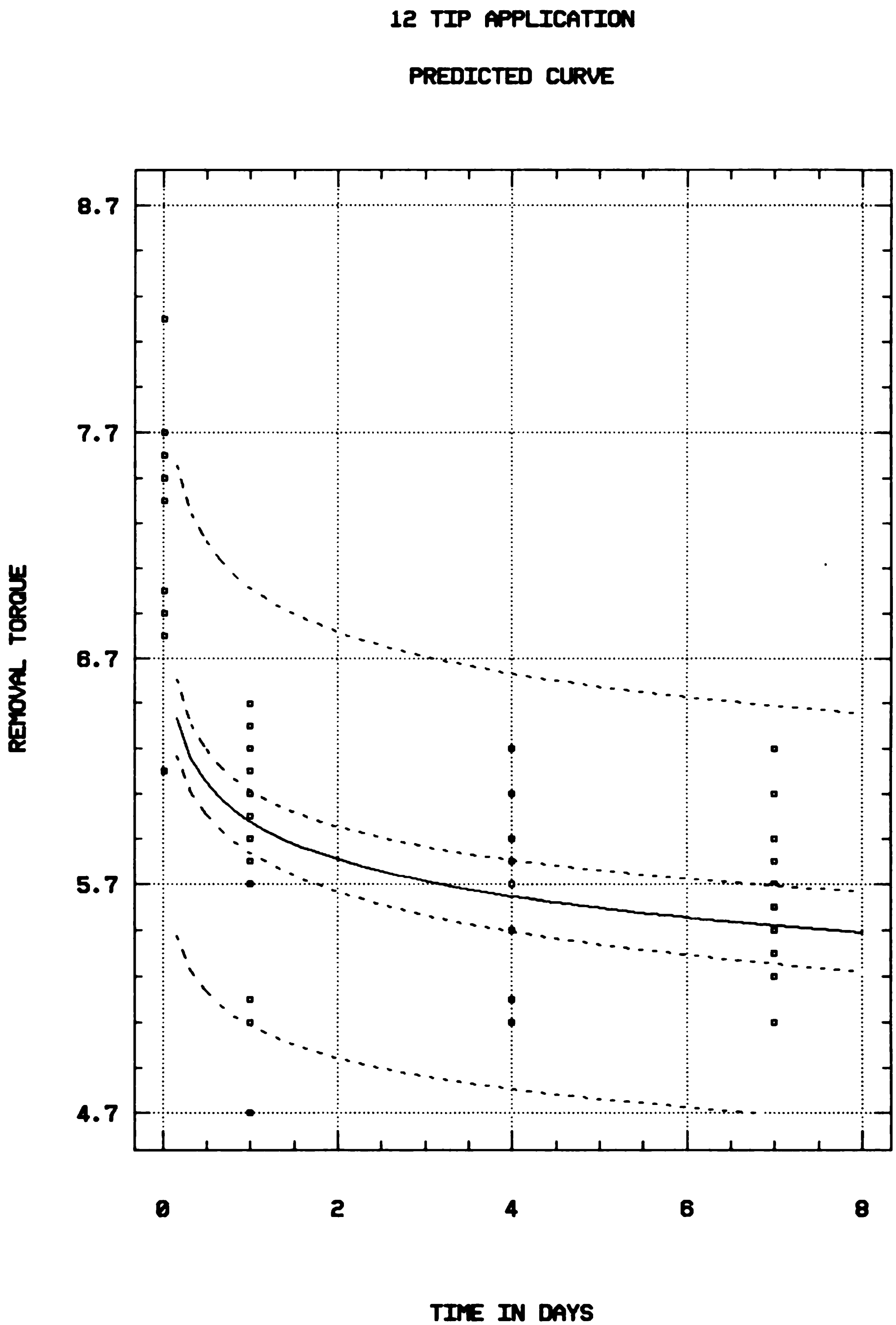
12 TIP APPLICATION
PREDICTED CURVE
8.7
7.7
6.7
5.7
4.7
REMOVAL TORQUE
0
2
4
6
8
TIME IN DAYS

FIGURE 7

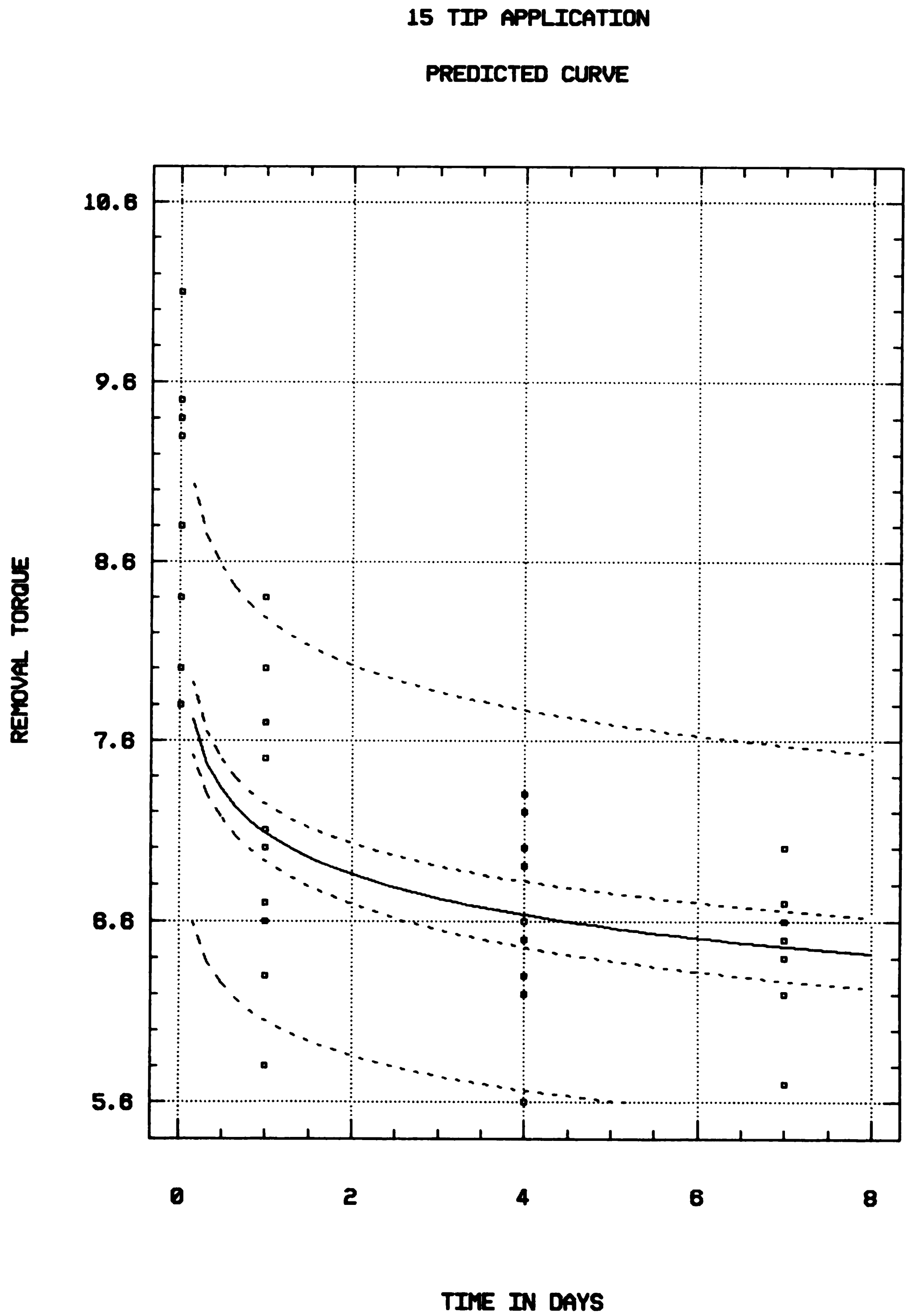
15 TIP APPLICATION
PREDICTED CURVE
REMOVAL TORQUE
10.6
9.6
8.6
7.6
6.6
5.6
0
2
4
6
8
TIME IN DAYS

FIGURE 8

18 TIP APPLICATION

PREDICTED CURVE

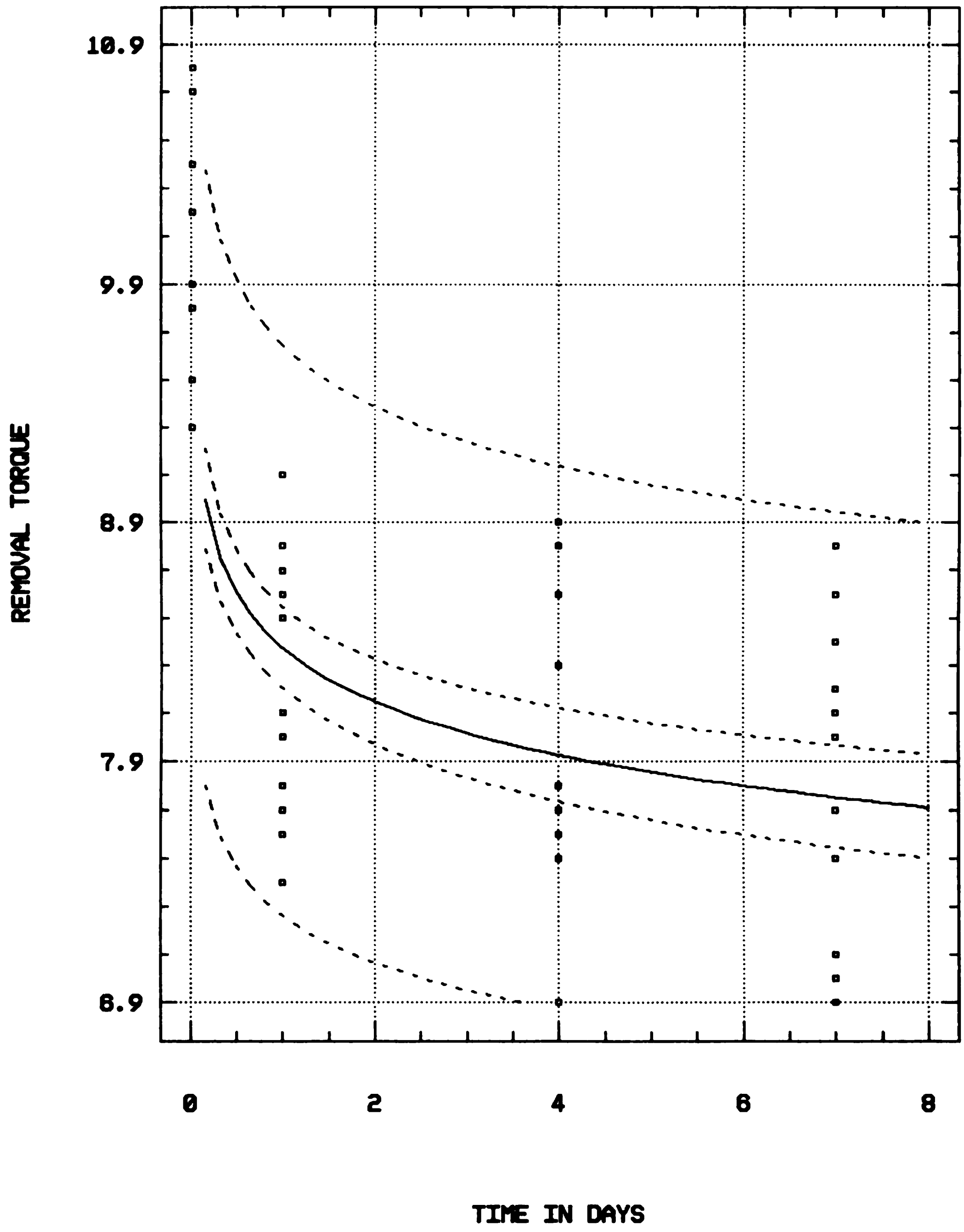

FIGURE 9

Based on the above data an application torque target of between 16 TIP and 18 TIP would ensure that a very small percentage of the torques would degrade to below five torque inch pounds during the shelf life of the product. Tail area probabilities are calculated in Chapter 7, which show the probabilities of falling outside specified limits based on calculated process variations. The five torque inch pound value is still two torque inch pounds above the minimum of three torque inch pounds required to unscrew the CRC because of the reverse ratchet mechanism. Any torques that degraded below five would have a very remote chance of falling anywhere close to three torque inch pounds. By setting an application target of between 16 TIP and 18 TIP, a target immediate removal torque of between 9.4 TIP and 10.5 TIP is achieved. These values were calculated using the following formula:

$$\text{Immediate Removal Torque} = 0.585 * \text{Application Torque} \quad (7)$$

6.4 Predicting the Minimum and Maximum Immediate Removal Torque Values

The minimum removal torque, based on the removal torque study, that can be tolerated in production is seven torque inch pounds. This would mean that a minimum application torque of 12 TIP would be allowed (based on the predicted Equation 7). This value would ensure that no removal torques would decay to below three torque inch pounds over the two year shelf life of the product.

The maximum removal torque that can be tolerated in production is 14 TIP. This would mean that a maximum application torque of 24 TIP would be allowed (based on the predicted Equation 7). This value is 5 TIP above the recommended supplier maximum. Previous data and current processes suggest that the closure system can withstand well in excess of the recommended 19 TIP value. A summary of the recommended process parameters is listed in Table 6 - Summary of Recommended Process Parameters:

Table 6 - Summary of Recommended Process Parameters

	APPLICATION TORQUE	REMOVAL TORQUE
TARGET	16-18 TIP	9.4-10.5 TIP
MINIMUM	12 TIP	7 TIP
MAXIMUM	24 TIP	14 TIP

7. TAGUCHI PROCESS EVALUATION

To evaluate two or more processes utilizing the Taguchi philosophy, one needs to know various statistical facts about each process. A Target (T) value has to be set, upper (USL) and lower (LSL) specification limits must be set, and the standard deviation for each process has to be calculated. Knowing all of these values, one can then calculate the Mean Squared Deviation (MSD), the Signal to Noise Ratio (S/N), the Loss, and the Savings associated with a given process. The Performance Characteristic or Process Capability Index (Cpk) can also be calculated to evaluate the "capability" and centrality of a given process mean within a given limits.

7.1 Assumptions

For the purpose of the Taguchi analysis, various assumptions were made regarding each of the given processes that were studied. Each process was assumed to be normally distributed. The distributions of each of the processes was shifted so that the average of each process was centered around the predicted target value. This target value was calculated to be 10.5 TIP based on the removal torque study discussed earlier. In practical terms the average value for each of the processes can be shifted by adjusting the torque roller separation so that average of a given process falls on the target value. To lower a process average the distance between the torque rollers will increase. To raise a process average, the torque rollers are moved closer together. This assumes that variation in a process does not change at different application torque levels.

The costs used in the analysis of cost comparisons between processes are not exact. This information, for proprietary reasons, cannot be fully disclosed. Therefore the cost of one unit that is rejected during production will be set at one dollar ($1.00).

7.2 The Current Process

The current process being used includes the standard operator set-up procedure on the Resina capper. This set-up does not include using the set-up gauge discussed previously. The process also uses the Secure Pak removal torque tester as the measurement device. The data that was used for the analysis of this procedure was taken from the production orders of three previous production runs. The data was collected in groups of five samples every hour over each of the production runs. Each production run is approximately seven hours in length. The raw data is listed in Table 7 in Appendix A. A summary of the data collected for this process is listed in Table 7 below.

Table 7 - Current Process Data Summary

SAMPLE SIZE	80
AVERAGE	15.2 TIP
ADJUSTED AVERAGE	10.5 TIP
TARGET VALUE	10.5 TIP
STD. DEV. (CLASSICAL)	2.21 TIP
STD. DEV. (TAGUCHI)	2.19 TIP
MEAN SQUARED DEVIATION	4.82 TIP *
VARIANCE	4.88 TIP
S/N RATIO	-6.83
Cpk	0.53

* M = 0 (Target Value = Average Value)

The current process produces a classical standard deviation of 2.21 TIP and a Taguchi standard deviation of 2.19 TIP. The Mean Squared Deviation is 4.82 TIP based on an adjusted process mean to the target value (M = 0). The Signal-to-Noise Ratio is negative 6.3 calculated from the MSD. The Process Capability Index is 0.53 based on the Adjusted Average. The data shows that this process is not very capable of producing the quality that is demanded by the company. Based on this data, six out of every one hundred closures applied will fall below 7 TIP and above 14 TIP. The calculated probability is 0.057.

7.3 Incorporating a Better Measurement Device (Sure Torque)

By incorporating the Sure Torque tester into the process, operator variability on the measurement device can be reduced significantly. During the data collection, the Resina capper was set up using the standard procedure (without the gauge). Removal torques were monitored over a three day period during a large production run. Twelve closures were evaluated every half hour throughout the run. The raw data is listed in Table 8 in Appendix A. A summary of the data collected for this process is listed in Table 8 below.

Table 8 - Improved Process Data Summary

SAMPLE SIZE	908
AVERAGE	8.7 TIP
ADJUSTED AVERAGE	10.5 TIP
TARGET VALUE	10.5 TIP
STD. DEV. (CLASSICAL)	1.13 TIP
STD. DEV. (TAGUCHI)	1.13 TIP
MEAN SQUARED DEVIATION	1.28 TIP *
VARIANCE	1.28 TIP
S/N RATIO	-1.06
Cpk	1.03

* M = 0 (Target Value = Average Value)

The improved process produces a classical standard deviation of 1.13 TIP and a Taguchi standard deviation of 1.13 TIP. The Mean Squared Deviation is 1.28 TIP. This is based on an adjusted process mean to the target value (M = 0). The Signal-to-Noise Ratio is negative 1.06 calculated from the MSD. The Process Capability Index is 1.03 based on the Adjusted Average. The data shows that this process is a vast improvement over the previous process. Based on this data, one out of every one thousand closures applied will fall below 7 TIP and above 14 TIP. The calculated probability is 0.001.

7.4 Incorporating the Set-up Gauge into the Process

Incorporating the set-up gauge discussed in chapter four into the above process results in further reduction in variation. The process utilizes the Sure Torque measurement device and the Resina capper is set up using the set-up gauge. Operator variability is minimized on both the measurement device and the Resina capper. The Sure Torque and the gauge contribute to reduced operator variability. A better overall set-up is achieved with the gauge. The raw data is listed in Table 9 in Appendix A. A summary of the data collected for this process is listed in Table 9 below.

Table 9 - Optimum Process Data Summary

SAMPLE SIZE	120
AVERAGE	7.0 TIP
ADJUSTED AVERAGE	10.5 TIP
TARGET VALUE	10.5 TIP
STD. DEV. (CLASSICAL)	0.88 TIP
STD. DEV. (TAGUCHI)	0.88 TIP
MEAN SQUARED DEVIATION	0.78 TIP *
VARIANCE	0.79 TIP
S/N RATIO	1.08
Cpk	1.32

* M = 0 (Target Value = Average Value)

The optimum process produces a classical standard deviation of 0.88 TIP and a Taguchi standard deviation of 0.88 TIP. The Mean Squared Deviation is 0.78 TIP based on an adjusted process mean to the target value (M = 0). The Signal-to-Noise Ratio is 1.06 calculated from the MSD. The Process Capability Index is 1.32 based on the Adjusted Average. The data shows that this process is the best (least amount of variation) and is the closest to producing the quality demanded by the company. Based on this data, four out of every one hundred thousand closure systems will fall below 7 TIP and above 14 TIP. The calculated probability is 0.00004.

The three actual process probability density functions are graphically represented in Figure 10 and show the distributions of the removal torque values around their actual means. The three adjusted process data density functions are graphically represented in Figure 11 and show the distributions of the removal torque values, for each process, around the adjusted mean (10.5 TIP).

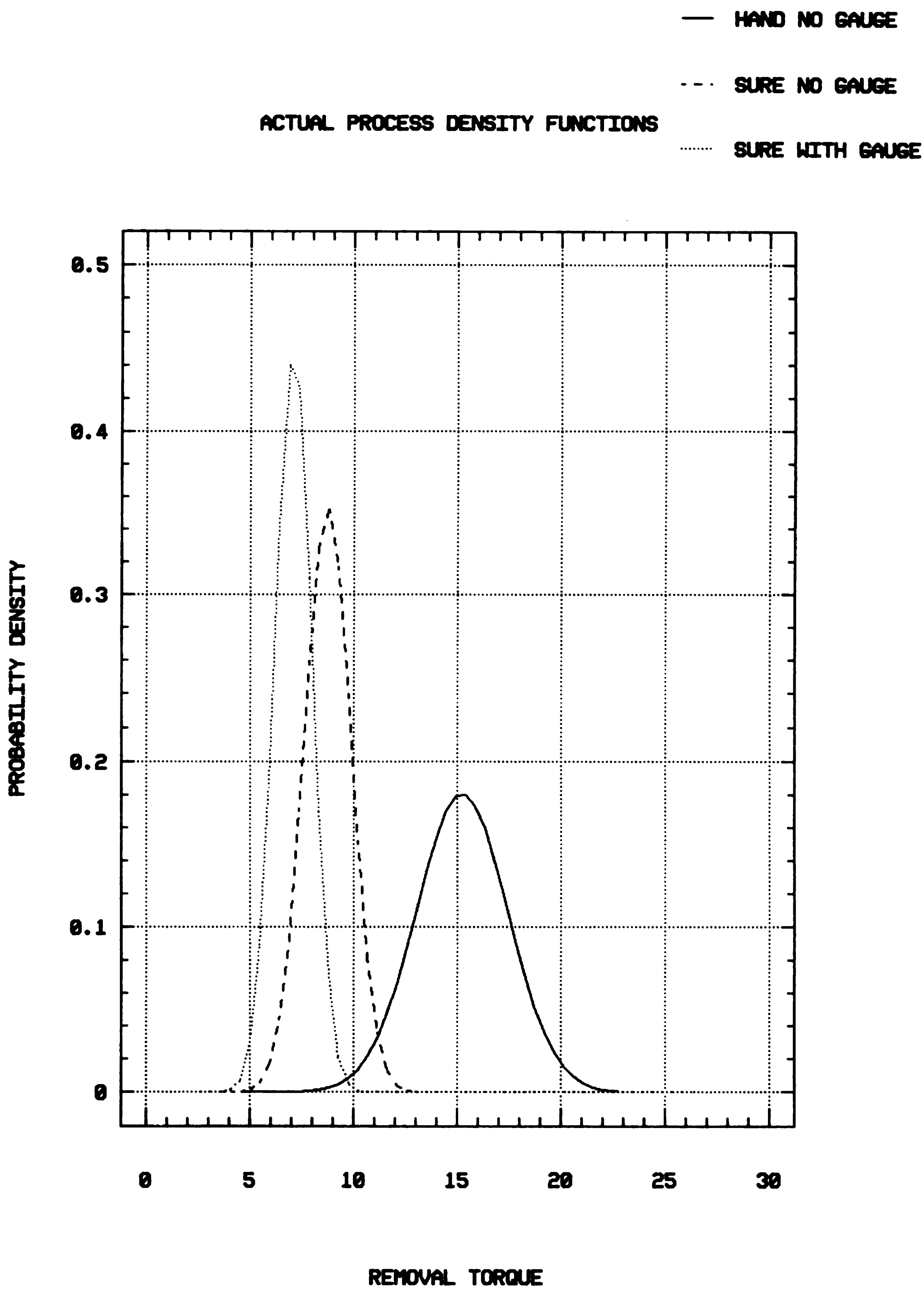
HAND NO GAUGE
SURE NO GAUGE
ACTUAL PROCESS DENSITY FUNCTIONS
SURE WITH GAUGE
PROBABILITY DENSITY
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
REMOVAL TORQUE

FIGURE 10

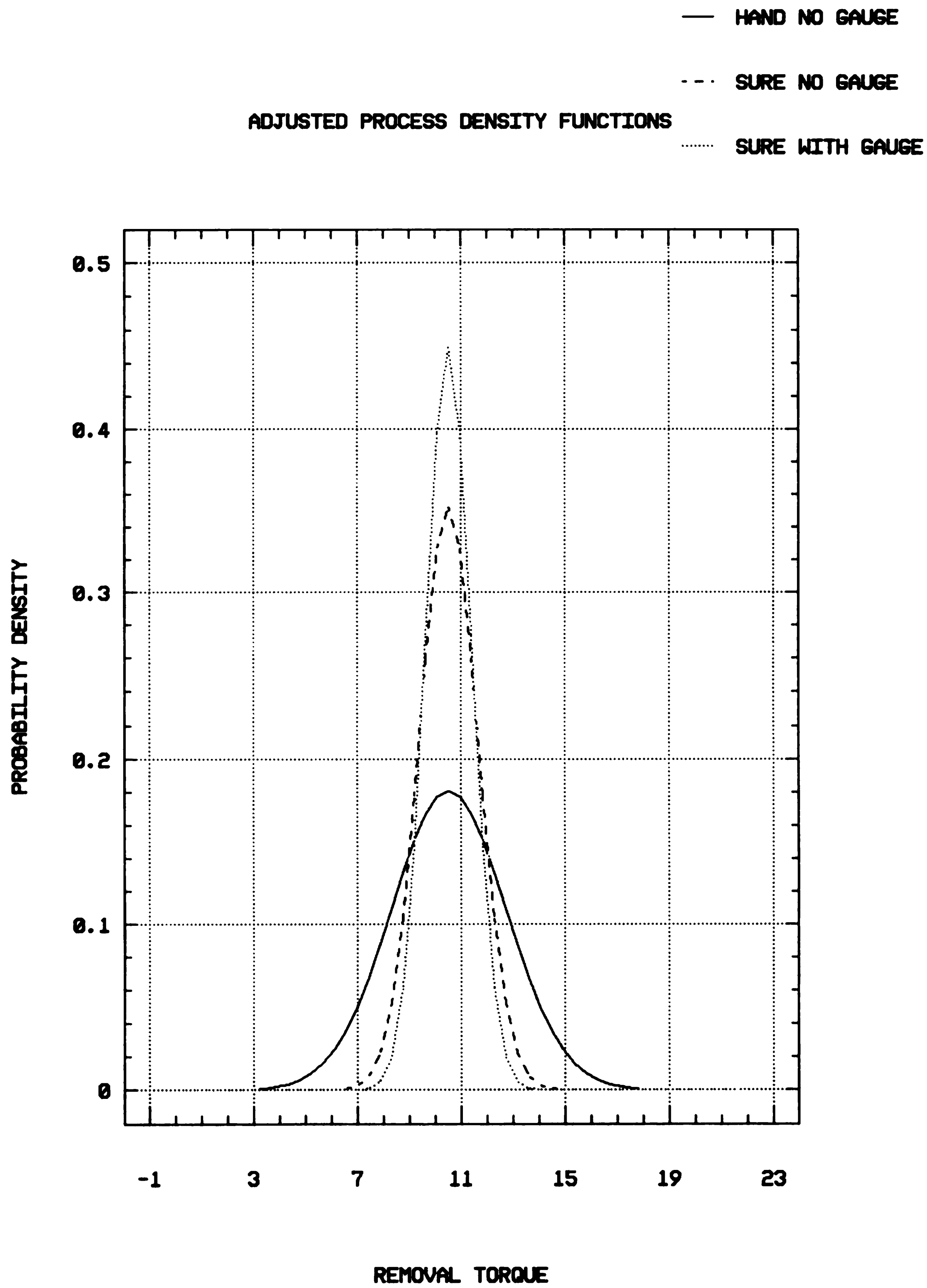
HAND NO GAUGE
SURE NO GAUGE
ADJUSTED PROCESS DENSITY FUNCTIONS
SURE WITH GAUGE
PROBABILITY DENSITY
0.5
0.4
0.3
0.2
0.1
0
-1
3
7
11
15
19
23
REMOVAL TORQUE

FIGURE 11

8. ESTIMATING THE LOSS AND SAVINGS GENERATED BY THE IMPROVED PROCESSES

8.1 Calculating the Loss Constant (K)

The Loss Constants (K) for the processes discussed in Chapter 7 will all have the same value. For each of the processes, the tolerance is the same and was calculated to be ±3.5 TIP. The loss associated with one defect during production was assumed to be one dollar. Although this is not an exact figure, it closely approximates the cost of a defective unit in production. This one dollar figure incorporates the costs of: labor, materials, and product materials. For proprietary reasons the exact costs cannot be disclosed in the thesis. The one dollar does not include research and development costs for the product itself, cost of returns, cost of a recall, cost of a lost customer etc.. The Loss Constant is calculated by substituting the appropriate values into the Loss Constant Equation 2:

$$
\begin{aligned}
K &= (\text{LOSS}/\text{UNIT})/(\text{TOLERANCE})^2 \\
&= \$1.00/(3.5\text{TIP})^2 \\
&= \$0.082/\text{TIP}^2 \\
&\text{WHERE:} \\
\text{TOLERANCE} &= (14\text{TIP} - 7\text{TIP})/2
\end{aligned}
$$

The resulting Taguchi loss curve that is produced from the above calculation is graphically represented in Figure 12 - The Taguchi Loss Function for Removal Torque.

THE TAGUCHI LOSS FUNCTION FOR

REMOVAL TORQUE

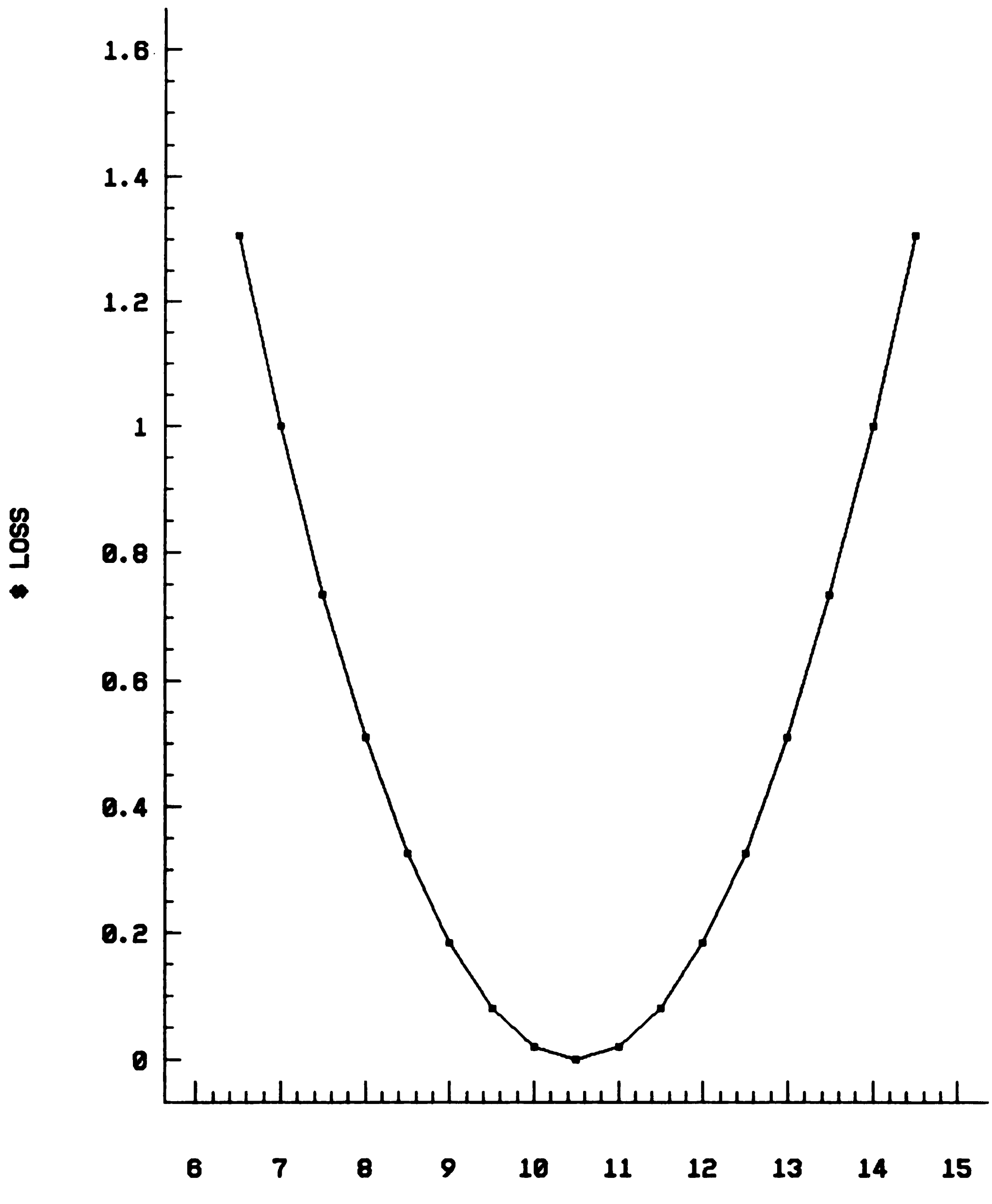

FIGURE 12

8.2 Comparing the Current Process to the Improved Process

The average Loss associated with one defective unit, utilizing the current process, is calculated by substituting the above Loss Constant (K) and the Mean Squared Deviation for the current process into the Taguchi Loss Function Equation 3:

$$\begin{aligned} LOSS &= K(MSD) \\ &= \$0.082 / TIP^2 * 4.82 TIP^2 \\ &= \$0.393 \text{ PER PART} \end{aligned}$$

The average Loss associated with one defective unit, utilizing the improved process, is calculated by substituting the above Loss Constant (K) and the Mean Squared Deviation for the improved process into the Taguchi Loss Function Equation 3:

$$\begin{aligned} LOSS &= K(MSD) \\ &= \$0.082 / TIP^2 * 1.28 TIP^2 \\ &= \$0.104 \text{ PER PART} \end{aligned}$$

The Savings or benefits of using the Sure Torque over the Secure Pak are calculated by comparing the Signal-to-Noise Ratios of each process (Current vs. Improved) as follows:

$$\begin{aligned} Savings &= (1 - 10^{\{-(S/N_2 - S/N_1)/10\}}) * 100 \\ &= (1 - 10^{\{-(-1.06-(-6.83))/10\}}) * 100 \\ &= (1 - 0.265) * 100 \\ &= 73.5\% \end{aligned}$$

The difference in S/N ratios reflects a reduction in variation from the three noise factors, environment in which the product is used, product deterioration with age, and manufacturing variations. External and Internal noise factors are relatively constant for both of the processes. As a result, the noise factor that has been reduced the most is that of Unit-to-Unit variation. Variations in the manufacturing process have been reduced by incorporating the Sure Torque into the manufacturing process. There is a definite advantage to using a measurement device that provides more precise removal torque data. In terms of cost, a seventy three point five percent improvement is realized. This cost improvement assumes that all out-of-tolerance components are rejected. In reality those components that are out-of-tolerance above the specified maximum (14 TIP) would not necessarily be rejected. A more realistic cost savings figure would be half of the calculated cost savings value (36.8%), assuming all components below the specified minimum (7 TIP) are rejected.

8.3 Comparing the Improved Process to the Optimum Process

The average Loss associated with one defective unit, utilizing the improved process, is calculated by substituting the Loss Constant (K) and the Mean Squared Deviation for the improved process into the Taguchi Loss Function Equation 3:

$$\begin{aligned} \text{LOSS} &= \text{K(MSD)} \\ &= \$0.082 / \text{TIP}^2 * 1.28\text{TIP}^2 \\ &= \$0.104 \text{ PER PART} \end{aligned}$$

The average Loss associated with one defective unit, utilizing the optimum process, is calculated by substituting the Loss Constant (K) and the Mean Squared Deviation for the optimum process into the Taguchi Loss Function:

$$\begin{aligned} LOSS &= K(MSD) \\ &= \$0.082 / TIP^2 * 0.78 TIP^2 \\ &= \$0.064 \text{ PER PART} \end{aligned}$$

The Savings or benefits of using the Sure Torque with the set-up gauge over using the Sure Torque alone are calculated by comparing the Signal-to-Noise Ratios of each process (Improved vs. Optimum) as follows:

$$\begin{aligned} Savings &= (1 - 10^{\{-(S/N_2 - S/N_1)/10\}}) * 100 \\ &= (1 - 10^{\{-(1.08 - (-1.06))/10\}}) * 100 \\ &= (1 - 0.611) * 100 \\ &= 38.9\% \end{aligned}$$

The Savings analyses show a definite advantage to using the set-up gauge which provides more consistency to the application process. Again, the noise factor that has been reduced the most is that of Unit-to-Unit variation. Variations in the manufacturing process have been reduced by incorporating the gauge into the manufacturing process that utilizes the Sure Torque. In terms of cost, a thirty eight point nine percent improvement is realized. Again, this cost improvement assumes that all out-of-tolerance components are rejected. A more realistic cost savings figure would be half of the calculated cost savings value (19.5%), assuming all components below the specified minimum (7 TIP) are rejected.

8.4 Comparing the Current Process to the Optimum Process

The average Loss associated with one defective unit, utilizing the current process, is \$0.393 and the average Loss associated with one defective unit, utilizing the optimum process, is \$0.064 (calculated above). The Savings or benefits of using the Sure Torque with the set-up gauge over using the Secure Pak alone are calculated by comparing the Signal-to-Noise Ratios of each process (Current vs. Optimum) as follows:

$$
\begin{aligned}
\text{Savings} &= (1 - 10^{\{-(S/N_2 - S/N_1)/10\}}) * 100 \\
&= (1 - 10^{\{-(1.08-(-6.83))/10\}}) * 100 \\
&= (1 - 0.162) * 100 \\
&= 83.8\%
\end{aligned}
$$

There is a definite advantage to using the Sure Torque and the set-up gauge compared to using the Secure Pak alone. The Sure Torque provides more precise data and the set-up gauge improves process consistency. In terms of cost, an eighty three point eight percent improvement is realized. Again, this cost improvement assumes that all out-of-tolerance components are rejected. A more realistic cost savings figure would be half of the calculated cost savings value (41.9%), assuming all components below the specified minimum (7 TIP) are rejected.

9. RECOMMENDATIONS

9.1 Measurement Device

The Secure Pak does not provide a consistent tool for measuring removal torque. The Sure Torque is more precise and more consistent than the Secure Pak. The cost benefit of utilizing the Sure Torque over the Secure Pak is evident in the Taguchi cost savings analysis. It would be beneficial for the Company to implement these Sure Torque removal torque devices on current packaging lines. The Sure Torque tester also lowers the probability of a recall occurring by reducing operator variability.

9.2 Resina Set-up Gauge

The set-up gauge that was designed to be used in conjunction with the Resina capper resulted in definite process improvements. Process variation was reduced and improved consistency of the capper set-up was realized. The probability of a recall occurring will be reduced by incorporating the set-up gauges on current packaging lines. The set-up gauges are inexpensive and can be made for each bottle style currently being run.

9.3 Critical Controls

The current process controls were determined by deduction rather than by conducting tests. The recommended critical controls contained in the thesis are based on testing rather than deduction. The current and recommended process controls are summarized in Table 10 - Summary of Process Controls. If these recommended process controls are implemented, the probability of a recall is reduced. The current process has only one critical control (minimum removal torque), which is too low to ensure that a recall does not occur. For a process to be effective, a target value, a minimum value, and a maximum value should be set to keep it under control.

Table 10 - Summary of Process Controls

CONTROL	CURRENT	RECOMMENDED
MINIMUM REMOVAL TORQUE	5 TIP	7 TIP
TARGET REMOVAL TORQUE	NONE	10.5 TIP
MAXIMUM REMOVAL TORQUE	NONE	14 TIP

9.4 Implement an Aggressive Statistical Process Control Program (SPC)

The current Quality Control program utilized on the packaging lines can be improved by implementing an SPC program. The current quality control program does not allow for effective in-process monitoring of quality. Statistical checks are made but nothing is done with that data during production. As a result, any defects that are found after production require a one hundred percent inspection of the lot to locate a specific problem area. Reworking is not cost and time effective. An SPC program will reduce process costs and manufacturing time. This is another component of K that is not accounted for. If this figure is calculated the value of K would be greater. SPC allows one to evaluate a process while it is in progress, so that defects can be identified and process adjustments can be made during production.

9.5 Purchase a New Capper?

Purchase of a new chuck style capper is currently under consideration. Based on the data contained in the thesis, there is no need to purchase a new capping machine. The Resina capper can produce the quality that is required by the company. The Company can save the cost of a new machine if the Sure Torque and the set-up gauges are incorporated into the process. All packaging materials will also have to be converted to the same components that are described in the materials section. This money can contribute better process improvements in other areas. If the Resina is replaced, the overall output of the packaging line will not increase. It would be better to apply this money to replace equipment that currently limits the process output (e.g. Liquid Filler).

9.6 Future Research

Future research areas include:

1. An investigation of other bottle/closure combinations. This research should focus on closure sizes different from the 28 mm closure already studied. Different materials combinations (e.g. metal caps on plastic bottles) should be evaluated. Not all closure systems behave in the same manner and different specification limits and target values will have to be determined for individual closure systems.

2. A more in depth investigation of removal torque decay over a longer period of time. Due to time constraints, the thesis did not allow for a longer test period. This will allow for more accurate predictions of removal torque after a specified time period.

3. A test of the effect of placing a shrink band around the closure system should be conducted to evaluate how the band reduces removal torque decay.

4. The effects of vibration on removal torque decay should be evaluated.

10. SUMMARY OF MATERIALS USED

10.1 Materials Tested

1. Product - Liquid (water for non-production testing and product for production testing).
2. Glass Bottle - 28 MM finish, 120 ML volume, and NP or better amber glass
3. Cap - 28 MM Child Resistant Closure with Outer (High Density Polyethylene) and Inner (Polypropylene).
4. Liner - Backing (0.035" pulp board), Facing (Polyethylene extrusion coated to 30 pound white paper), and Coating (0.001" paraffin wax).

10.2 Equipment Used

1. Sure Torque Tester (Model NEBT33).
2. Secure Pak Tester (ET 87503), Serial Number: (100 115D).
3. Resina Capper (U40 805), Serial Number: (81 6174).
4. Resina Set-up Gauge - manufactured in company maintenance shops according to specifications laid out by Christopher A. I. Clarke.

10.3 Testing Conditions

All testing was conducted at the Company's ambient conditions: 70-75°F and less than 40% RH.

10.4 Analytical Tools

1. Statgraphics Plus Version 6.0 Software
2. Qualitek-4 Software
3. IBM 386 Computer

APPENDIX

APPENDIX A - RAW DATA TABLES

TABLE 1		
OPERATOR VARIABILITY STUDY - SECURE PAK (HAND)		
SAMPLE	OPERATOR ONE	OPERATOR TWO
1	14.7	13.0
2	14.3	11.3
3	17.1	12.3
4	12.1	12.6
5	19.1	13.1
6	13.0	12.2
7	14.8	13.5
8	14.4	12.2
9	14.1	13.5
10	15.0	14.5
11	16.7	11.4
12	18.6	12.6
13	17.6	10.3
14	15.6	12.2
15	16.7	14.0
16	15.8	12.9
17	17.4	12.8
18	17.0	12.6
19	15.4	13.9
20	15.6	13.1
21	15.6	13.4
22	14.6	13.3
23	15.5	14.0
24	17.2	14.2
25	16.5	14.8
26	15.5	13.0
27	16.4	14.4
28	16.6	12.8
29	16.3	14.8
30	19.7	14.4
31	14.3	14.8
32	14.4	10.4
33	15.1	15.5
34	16.1	13.3
35	17.5	14.1
36	14.6	12.9
37	18.2	14.3
38	16.0	12.3
39	17.8	14.1
40	16.4	13.8
41	16.5	13.9
42	15.7	12.9
43	18.5	14.8

OPERATOR VARIABILITY STUDY - SECURE PAK (HAND) - CONTINUED					
44		15.6		14.5	
45		17.3		13.3	
46		17.8		14.1	
47		17.5		12.3	
48		17.3		14.2	
49		17.9		15.4	
50		17.8		12.7	
* ALL VALUES IN TORQUE INCH POUNDS (TIP)					

TABLE 2		
OPERATOR VARIABILITY - SHURE TORQUE TESTER		
SAMPLE	OPERATOR ONE	OPERATOR TWO
1	14.0	10.1
2	12.1	10.9
3	11.7	11.0
4	10.9	11.5
5	8.2	10.9
6	13.2	10.9
7	11.1	12.8
8	10.5	10.0
9	9.9	11.0
10	9.3	9.7
11	10.5	13.3
12	12.9	11.8
13	N/A	14.5
14	12.0	11.3
15	12.7	11.0
16	12.2	10.6
17	11.7	12.0
18	13.8	11.3
19	9.9	12.0
20	9.2	13.5
21	N/A	12.1
22	11.6	12.0
23	13.8	11.7
24	13.2	11.8
25	12.4	11.6
26	12.0	12.4
27	12.1	10.4
28	13.4	10.3
29	11.7	9.5
30	13.4	11.3
31	13.5	11.0
32	14.2	12.1
33	13.0	11.3
34	8.7	10.5
35	13.5	10.0
36	14.0	11.2
37	12.5	11.7
38	12.1	10.0
39	11.6	10.5
40	13.0	11.1
41	15.6	11.6
42	12.3	11.7
43	12.7	12.2

OPERATOR VARIABILITY - SHURE TORQUE TESTER - CONTINUED							
44		13.2		10.7			
45		13.2		14.5			
46		14.1		11.8			
47		13.8		10.2			
48		12.3		11.9			
49		14.4		12.4			
50		12.4		12.3			
N/A - CAPS WERE NOT IN THE LOCKED POSITION AND WERE DISCARDED							

TABLE 3					
TORQUE TESTER VARIABILITY					
SAMPLE	SECURE PAK (HAND)		SHURE TORQUE (AUTO.)		
1		14.7		14.0	
2		14.3		12.1	
3		17.1		11.7	
4		12.1		10.9	
5		19.1		8.2	
6		13.0		13.2	
7		14.8		11.1	
8		14.4		10.5	
9		14.1		9.9	
10		15.0		9.3	
11		16.7		10.5	
12		18.6		12.9	
13		17.6		N/A	
14		15.6		12.0	
15		16.7		12.7	
16		15.8		12.2	
17		17.4		11.7	
18		17.0		13.8	
19		15.4		9.9	
20		15.6		9.2	
21		15.6		N/A	
22		14.6		11.6	
23		15.5		13.8	
24		17.2		13.2	
25		16.5		12.4	
26		15.5		12.0	
27		16.4		12.1	
28		16.6		13.4	
29		16.3		11.7	
30		19.7		13.4	
31		14.3		13.5	
32		14.4		14.2	
33		15.1		13.0	
34		16.1		8.7	
35		17.5		13.5	
36		14.6		14.0	
37		18.2		12.5	
38		16.0		12.1	
39		17.8		11.6	
40		16.4		13.0	
41		16.5		15.6	
42		15.7		12.3	
43		18.5		12.7	

TORQUE TESTER VARIABILITY - CONTINUED					
44		15.6		13.2	
45		17.3		13.2	
46		17.8		14.1	
47		17.5		13.8	
48		17.3		12.3	
49		17.9		14.4	
50		17.8		12.4	
51		13.0		10.1	
52		11.3		10.9	
53		12.3		11.0	
54		12.6		11.5	
55		13.1		10.9	
56		12.2		10.9	
57		13.5		12.8	
58		12.2		10.0	
59		13.5		11.0	
60		14.5		9.7	
61		11.4		13.3	
62		12.6		11.8	
63		10.3		14.5	
64		12.2		11.3	
65		14.0		11.0	
66		12.9		10.6	
67		12.8		12.0	
68		12.6		11.3	
69		13.9		12.0	
70		13.1		13.5	
71		13.4		12.1	
72		13.3		12.0	
73		14.0		11.7	
74		14.2		11.8	
75		14.8		11.6	
76		13.0		12.4	
77		14.4		10.4	
78		12.8		10.3	
79		14.8		9.5	
80		14.4		11.3	
81		14.8		11.0	
82		10.4		12.1	
83		15.5		11.3	
84		13.3		10.5	
85		14.1		10.0	
86		12.9		11.2	
87		14.3		11.7	
88		12.3		10.0	
89		14.1		10.5	
90		13.8		11.1	

TORQUE TESTER VARIABILITY - CONTINUED					
91		13.9		11.6	
92		12.9		11.7	
93		14.8		12.2	
94		14.5		10.7	
95		13.3		14.5	
96		14.1		11.8	
97		12.3		10.2	
98		14.2		11.9	
99		15.4		12.4	
100		12.7		12.3	
* ALL VALUES IN TORQUE INCH POUNDS (TIP)					
N/A-CAPS WERE NOT IN THE LOCKED POSITION AND WERE DISCARDED					

TABLE 4								
REMOVAL TORQUE STUDY VS. TIME SHOWING REMOVAL TORQUE DECAY								
		IMMEDIATE			DAY 1			
APPLICATION	12	15	18	12	15	18		
IMMEDIATE	7.4	8.4	10.2	5.8	7.5	7.8		
	7.7	9.5	9.9	5.9	8.4	8.5		
	6.9	8.4	10.2	6.2	7.5	8.8		
	7.4	8.0	9.3	4.7	6.6	7.7		
	7.6	8.8	9.8	6.4	7.0	9.1		
	8.2	8.4	10.8	6.1	6.7	7.4		
	7.7	10.1	10.4	6.3	5.8	8.7		
	7.0	9.4	9.5	5.1	6.3	8.6		
	7.5	8.8	10.8	5.7	7.1	8.0		
	6.2	8.8	10.7	6.0	8.0	7.6		
	6.9	7.8	9.9	6.5	7.7	8.0		
	6.8	9.3	9.8	5.2	7.0	8.1		
AVERAGE	7.28	8.81	10.11	5.83	7.13	8.19		
STD	0.53	0.67	0.50	0.56	0.73	0.54		
		DAY 4			DAY 7			
APPLICATION	12	15	18	12	15	18		
IMMEDIATE	5.8	6.6	8.9	5.1	6.6	7.0		
	6.1	6.6	7.6	5.7	6.6	8.1		
	5.9	6.6	8.3	5.4	6.2	8.4		
	5.9	5.6	7.7	5.4	7.0	7.7		
	5.1	6.9	8.6	6.3	6.5	8.8		
	5.1	6.3	7.8	5.5	6.7	6.9		
	6.1	7.2	8.8	6.1	5.7	8.1		
	5.7	6.2	7.5	5.3	6.4	8.0		
	5.5	6.6	6.9	5.4	6.2	8.2		
	6.3	6.5	7.5	5.8	6.6	7.5		
	5.5	7.0	7.7	5.6	6.4	8.6		
	5.2	7.3	8.6	5.9	7.0	7.1		
AVERAGE	5.68	6.62	7.99	5.63	6.49	7.87		
STD	0.41	0.46	0.63	0.35	0.36	0.63		
ALL VALUES IN TORQUE INCH POUNDS								

TABLE 7							
CURRENT PROCESS RAW DATA							
SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE
1	18.9	21	11.2	41	18.4	61	14.0
2	15.6	22	11.1	42	18.7	62	16.0
3	17.1	23	10.2	43	17.9	63	15.0
4	15.9	24	15.9	44	18.2	64	15.0
5	14.7	25	10.4	45	16.3	65	17.0
6	14.6	26	10.9	46	17.5	66	15.0
7	14.9	27	11.5	47	15.9	67	14.0
8	14.1	28	13.1	48	16.1	68	16.0
9	15.2	29	12.8	49	16.8	69	15.0
10	15.0	30	11.8	50	17.1	70	13.0
11	12.6	31	16.1	51	11.0	71	15.0
12	13.0	32	16.5	52	15.0	72	15.0
13	15.5	33	14.5	53	15.5	73	14.0
14	16.6	34	17.5	54	13.0	74	16.0
15	14.7	35	17.9	55	15.1	75	14.0
16	15.7	36	17.5	56	15.0	76	14.0
17	13.4	37	19.8	57	16.0	77	14.0
18	13.0	38	18.4	58	15.0	78	15.0
19	21.2	39	17.0	59	15.0	79	15.0
20	15.1	40	19.3	60	17.0	80	14.0
* ALL VALUES IN TORQUE INCH POUNDS							

TABLE 8

IMPROVED PROCESS RAW DATA

SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE
1	11	41	8.5	81	8.5	121	7.8
2	9.4	42	9	82	8.9	122	8.9
3	9.9	43	7.8	83	9.7	123	9.9
4	10.2	44	9.4	84	8.3	124	9.3
5	9.1	45	9.1	85	8.3	125	8.6
6	10.1	46	8.3	86	7.7	126	9.9
7	10.3	47	10.3	87	11.8	127	8.4
8	9.9	48	8.9	88	7.8	128	10.4
9	9.3	49	9.7	89	9	129	9.9
10	8.5	50	8.4	90	9.4	130	8.4
11	9.9	51	11	91	10.4	131	7
12	8.1	52	7.8	92	10.5	132	7.3
13	9.8	53	9.5	93	10.6	133	7.6
14	11.3	54	8.7	94	10.1	134	9.1
15	9.9	55	9.3	95	10.3	135	7.5
16	9	56	11	96	9.5	136	8.4
17	8.6	57	11.3	97	9.8	137	8.8
18	10.2	58	7.1	98	11.3	138	8.7
19	10.3	59	7	99	9.4	139	8.8
20	10.9	60	7.3	100	10.2	140	8
21	10.4	61	7.9	101	9.1	141	10
22	9.9	62	7.9	102	8.5	142	11.2
23	8.7	63	9.9	103	9.6	143	9.6
24	9.9	64	9.4	104	9.5	144	7.9
25	9.5	65	9.8	105	8	145	8.4
26	9.3	66	9.9	106	10.2	146	8.4
27	9.6	67	8.4	107	13.5	147	9.1
28	8.4	68	9.2	108	10.6	148	9
29	8.1	69	7.7	109	9.5	149	9.7
30	7.8	70	8.7	110	10.1	150	8.4
31	12.6	71	9.5	111	9.3	151	9
32	9.9	72	9.2	112	9.6	152	8.7
33	9.3	73	8.6	113	8.6	153	9.1
34	9.9	74	8.8	114	7.9	154	9.6
35	8.9	75	8.8	115	9.3	155	9.2
36	9.7	76	9.1	116	8.1	156	9.8
37	9.6	77	8	117	8	157	9.5
38	10.5	78	9	118	8.4	158	9.5
39	8.3	79	10.1	119	9.3	159	8.7
40	8	80	8.9	120	8.4	160	8.9

TABLE 8 - CONTINUED							
IMPROVED PROCESS RAW DATA							
SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE
161	7.9	201	8.8	241	7.9	281	7.5
162	8.4	202	7	242	9.9	282	7.2
163	9.4	203	11.9	243	8.9	283	10.4
164	9.9	204	9	244	8.2	284	9.7
165	9.1	205	8.9	245	10.1	285	10
166	8.3	206	7	246	10.4	286	9.2
167	9.2	207	8.8	247	7.6	287	7.2
168	9.7	208	7.7	248	9.6	288	8.8
169	8.9	209	10.9	249	9.6	289	7.4
170	7.6	210	8.6	250	9.2	290	8.8
171	8.4	211	9.6	251	8.9	291	9.9
172	9.8	212	8.9	252	9.3	292	8.5
173	9.4	213	9.1	253	10	293	9
174	9.4	214	8.9	254	9.7	294	8.7
175	10.8	215	9.9	255	8.7	295	9.1
176	7.7	216	8	256	8.1	296	9
177	8.8	217	9.1	257	7.3	297	9.3
178	8.4	218	9.6	258	7.6	298	11
179	8.6	219	10.1	259	9.9	299	8.2
180	9.1	220	9.6	260	10	300	8.5
181	9.2	221	8.4	261	8.9	301	9.3
182	9	222	6.9	262	8.4	302	9.9
183	11	223	7.6	263	7.6	303	9.5
184	10.1	224	9.8	264	8.9	304	10.4
185	8.5	225	8.7	265	9.1	305	8.7
186	10.2	226	10.2	266	10.6	306	9.9
187	8.1	227	11.4	267	8.1	307	7.7
188	10.1	228	8.4	268	9.2	308	6.8
189	9.1	229	10.3	269	11.3	309	7.8
190	9.8	230	7.7	270	8.8	310	7.9
191	9.8	231	10.2	271	8.6	311	9
192	8.9	232	8.5	272	7	312	8.5
193	8.8	233	9.1	273	9.6	313	8.5
194	10.6	234	8.3	274	9.1	314	8.8
195	8.8	235	9.3	275	9.5	315	8.6
196	10.7	236	10.6	276	9.1	316	10.3
197	8.7	237	8.2	277	8.7	317	10.5
198	9.5	238	8.1	278	10.9	318	10.8
199	9.5	239	9.6	279	11.7	319	9.4
200	11.3	240	9.9	280	8.6	320	10.2

TABLE 8 - CONTINUED							
IMPROVED PROCESS RAW DATA							
SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE
321	8.2	361	8.3	401	7.8	441	9.2
322	9.7	362	7.9	402	8.4	442	8
323	9.3	363	8.9	403	8.9	443	10.2
324	11	364	7.3	404	7.7	444	7.9
325	8.8	365	9.5	405	9.5	445	9.4
326	9.6	366	8.1	406	7.6	446	8.8
327	7.6	367	8.1	407	9.9	447	7.7
328	8.5	368	7.4	408	9.5	448	8.9
329	9.1	369	7.6	409	9.4	449	7.5
330	10.2	370	9.5	410	9.1	450	7.7
331	9.5	371	9.2	411	8.2	451	8.4
332	7.9	372	8.2	412	9.9	452	8.1
333	7.1	373	8.7	413	8.2	453	9.4
334	10.5	374	9	414	8.2	454	8.8
335	8.7	375	9.3	415	8.8	455	10.2
336	9.4	376	8	416	8	456	7.4
337	8	377	9.8	417	10.7	457	8.4
338	8.5	378	8.4	418	9.9	458	8.8
339	9.5	379	9.1	419	8	459	9.1
340	9	380	9.1	420	10.5	460	8.3
341	12.6	381	9.1	421	9.9	461	8.4
342	8.3	382	7.7	422	9.5	462	8.3
343	9	383	9.7	423	8.8	463	8.3
344	11.3	384	8.3	424	8.4	464	10.6
345	10.5	385	8.4	425	9.1	465	8.8
346	7.8	386	8.2	426	8.4	466	8.7
347	8.9	387	10.5	427	7.5	467	8.6
348	8.9	388	11.3	428	8	468	7.8
349	8.6	389	10.1	429	8.8	469	8
350	11.2	390	10.8	430	8.8	470	7.8
351	9.5	391	9.9	431	9.8	471	9.2
352	8.3	392	10	432	7.7	472	8
353	9.3	393	8.1	433	9.1	473	7
354	8.1	394	8.7	434	8.5	474	9
355	8.3	395	10	435	9.1	475	10.2
356	9.6	396	8.4	436	9.7	476	9.8
357	9.6	397	8.2	437	7.8	477	7.3
358	9.1	398	8	438	7.3	478	9.9
359	6.6	399	9.1	439	7.9	479	7.7
360	8.8	400	8.8	440	9.1	480	8.8

TABLE 8 - CONTINUED

IMPROVED PROCESS RAW DATA

SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE
481	7.9	521	9.3	561	10	601	9.4
482	8.3	522	9.4	562	9.6	602	8.6
483	8.7	523	9.5	563	7	603	6.2
484	7.7	524	6.6	564	8.9	604	8.6
485	8.4	525	8.4	565	8.3	605	7.6
486	7.8	526	8.4	566	8.5	606	8.9
487	8.1	527	9.9	567	9	607	8.2
488	11	528	9.2	568	8.7	608	7.1
489	7.1	529	9	569	10.2	609	8.9
490	8.3	530	10.3	570	8.2	610	7.4
491	9.5	531	7.1	571	7.6	611	9.1
492	9.5	532	7.6	572	8.7	612	7.2
493	8.5	533	8.4	573	9.5	613	6.4
494	8.8	534	8.1	574	7	614	7.1
495	7.2	535	9.5	575	8.7	615	9.8
496	8	536	5.1	576	10.2	616	8.3
497	9.9	537	8.5	577	9.1	617	8.4
498	7.4	538	8.5	578	7.3	618	9.2
499	7.7	539	9.5	579	8.6	619	8.1
500	7.3	540	8.5	580	9.2	620	9.1
501	9	541	7.6	581	8.4	621	9.1
502	7.2	542	7.8	582	7.8	622	8.2
503	9	543	7.4	583	8	623	7.2
504	7.9	544	8.7	584	6.7	624	8.9
505	10.4	545	9.3	585	6.5	625	7.2
506	8.9	546	7.7	586	9.3	626	8.4
507	11	547	9.5	587	9.7	627	9.6
508	10.5	548	8.4	588	9.5	628	8.5
509	9.3	549	8.9	589	11	629	9.2
510	10.1	550	10.3	590	8.3	630	9.4
511	10.3	551	7.6	591	8.8	631	8.4
512	8	552	7.1	592	8.3	632	7.7
513	6.6	553	6.1	593	8.4	633	9.4
514	9.5	554	7	594	8.8	634	8
515	8.2	555	8.1	595	10.2	635	6.7
516	9.9	556	9.5	596	10.1	636	7.3
517	8	557	6.2	597	8.8	637	
518	7.5	558	9	598	9.3	638	8
519	10.6	559	9.1	599	8.6	639	9.3
520	8	560	7.9	600	8.1	640	8.8

TABLE 8 - CONTINUED							
IMPROVED PROCESS RAW DATA							
SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE
641	9.5	681	8	721	7.4	761	9.5
642	10.6	682	8.2	722	7.2	762	7.8
643	6.3	683	9	723	7.7	763	8.5
644	6.8	684	9.4	724	8.5	764	9.1
645	8.7	685	9.1	725	9.9	765	8.5
646	8.4	686	9.8	726	8.5	766	8.5
647	9.4	687	8.1	727	8	767	8.3
648	8.8	688	7.8	728	7.3	768	8
649	8.6	689	10.3	729	7.4	769	13.3
650	8.5	690	6.5	730	6.9	770	8.4
651	7.7	691	8.7	731	10	771	10
652	8	692	8.7	732	7.7	772	8.9
653	9.1	693	7.3	733	10.6	773	7.9
654	6.3	694	7	734	8.1	774	6.9
655	6.9	695	9.7	735	8.1	775	9.2
656	7.7	696	7.7	736	10.2	776	7.7
657	7.4	697	7.9	737	10.6	777	7.8
658	7.5	698	7.9	738	9.4	778	8.6
659	7.8	699	8.7	739	8.6	779	8.4
660	9.9	700	8.3	740	8.4	780	9.8
661	6.9	701	8.7	741	8.3	781	8.7
662	6.9	702	8.1	742	8.6	782	9.4
663	8.7	703	9.8	743	8.6	783	8.7
664	7.3	704	8.6	744	6.8	784	7.7
665	8.9	705	9.1	745	9.2	785	8.4
666	6.8	706	9.7	746	8.4	786	6.8
667	6.9	707	7.4	747	6.9	787	9.9
668	8.4	708	7.9	748	8	788	8.2
669	8.6	709	7.6	749	7.7	789	8.8
670	7	710	6.3	750	6.7	790	7.2
671	9.6	711	7.5	751	8.4	791	9.6
672	8.8	712	7.1	752	8	792	7.8
673	7.3	713	6.9	753	8.3	793	9.6
674	6.6	714	6.9	754	7.5	794	7.8
675	6.6	715	6.5	755	7	795	9.5
676	7.3	716	9.8	756	8.8	796	9.7
677	5.3	717	9.3	757	7.6	797	8.2
678	9.2	718	8.5	758	8.5	798	8.3
679	7.7	719	6.7	759	9.4	799	8.4
680	6.6	720	9.7	760	7.6	800	8.4

TABLE 8 - CONTINUED							
IMPROVED PROCESS RAW DATA							
SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE		
801	8.5	841	9.2	881	9.9		
802	9.8	842	8.4	882	7.5		
803	9.5	843	7.9	883	8.7		
804	8.4	844	7	884	6.9		
805	9.8	845	8	885	7.7		
806	7.9	846	8.6	886	6.6		
807	8.7	847	8.4	887	8.9		
808	7.9	848	5.9	888	7.9		
809	7.7	849	9.1	889	8.6		
810	8.8	850	8.8	890	9.1		
811	8.4	851	7.5	891	7.1		
812	8.6	852	8.8	892	8.8		
813	7.1	853	8.2	893	7		
814	8.4	854	8.4	894	8.8		
815	8	855	7.5	895	7.4		
816	7.1	856	5.5	896	8.2		
817	7.3	857	7.7	897	8.4		
818	8.6	858	7.9	898	7.9		
819	8.8	859	7.4	899	9.6		
820	8	860	8.2	900	7.7		
821	6.7	861	8.7	901	9.1		
822	7	862	8.4	902	8.9		
823	7.4	863	9.3	903	8		
824	7.6	864	9.2	904	6.9		
825	8	865	8.9	905	8		
826	7.3	866	7.7	906	7.1		
827	6.6	867	10	907	13.8		
828	8.4	868	7.6	908	8.7		
829	8.8	869	6.9				
830	6.2	870	7.4				
831	7.7	871	8				
832	8.4	872	6.5				
833	7.8	873	8				
834	9.4	874	8.3				
835	10	875	8				
836	5.7	876	8.8				
837	7.1	877	8.8				
838	7.5	878	8.5				
839	7.4	879	9.3				
840	9.2	880	8.2				

TABLE 9					
OPTIMUM PROCESS RAW DATA					
SAMPLE	VALUE	SAMPLE	VALUE	SAMPLE	VALUE
1	6.9	41	5.7	81	5.8
2	7.3	42	7.1	82	8.8
3	8.4	43	9.9	83	6.9
4	6.4	44	7.9	84	6.1
5	6.1	45	7.3	85	5.9
6	6.3	46	7.2	86	5.8
7	5.8	47	7.3	87	6.9
8	8	48	6.5	88	6.9
9	5.9	49	6.6	89	6.5
10	6.2	50	7.3	90	6.2
11	6.1	51	8.1	91	6.9
12	6.1	52	5.8	92	7.5
13	6.2	53	6	93	6
14	5.9	54	6.7	94	5.7
15	6.1	55	7.3	95	6.2
16	6.3	56	8.4	96	6
17	7.2	57	8.8	97	6.9
18	7.3	58	8.4	98	6.5
19	7	59	8.7	99	6.9
20	6.6	60	7.7	100	6.6
21	5.7	61	8.2	101	7.1
22	5.7	62	6.7	102	6.9
23	7.5	63	7.3	103	6.7
24	6.2	64	8.3	104	6.6
25	6.9	65	9.1	105	6.2
26	7.9	66	9.4	106	7.7
27	8	67	7.3	107	7
28	7.9	68	8.5	108	6.7
29	8.3	69	7.7	109	7.3
30	6.1	70	7.9	110	6.8
31	7.3	71	8.3	111	7.8
32	7.1	72	8.3	112	7
33	6.7	73	5.8	113	6.6
34	6.6	74	6.5	114	6.4
35	7.3	75	6.7	115	6.8
36	7.1	76	6.8	116	7.5
37	8	77	6.5	117	6.8
38	7.5	78	7.3	118	7.2
39	8.4	79	6.8	119	7.5
40	7.8	80	6.3	120	7.7
* ALL VALUES IN TORQUE INCH POUNDS					

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