2014

"Clicker-Type" Torque Tooling - Calibration Study

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Abstract

The purpose of this study is to identify why torque is important and why it must be monitored in a factory setting. The goal of this research is to establish a torque control plan and auditing timeline for all torque controlled tooling for manufacturing firms. The overall goal is to ensure consistency and quality for all facets of the manufacturing environment. This study will include "clicker-type" torque wrenches at John Deere Waterloo Works Drive Train facility. A separate method ~ill need to be designed for air tooling than for "clicker-type" torque wrenches as more variables can affect the repeatability and consistency of air tools and therefore the air tool method will not be included in this study. The researcher will evaluate the repeatability of the assembly torque tooling and evaluate the data to determine if there are trends show a timeline for auditing tools.

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Industrial Technology
Research Paper

A Research Paper for Presentation
to the Graduate Faculty of
the Department of Industrial Technology
University of Northern Iowa

In Partial Fulfillment of the Requirements for
The Non-Thesis Masters of Arts Degree

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October 3rd, 2014

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“CLICKER-TYPE” TORQUE TOOLING – CALIRATION STUDY

Introduction

Torque is a physical quantity that is related to fastening bolt in various fields of industry (Park, Kim, Lee, Lee, & Kang, 2009). In the manufacturing and assembly world, tightening, controlling, or measuring torque fasteners is imperative for productive efficiency. An inadequately torqued joint can vibrate or work loose: conversely, if the tension is too high, the fastener can snap or strip its threads. Either of these situations causes failure and a produces a product that will not meet quality standards (Estes, Ferguson, Reese, Kassel, Levsen, Benedict, & Craig, 2006). Faced with these problems, manufacturers must realize that precise torque control can be the difference between a safe, reliable, and economical product and a complete failure.

Statement of the Problem

Threaded fasteners have been around, and used to assemble a variety of products for so long that it is often assumed that everything is known about them. This confident assumption often leads operators to tighten a given fastener until it 'feels' tight and they are done with it. In some applications this approach may prove satisfactory, but with critical applications, which can impact a financial bottom line through costly rework or warranty repairs, the old 'feels tight, must be right' method is inadequate. Fasteners of various types can account for as much as 50% of the parts count in a typical bill of materials, so it is important that the correct fasteners are used properly to ensure product quality and efficient manufacturing. In order to tighten fasteners to the given specifications a torque wrench must be used. If the operator applying the torque is allowed to determine when a fastener is tight then the result will be a failure (Miller, 2007).

Manufacturing firms use torque tooling in their production, but most do not have a set guidelines for maintaining their torque tooling. An example of this situation is John Deere who currently has very broad methods for identifying and auditing its torque tooling at their assembly facilities. The researcher has experienced two various auditing timelines at John Deere. One facility conducts audits on a monthly basis while the other facility conducts these audits on a yearly basis. There is a need for manufacturing companies to understand the importance of monitoring torque at their facilities to ensure the quality of the products they are producing. By ensuring the torque they reduce the possibility of a mistake or quality issue in the product that they are producing.

Purpose of the Study

The purpose of this study is to identify why torque is important and why it must be monitored in a factory setting. The goal of this research is to establish a torque control plan and auditing timeline for all torque controlled tooling for manufacturing firms. The overall goal is to ensure consistency and quality for all facets of the manufacturing environment. This study will include "clicker-type" torque wrenches at John Deere Waterloo Works Drive Train facility. A separate method will need to be designed for air tooling than for "clicker-type" torque wrenches as more variables can affect the repeatability and consistency of air tools and therefore the air tool method will not be included in this study. The researcher will evaluate the repeatability of the assembly torque tooling and evaluate the data to determine if there are trends show a timeline for auditing tools.

Need and/or Justification

Manufacturing firms need to develop a method for identifying and auditing the torque tooling at their facilities. By identifying the torque tooling the firm will be able to ensure the appropriate tools are monitored. By monitoring these tools firms will be able to ensure quality of the product they are building at these facilities. In the sample being used by the researcher (John Deere) the tooling at their facilities has yet to be fully tested for repeatability and it is not yet known when tooling needs to be audited.

Hypothesis/Research Questions

The researcher would like to verify that torque tooling is consistent overtime and that manufacturing use causes a slow decreasing trend. In addition the researcher would like to analyze a time frame for auditing torque wrenches to test if a monthly time frame for audits is appropriate for ensuring quality. It is hypothesized that the torque tools in manufacturing facilities are repeatable and testable. The tools can be identified and audited. The amount of variation in the average monthly torque audits will display a trend over time that can be a baseline for all tools and can thus be used in conjunction with a firm's quality standard to determine an appropriate timeframe for auditing "clicker-type" torque wrenches.

Literature Review

To understand the importance of proper torque application the researcher must first define the application of torque and explain the risk associated with not monitoring the torque tooling. Bernard Reiland explains torque tooling application and the need for monitoring torque:

> The conventional manner of applying a threaded fastener to an assembly and ensuring that the fastener is seated under a desired tension is to use a manual or power torque wrench which is designed to drive a fastener into a parent body until a preset applied torque level is reached. However, such adjustable torque wrenching tools are subject to human error in setting the desired driving torque. Such tools are also subject to mechanical malfunction whereby the torque actually applied to the fastener may differ from the torque setting of the tool. Furthermore, in using a torque wrench, it is impossible to tell by visual inspection whether or not a given fastener has been driven into an assembly with the desired torque (3,812,757, 1974).

Reiland explains in his patent the need to monitor torque as errors can occur. Without proper quality control on these tools there is a risk of not achieving the desired torque specification. There are many factors that can affect the torque delivered by a tool. Röske explains these factors in a study for calibration equipment. These factors include: environmental conditions, tool drive wear, ratchet wear, and force introduction points. These are all variable that can affect end torque results at the joint (Röske, 2014). Risović, Žeželj, and Panić also add that when dealing with a mechanical device such as a torque wrench that human error and variation can occur. How the operator applies force to the torque wrench can change the outcome of the torque applied. Steady force versus quick jerking force will provide more accurate results. This reliance on human physical performance indicates another risk factor in torque application (Risović, Žeželj, & Panić, 2008). These factors will not only affect the calibration readings, but the production joints. To reduce this risk a firm must monitor their torque tooling to ensure consistency over time or invest in improved tooling.

After reviewing the research available related to torque application and auditing the researcher found that there is limited information available in regards to auditing timelines. Bangi, Maranga, Nganga, and Mutuli describe a "clicker" type torque wrench as a torque tool that is preset to the desired torque and will click tactilely and audibly when it reaches the desired torque. At the point where the desired torque is reached, the clutch slips, signaling the desired torque and preventing additional tightening. It should always be turned down and stored at the lowest possible setting. The continuous "stress" on the internal spring can be responsible for a long-term decrease in accuracy. It is necessary, before performing calibration, to keep the torque at the minimum setting for a certain amount of time (12 hours), in order to exclude or reduce this effect (Bangi, Maranga, Nganga, & Mutuli, 2014). In a manufacturing setting these requirements cannot always be met as production efficiency must be maintained and production can occur on multiple shifts and not allow proper downtime for the tooling. These limitation are even more reason to ensure quality through an audit process. Dan Marinucci feels that torque wrench accuracy and calibration are still probably the farthest things from a technician's mind. But there's no denying that a torque wrench is a mechanical device, and as such it can and does go out of whack with use. This is an ongoing concern in manufacturing and the mindset needs to be changed (Marinucci, 2002). Marinucci's research contained a rule of thumb provided by Ben Spurlock at Angle Repair and Calibration, a large torque wrench producer in the United States. Spurlock's rule of thumb is that if you use a torque wrench three to four times a month you should have it checked at least once a year (Marinucci, 2002). This rule of thumb provided by Spurlock is very broad and in any manufacturing setting a torque wrench will be used more than 3 or 4 times a day and will need to be checked more than once a year. John Deere has been chosen by the researcher to be the representative for manufacturing firms. At one John Deere facility tool audits are conducted on a monthly basis and the tools are held to a plus or minus seven percent of the target torque. At another facility the same tool specifications are held, but the audits and re-calibration happen on a yearly basis. There was a study completed that did support a similar audit plan depending on many factors. Bangi, Maranga, Nganga, & Mutuli state the following in regards to torque wrench calibration:

> The calibration interval shall be chosen on the basis of the factors of operation such as required accuracy, frequency of use, typical load during operation as well as ambient conditions during operation and storage conditions. The interval shall be adapted according to the procedures specified for the control of test devices and by evaluating the experience gained during recalibration. If the user does not utilize a control procedure, a period of use of 12 months, or approximately 5000 cycles, can be taken as a default value for the recalibration interval. This period should be reduced when the tool is frequently used. The TW shall be recalibrated when it has been subjected to an overload higher than that applied in the overloading test, after repair or after inexpert handling, which may

have an effect on the uncertainty of measurement (Bangi, Maranga, Nganga, & Mutuli, 2014).

This summary gives a basic overview for torque setting, but it is very broad and is not very specific. This study specifies that every situation can require different timelines for audits, but that it is imperative that audits be conducted to ensure quality for torque application.

In order to determine if these tools can be audited the researcher will need to verify that the "clicker" type torque wrenches are repeatable and that their application of torque is a controlled process. This can be conducted through a process capability analysis. The aim of a process capability analysis is to estimate, monitor, and possibly reduce variability in industrial production processes. To start the analysis a few measurable properties which can give a significant insight into the quality of the output of the process under consideration must be defined; then, one has to associate an upper specification limit (USL) and a lower specification limit (LSL), to each of the measurements of interest. Capability analyzes are based on the crucial assumption that the process itself is in control. Obviously, some values (measures) might be out of the specification limits: the capability study problem consists in the estimation of a statistical model for the process, in order to be able to predict the number of points falling out of the specification limits, and therefore give a measure of the capability. Then the next objective is to define some measure of the variability and compare it with the width of the specification interval. This leads to the definition of the process capability ratio Cp.

Clearly, the aim of process control is to make as large as possible. The definition given above for the process capability ratio does not account for any location parameter of the distribution, its mean or its median; in order to avoid this problem the more general index was proposed, which is defined as Cpk. This definition clearly serves the purpose of avoiding the kind of ambiguity described above for the case of off-center processes, as the two specification limits are treated separately and the process mean is duly taken into account (Bittanti, Lovera, & Moiraghi, 1998). The researcher will use the target, upper, and lower limits provided by John Deere. The target torque applied is determined by an Engineering standard which is determined by the hardware size or joint characteristics. The upper and lower limits are plus or minus seven percent of the target torque. These guidelines will be used to develop the Cpk which will be the primary measure to be used by the researcher to determine if the tools are capable to performing to the standard developed by John Deere.

The researcher found a number of sources supporting a Cpk of greater than 1.33 to be a controlled process capable of meeting the expectations of the upper and lower limits specified (Dudek-Burlikowska, 2005; Czarski, 2008; Lee, 2008; Hsieh, Lin, & Manduca, 2007). Values less than 1.33 identify a process that is not in control and need to be monitored or altered to ensure quality in the process. The researcher will use the guideline specified to determine if the process is controlled and at what point in the lifespan the process begins to become out of control. Tool wear will begin to increase the tool variability and conversely decrease the Cpk value. This information should provide some insight to determine an appropriate auditing timeline for "clicker" type torque tooling.

Assumptions

The researcher made the assumption that the data that previously collected was collected ethically by the monthly auditors, manufacturing engineers, and quality engineers at John Deere. It was assumed that tooling had the appropriate adapters attached and that additional extensions were not used. The researcher also assumed that all torque tooling went through the same day to day activities, basically there wasn't additional work being performed with a tool outside of the work it was assigned to. This includes tooling being dropped or used to strike something; essentially the torque settings were not tampered with in any way during the study time period. It was assumed that all of the torque auditing equipment was used correctly and that the equipment was calibrated and maintained throughout the auditing process.

Limitations

Data collection is time consuming and requires the assembly line to stop for each wrench, so the research will rely on past data collection. This will not allow for manipulation for the majority of the data to be collected. Funds may not be available to further test to see if changes in number of audits per year will affect the quality of the product. In addition the researcher will not have funds to purchase and test new torque monitoring software to verify if the equipment in place can be improved. Tools are an ever changing part of manufacturing, so some tools will be in production for many years while others may be new tools to the assembly line. The amount of data will not be consistent for all tools and some tools will have to be eliminated from the data in order to ensure data integrity.

Definition of Terms

Torque

Torque is a force that produces or tends to produce rotation or torsion. Also, torque is referred to as a measure of the effectiveness of such a force that consists of the product of the force and the perpendicular distance from the line of action of the force to the axis of rotation. Essentially torque is a turning or twisting force.

Tool list

A tool list is a list of tools in a given area, whether they are separated by business unit or by department. These will include the tool asset number (individual number assigned for tooling tracking), location of tool (typically bench number where tool is kept), and torque specifications for the tool.

Optacomms

A computer program used by John Deere to store and monitor torque readings obtained during a torque audit. This program allows for the entry of the tool list, uploading of the list onto the torque star for the audit, and download of the audit results from the torque audit. Optacomms is a data collection program created and licensed by Crane Electronics.

Torque Star

The torque star is the equipment used to store the data retrieved in the torque audit. It is a portable box that auditor can use to collect the torque readings and then the readings are transferred into the Optacomms software for data analysis.

Transducer

For this situation a transducer is used to read the torque of the tool and relay that information to the torque star. Transducers have a limited range for torque they can read. John Deere has three transducers in order to cover all ranges of torque tooling.

Torque Audit

The process of uploading a tool list from Optacomms, checking each tool with the appropriate transducer, the transducer relays the torque reading to the torque star, the information is then downloaded back onto Optacomms, and finally the torque readings are then evaluated based on the engineering specifications and the past readings given by the tool.

Procedure to be employed

In order to test whether torque tooling is consistent the researcher will use equipment provide by John Deere to check the torque provided by the tooling. The data was collected by past researchers using the following procedure: Creating the tool list is Optacomms using the torque specifications provided by engineering, downloading this list onto the Torque Star, manually check each tool on the transducer following the torque audit process, uploading the results back into Optacomms form the Torque Star, and exporting the data to excel and storing the data into a central location for analysis. This process allows for analysis of what the torque setting is for each tool and what the recordings were during the audit.

The cost required to complete this researcher will be minimal. The equipment used to complete the torque audits will be provided by John Deere and will not require additional costs to the researcher. The torque audits have been completed in the past so there would be no cost for the researcher.

Statistical Analysis

With the collected data from John Deere Waterloo Works the researcher will determine the Cpk for each wrench and use this value to determine if the process is in statistical control. The data will need to be filtered to eliminate tools that only have a few data points or that have large outliers such as one big change in torque value. The construed data will need to be thrown out to keep the data valid. In addition to this the researcher can determine a timeline for auditing necessity for each type of tooling by taking the data and doing a timeline graph of the variation. The analysis will show if auditing all tools on a monthly basis is efficient or if auditing certain tools more or less frequently would be more cost effective. If a tool is found outside of the range the tool will be adjusted back to that target torque and a new record will be created for that data set. The researcher will use these adjustments to determine if the timeline for audits is appropriate.

The tools used in the study were all set to a target torque that was determined by Engineers at John Deere. The upper and lower range for setting all tooling at this facility is plus/minus 7% of the target torque. These targets, upper and lower limits were then used in the Cpk analysis. A typical Cpk of greater than 1.33 indicates that a process is producing a product that conforms to specification (Kane, 1986). The researcher calculated Cpk in the following manner:

USL – Upper specification limit

LSL – Upper specification limit

– Standard Deviation for the data set

– Average for the dataset

An example would be a tool set to 120Nm with average measurements of 118.3Nm and a standard deviation of 1.55. The USL would be 128.4Nm and the LSL would be 111.6Nm. Using this information the researcher can then calculate the Cpk=min(128.4-118.3)/(3*1.55)),(118.3-111.6)/3*1.55)). Cpk=min(2.172,1.44). The Cpk in this example would be 1.44.

The researcher gathered data for 518 "clicker" type torque wrenches. Of the 518 torque wrenches 123 of these wrenches had less than six data points collected. These wrenches were deemed as unusable data in the study because they have not been used in a production setting for a long enough duration. Of the remaining 395 wrenches remaining a Cpk analysis was done to determine if the tools and the monthly torque audit maintenance plan could produce an output that conforms to the specifications. The researcher used the 395 tools with the acceptable number of data points and found that within this data set there were 97.2% of tools with a Cpk value of over 1.33. Eleven tools were below a Cpk value of 1.33. There were six tools whose process capability is less than one. When looking at each of the tools that were below 1.33 Cpk the research found in many instances that there were one or two values that were significantly higher or lower on one of the three readings. This could potentially be due to operator error in collecting the data or an issue was found and corrected during the audit. With the high percentage of tooling be found to be in an acceptable range the researcher concludes that the repeatability of tools within the process specifications is acceptable. Many of the tools had a very high Cpk value. Knowing that the process is repeatable and can be audited the researcher can feel confident that tools can be monitored over a long duration. Each tool dataset was then generated into bar graphs to show each data set over time and how the average changed overtime. Each graph shows the target torque and the upper and lower specification limits. Using these graphs the researcher reviewed the tools with low Cpk to find the outliers and see how they related back to the target and to other historical data points. Due to the large amount of data the researcher will include in this report the fourteen tools (see Figures 1-14) with the most data sets as they have the most historical data. All of these tools have over fifty data sets or over a four year data collection time frame. Two of the data sets have Cpk values of under 1.33.

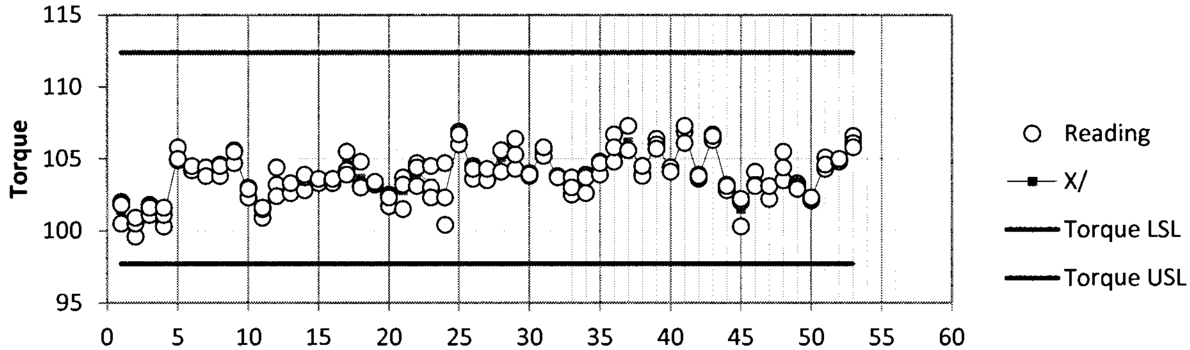

Figure 1 - Tool 387003614 - Cpk 7.683

Never re-calibrated

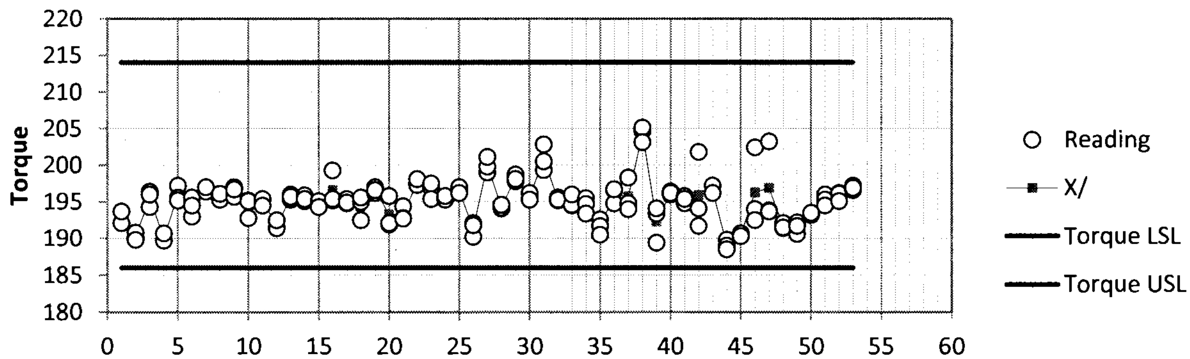

Figure 2 - Tool 387004003 - Cpk 6.643

Never re-calibrated

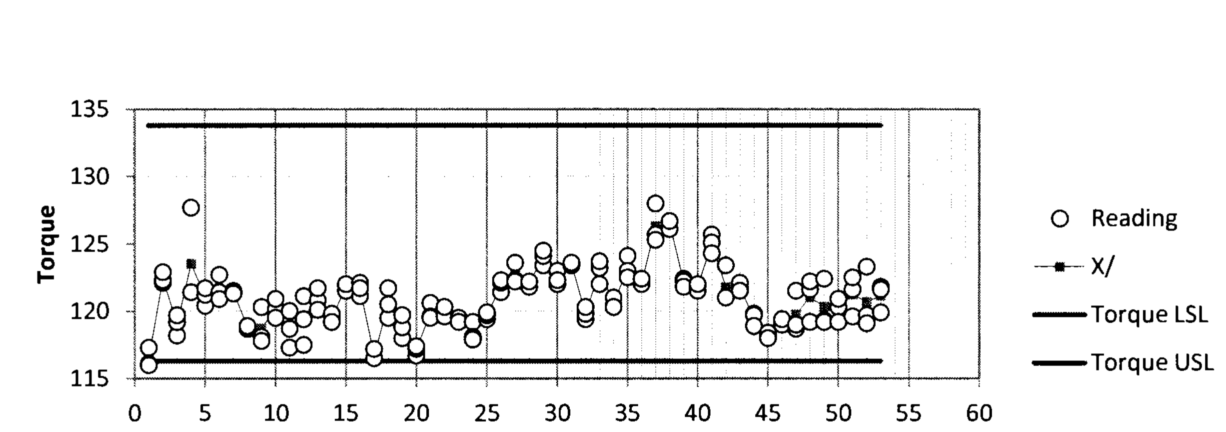

Figure 3 - Tool 387003498 - Cpk 5.689

Never re-calibrated

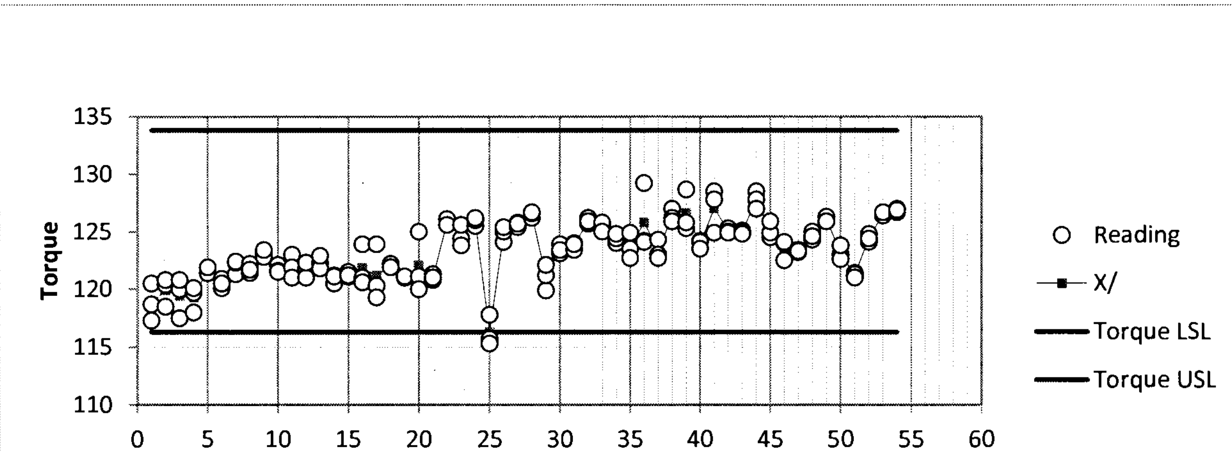

Figure 4 - Tool 387004004 - Cpk 4.992

(1) Re-calibration – 25^{th} data set. This means that the tool was not calibrated for 25 months of use and did not get recalibrated after this first recalibration.

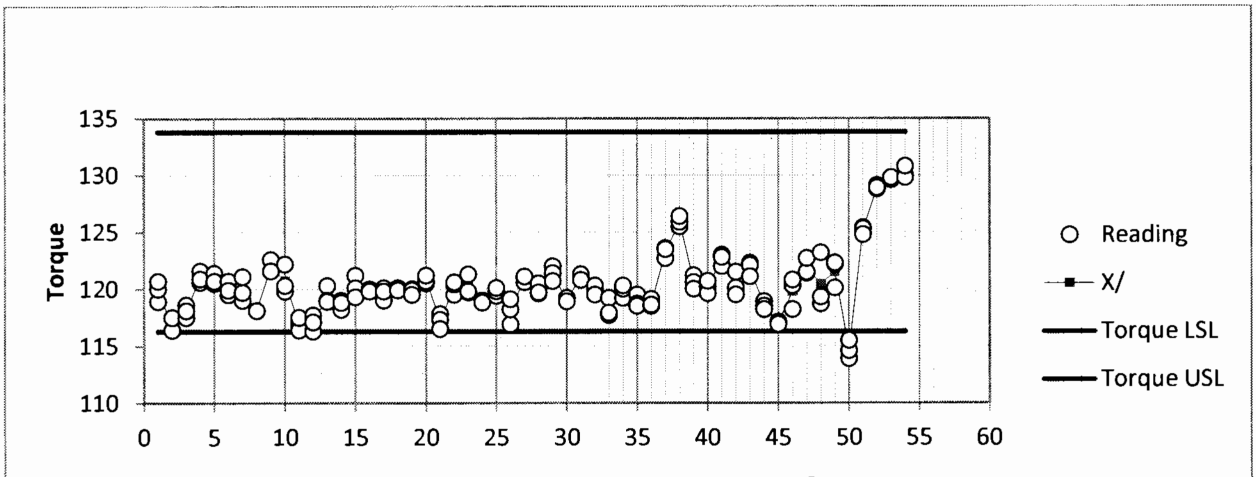

Figure 5 - Tool 387004019 - Cpk 4.03

(1) Re-calibrated – 50th data set. This indicates that the tool was not calibrated for 50 months and then it did not get recalibrated again.

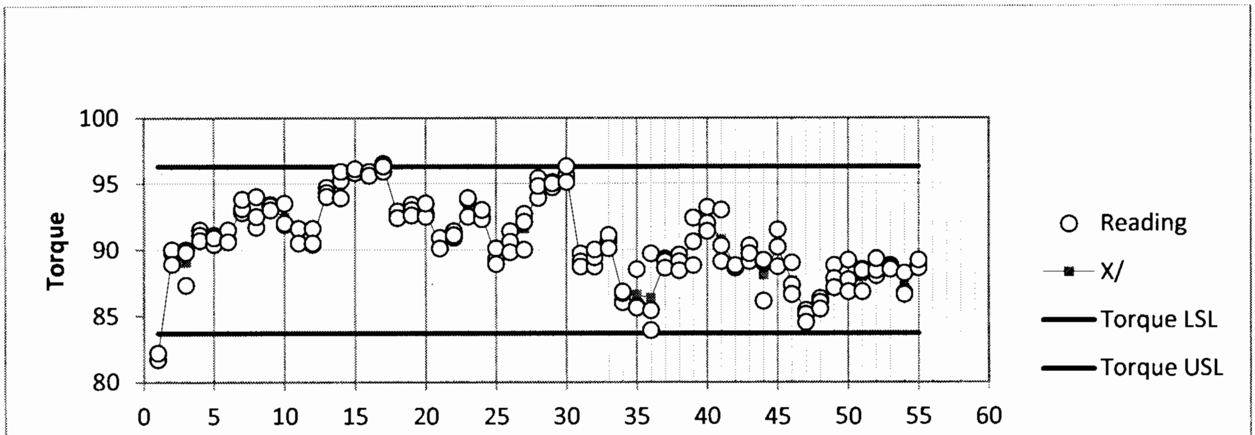

Figure 6 - Tool 387003521 - Cpk 3.445

(2) Re-calibrated – 17th and 29th data sets (setup calibration also shown, but not included). The researcher did not include the initial calibration in the count, so the first calibration occurred after 17 months and then the second occurred 12 months later.

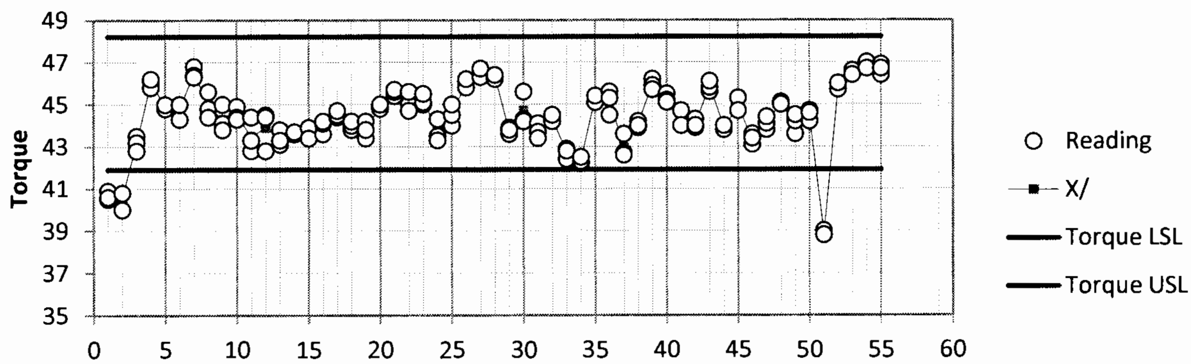

Figure 7 - Tool 387003492 - Cpk 3.032

(2) Re-calibrated – 11th and 50th data sets. Looking the data the research can see that 11 months into production this tool was recalibrated, but it did not fall out of the normal range. After this calibration the first reading outside of the upper and lower specification limits happened at 50 weeks.

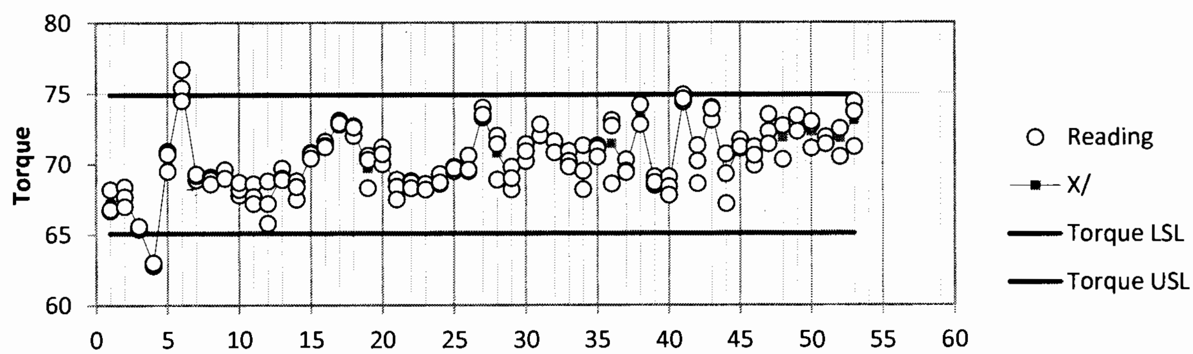

Figure 8 - Tool 387004102 - Cpk 2.836

Never re-calibrated

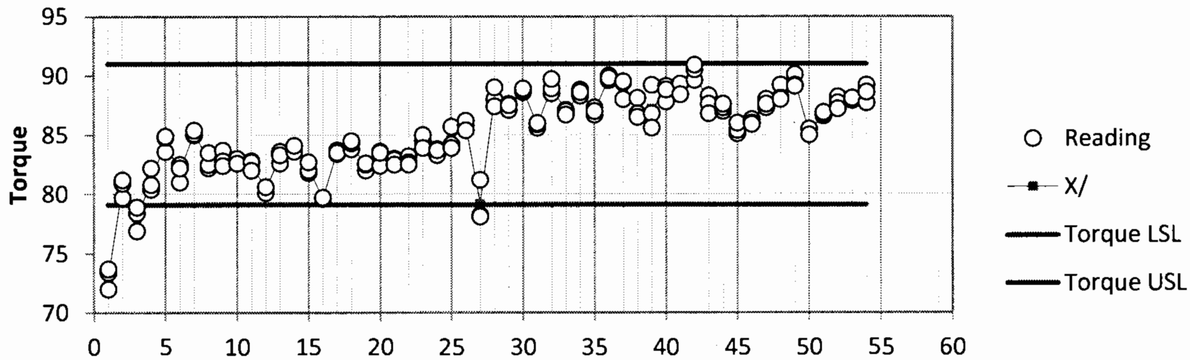

Figure 9 - Tool 387003999 - Cpk 2.545

(1) Re-calibated – 27th data set. This tool appears to have been in production for 27 months before it was re-calibrated. It appears that there were some trials to get the tool calibrated originally, but one the one re-calibration during the lifetime of the tool.

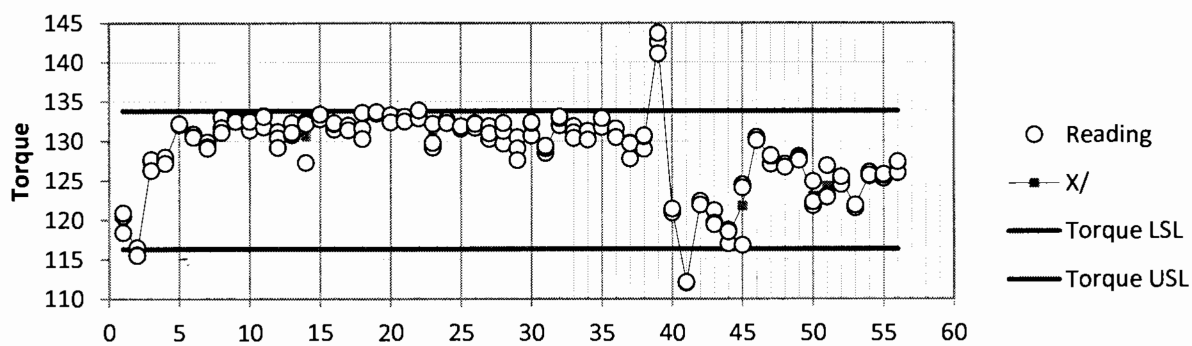

Figure 10 - Tool 387004022 - Cpk 2.291

(3) Re-calibrations – 22nd, 32nd, and 33rd data sets. This tool was not calibrated until 22 months in production. After 10 months of production and having reading near the upper limit the tool was re-calibrated in back to back months. The researcher is seeing some high and low values after the last calibration at 33 months, but then the data appears to steady near the target.

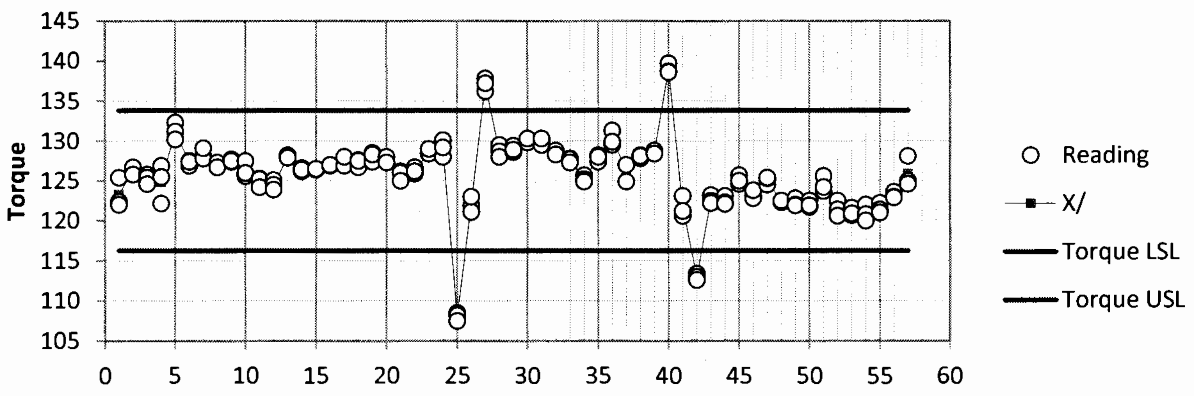

Figure 11 - Tool 387004016 - Cpk 2.204

(4) Re-calibrations – 25th, 26th, 38th, and 39th data sets. This tool was in production for 25 months prior to its first calibration. It appears that it took two consecutive months to get the calibration corrected and this stayed steady for 12 more months when a re-calibration occurred again and took two months to get back into the target range appropriately.

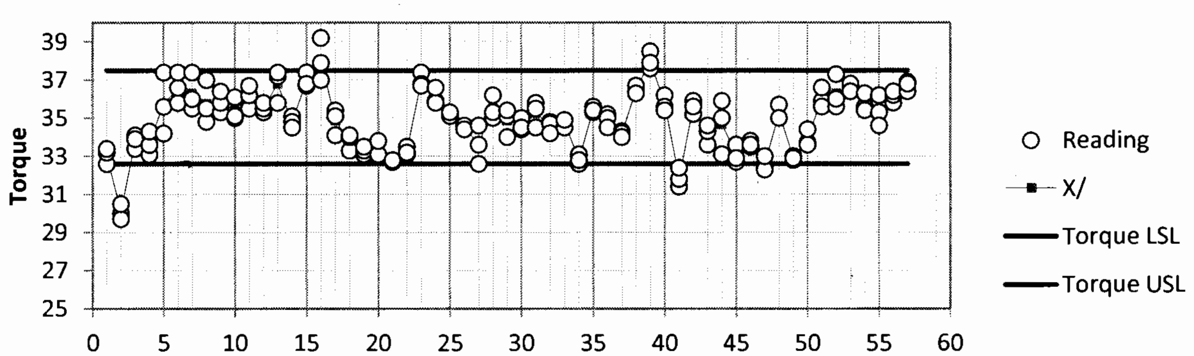

Figure 12 - Tool 387003992 - Cpk 2.075

(3) Re-calibrations – 16th, 38th, and 39th data sets. This tool was re-calibrated after 16 months for the first time once its measurement went above the upper specification limit. Then 22 months

later the tool needed to be re-calibrated again. It appears that the calibration put the tool on the lower specification limit so the following month it was re-calibrated again.

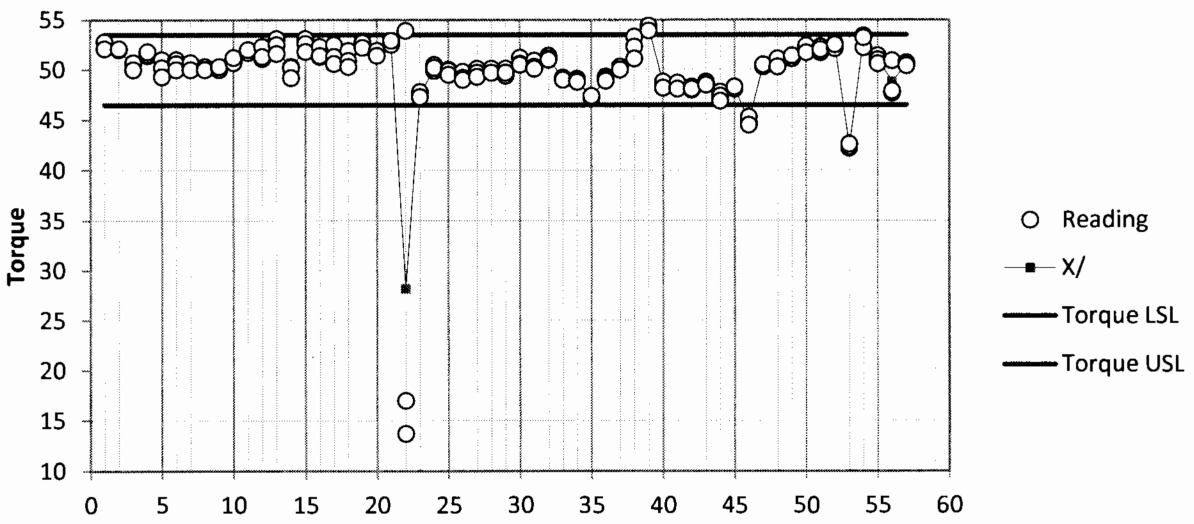

Figure 13 - Tool 387003518 - Cpk 0.691

(3) Re-calibrations – 22nd, 38th, and 50th data sets. This tool was re-calibrated after 22 months for the first time once its measurement went below the lower specification limit. Then 16 months later the tool needed to be re-calibrated again when the data peaked above the upper specification limit. Then the final recalibration occurred at 50 months into the life of the tool.

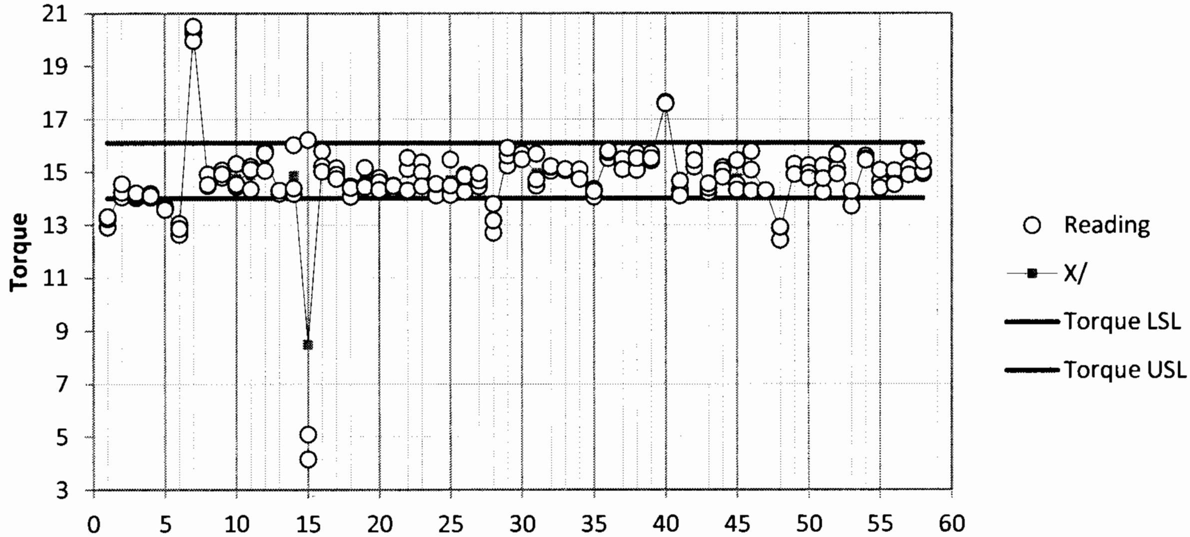

Figure 14 - Tool 387004025 - Cpk 0.509

(5) Re-calibrations – 15th, 27th, 38th, 45th, and 49th data sets. This tool has a very low torque setting and thus a small range. The increase in the number of re-calibrations could be due to operator error when checking the tools as the variation in torque applied will make a much larger impact at a lower torque setting than a larger one.

The data does support some common themes in that calibration has occurred at different rates for different tools. A common number in the 14 tool sets shown above is the 38th data set. There are tools that have had no re-calibration completed and others that have been re-calibrated a number of times. In analyzing all tools the researcher found that every tool is unique and there doesn't appear to be a trend in when tools are being re-calibrated or how often. Some tools are re-calibrated very early in their existence while others can be on the assembly line for months or years without requiring a calibration. Many tools found in the study did not require a re-calibration during their existence to date. The vast majority 77.7% of the tooling had been on the production line being monitored for less than two full years. This data set of tooling is yielding and average Cpk of 5.9. The remaining 22.3% of tools that have existed longer than two years has been yielding less control with a Cpk of 3.3. Looking deeper into these time frames the researcher has found that the Cpk for tools between the age of two years and three years yield a Cpk of 3.42. and tools with over three years of production use have a Cpk of 3.18. This data supports the hypothesis that tools tend to move away from their target and nearer to their limits over time with extended use. Additionally the month audits and re-calibrations are helping to keep the process in control, but at a lower success rate as tooling begins to wear down over time with usage. To evaluate the timeline for conducting torque tool audit the researcher will evaluate the percentage of tools that required a torque calibration along with the duration prior to requiring the first re-calibration.

Table 1 displays the information for Cpk for the tools as well as the calibration information for the tooling (see Table 1). The research found that the average number of times the tools are re-calibrated is less than once (0.845) for the life of the tool year to date. The researcher found that 227 tools were never re-calibrated because they didn't fall outside of the specifications. When we remove the tools that were never re-calibrated then the data shows that the number of times the tools are recalibrated more than doubles to 1.988 times per life cycle to date. This information is an identifier to the researcher that another study could be conducted on these tools to determine if proper application is taking place. The average number of days before a re-calibration occurs is 309.6 days. With a large number of tools not requiring a re-calibration for such a long period of time the researcher decided to break the information down into two categories to better understand the risk.

The first review would be to analyze the tools that have at least two years of production exposure. Shown in Table 2 we can see the 88 tools that were over two years of service only

25% of the tools did not need to be calibrated (see Table 2). This was a large drop from 57% when we included all of the data. This information further supports the hypothesis that tools in a production environment can be consistent, but need to be monitored as they will begin to wear down overtime and without proper monitoring they will not meet specification.

The second review was put together by the researcher to attempt to determine a proper timeline for conducting torque tool audits. Table 3 displays the number of tools and the percentage of the whole that required a re-calibration in the first month of service and continues until the first year of service (see Table 3). There does appear to be a steady trend upward for the first 6 months and then the number of additional wrenches requiring a re-calibration begins to flatten out. Every firm will have varying opinions on what is acceptable for a risk on assembly torque tooling. Some firms have quality standards that strive to achieve zero quality defects and will pay a premium to ensure that is accomplished. According to the data a firm that requires zero defects would need to monitor their torque tooling more frequently than once per month. A firm that can accept seven to ten percent risk to save cost could audit their tooling every quarter to achieve this goal. The costs and time used to collect the audit information would depend on the firm, the number of tools, and the cost for the labor to do so. A cost/benefit analysis would need to be conducted by the firm to determine the appropriate level of quality inspection for the right price.

Table 1
Summary of Cpk

Description	Value
Tools with Cpk under 1.33	11
Tools with Cpk over 1	384
% of tools within Cpk	0.972151899
Average number of times recalibrated - all tools	0.845
Average number of times recalibrated - excluding tools never recalibrated	1.988
Average days before first re-calibration	309.6
Number of tools never re-calibrated	227
% of tools never re-calibrated	57%

Table 2
Tools in Production for Over Two Years

Description	Value
Number of tools in service for more than two years	88
Number of tools over two years that were never re-calibrated	22
Average days before first re-calibration for more than two years	478.4
% of tools over two years did not need to be recalibrated	25%

Table 3
Re-calibration Timeframe

Tooling Risk Assessment	Value	Percentage
Tools requiring re-calibration after - One Month	8	2.03%
Tools requiring re-calibration after - Two Months	18	4.56%
Tools requiring re-calibration after - Three Months	26	6.58%
Tools requiring re-calibration after - Four Months	38	9.62%
Tools requiring re-calibration after - Five Months	57	14.43%
Tools requiring re-calibration after - Six Months	72	18.23%
Tools requiring re-calibration after - Seven Months	83	21.01%
Tools requiring re-calibration after - Eight Months	85	21.52%
Tools requiring re-calibration after - Nine Months	85	21.52%
Tools requiring re-calibration after - Ten Months	86	21.77%
Tools requiring re-calibration after - Eleven Months	95	24.05%
Tools requiring re-calibration after - Twelve Months	100	25.32%

Conclusions and Recommendations

The researchers concludes that the data collected does support that "clicker" type torque tooling is a controlled process that can be monitored and maintained within the specifications provided by a manufacturing firm. The data also supports the need to monitor and re-calibrate assembly tooling as they're used in a manufacturing setting. The data analysis also supports the hypothesis that as duration and usage increases the reliability of being within specification decreases due to tool wear. The data analysis also provided a breakdown for risk from this dataset for manufacturing firms to use as a guideline for determining the frequency of torque tooling audits.

To further this study the researcher would recommend conducting a study with the assembly tools in a controlled environment to ensure all data is collected the same and all tools are subject to the same conditions and usage to see if this would yield any additional findings. There were tools that were found to be re-calibrated more frequently than others. Determining root cause to these differences would be an additional study that could be conducted by adjusting the variables and doing a controlled study. One example for analysis would be to change the usage amounts for the tools and monitor calibration and process control at various usages per day. All torque wrenches have a range that they can be set to. Another study would involve setting wrenches to various parts of their range and then monitor the calibration schedule and process control charts to variation. The assumption would be that if the tool is at the higher end of the range then more stress would be applied to the spring and this would cause in more rapid display of inconsistency.

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