RMS FASTENER TORQUE CONTROL

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ABSTRACT

When vehicles are subjected to vibration or extreme temperature fluctuation, the fasteners holding them together must remain intact or they may cause the vehicle to fail. When these vehicles are used in a manner such that failure can cause injury or death, it is all the more critical that the fasteners perform as designed. Tightening fasteners by applying pre-determined torque values in manufacturing facilities in the automotive and defense industries has historically been accomplished through the use of a periodic calibration system and closely controlled work instructions. This system requires periodic recall of the torque tools to verify the tools are still performing at the set values. However, this system is flawed in that discovery of out of tolerance tools occurs well after the tools have been used to apply out of tolerance fasteners in tens, hundreds, or even thousands of products. Worse still, in today's Just In Time business environment, many of these newly discovered out of tolerance products are already in the customers' hands! The solution to this manufacturing nightmare is to shift the discovery of out of tolerance conditions from the end of a manufacturing interval to the beginning. In this way, manufacturers can repair or replace out of tolerance torque tools before they are used to create nonconforming products.

DISCLAIMER

This report is based on research conducted at Raytheon Missile Systems by a Raytheon Missile Systems employee. The views represented herein are solely those of the author and in no way represent Raytheon Missile Systems opinions.

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INTRODUCTION

Raytheon Missile Systems (RMS) is an ISO 9001:2000 registered company headquartered in and employing over 10,000 people in Tucson, Arizona. RMS is home to numerous weapons programs that require intensive mechanical assembly in a fairly typical factory environment. Many of the weapons are designed to include the use of threaded fasteners as a means of securing components to one another and because of the high vibration and extreme temperature environments these weapons are designed to operate in, the threaded fasteners and torque tools are selected for their material properties and engineered for installation at specific torque values with specific tolerances. The guidance for selecting the fasteners and torque tools is vast and for the purposes of this project the author consulted Military Handbook 5, Military Handbook 627, the MEC Torque Tool Selection Guide, and RMS MP 1201.

Fastener Torque Control is the ability to accurately control the application of the specific torque values during assembly operations, and is accomplished through the use of both pre-set and adjustable torque wrenches that have been previously certified as “in calibration” through a controlled calibration program administered by the Metrology Department. This system is very similar to the system in use for many years at most manufacturing facilities that require precise control of fastener torque values, like those in the automotive or aerospace and defense industries. Essentially this system, governed at RMS by Quality Assurance Procedure (QAP) 2.2 and Job Operating Instruction (JOI) MET-105G, begins by certifying the accuracy of a torque tool. Once certified, the tool is released to the factory for production use and recalled many months later to "verify" that it is still operating within tolerance.

Fastener Torque Control is not only just a good idea; it is a requirement of the ISO 9001:2000 standard that RMS subscribes to. In section 7.6, the standard states,

"Where necessary to ensure valid results, measuring equipment shall

a) be calibrated or verified at specified intervals, or prior to use, against measurement standards traceable to international or national measurement standards; where no such standards exist, the basis used for calibration or verification shall be recorded;

b) be adjusted or re-adjusted as necessary;

c) be identified to enable the calibration status to be determined;

d) be safeguarded from adjustments that would invalidate the measurement result;

e) be protected from damage and deterioration during handling, maintenance and storage

In addition, the organization shall assess and record the validity of the previous measuring results when the equipment is found not to conform to requirements. The organization shall take appropriate action on the equipment and any product affected. Records of the results of calibration and verification shall be maintained."

Additionally, the RMS Enterprise Quality System Manual, in Section 7.6, Control of Monitoring and Measuring Devices, includes virtually the same requirement in nearly identical language used in the ISO standard. Furthermore, U.S. Government quality standards that pre-date the ISO standard (and had been in effect for over 40 years until superceded by the ISO Standards) contain similar requirements. For example, one of the Government quality standards, MIL-Q-9858A, states in Section 4.2,

"The contractor shall provide and maintain gages and other measuring and testing devices necessary to assure that supplies conform to technical requirements. These devices shall be calibrated against certified measurement standards which have known valid relationships to national standards at established periods to assure continued accuracy. The objective is to assure that inspection and test equipment is adjusted, replaced, or repaired before it becomes inaccurate. The calibration of measuring and testing equipment shall be in conformity with military specification MIL-C-45662. In addition, the contractor shall insure the use of only such subcontractor and vendor sources that depend upon calibration systems which effectively control the accuracy of measuring and testing equipment."

It is clear that measuring and test equipment calibration is required on multiple levels and that manufacturers need to maintain close control of their manufacturing and measurement systems as part of their Fastener Torque Control systems. The problem is that by adhering to these requirements in a traditional sense, manufacturers, RMS included, have entrenched themselves in a "backwards" system that only identifies an out of tolerance condition after a tool has been used for many months, potentially jeopardizing the quality of hundreds if not thousands of products. Ironically, the manufacturers have been blind to this risk because they have been "requirements-driven" and not able to see that sometimes, simply complying with the language of the requirements does not meet the intent of the requirements. MIL-Q-9858A speaks to this intent, stating "The objective is to assure that inspection and test equipment is adjusted, replaced, or repaired before it becomes inaccurate." Somehow this intent never crossed over into the superceding ISO Standards, and the result is a proliferation of "backwards" fastener torque control systems, including the system currently in place at RMS.

This project contains research into the problems that a backwards fastener torque control system can and has created at RMS, using 2001 data, and proposes some solutions to shift the identification of torque tool out of tolerance conditions from the end of a manufacturing interval to the beginning. These solution proposals have already been formally submitted to the Manufacturing Engineering Center Manager and the Metrology Department Manager for consideration. Identifying out of tolerance conditions prior to use on production hardware will meet the intent of MIL-Q-9858A and will help prevent nonconforming products from reaching customers.

CHAPTER 2

BACKGROUND

Components in an assembly process are often clamped together with threaded fasteners, a cost effective design method, into what is commonly called a joint. The integrity of these joints at Raytheon Missile Systems is at the heart of this project. There is a lot of readily available technical material describing different joint properties and fastener properties, and additional material describing which materials are compatible with other materials, but the thrust of this project is not material in nature. This project is about the methods or processes used to control the clamping force applied to critical components in weapons at RMS, with some specific references to the JSOW Missile Program, to ensure the safe completion of their intended mission.

Measuring the tension of an installed fastener is difficult in a manufacturing environment, though in a laboratory environment it is not so difficult. The Federal Standard H28A, describes this as follows:

"In the laboratory the tension induced in a bolt by tightening the nut can be accurately determined in a tensile testing machine. In the practical application of fasteners there are five generally used methods for setting bolt tension as follows:

1. Micrometer method, in which both ends of the bolt must be accessible to measure the change in the overall length of the bolt.

2. "Feel" method, applicable only when the desired tensile stress is just beyond the yield point of the bolt material.
3. Torque measurement methods, which require that the torque-tension relationship be established for the specific conditions of assembly.
4. Angular turn-of-the-nut method.
5. Use of special devices for controlling tension."

Item 3 above is the method of interest for the purposes of this project, and the means of controlling the torque values is of particular interest. In a factory environment, the challenge is to provide a cost-effective means for the assembler to be certain that the fasteners he or she has installed meet the design tolerance for joint clamping force. Standard H28A goes on to state:

"In most applications of threaded fasteners, it is not practical to measure directly the tension produced in each fastener during assembly. Fortunately, for many applications the tension may be controlled within satisfactory limits by applying known torques in tightening the nuts on the bolts or studs. Tests in numerous laboratories have shown that satisfactory torque-tension relationships may be established for a given set of conditions."

RMS has historically used these commonly available torque-tension relationships to call out specific torque values and associated tolerances on its product drawings. The means of controlling the applied torque values during assembly has been through the torque wrench calibration system described earlier in Chapter 1 of this report. When torque wrenches are found out of tolerance by the Metrology Lab at RMS during routine calibration, a Notice of Out of Tolerance Condition (NOTC) report is generated to inform the responsible program of the out of tolerance condition. It is through this NOTC system that the idea for this project was born.

As a quality engineer on the JSOW Missile Program, this author was and still is an integral part of the NOTC approval or review process, and has remained in this position within the JSOW engineering organization for over three years beginning in 2000. During this time, it has been extremely difficult to investigate, with absolute certainty, whether or not production hardware has been jeopardized by the discovery of out of tolerance torque wrenches. Unfortunately, because of the "backwards" nature of the calibration system, torque wrenches are used on production hardware for periods typically between 1 month and 1 year before they are identified as being out of tolerance. Worse, RMS does not require assemblers to document which wrench was used to apply torque to particular fasteners on particular missiles, which makes it extremely difficult to pinpoint where these out of tolerance wrenches were used. Fortunately, in many of these cases, the engineers are able to determine that while the wrenches are found out of tolerance, the product drawing tolerances are substantially larger. Consequently the fasteners, though not applied at the target value, were still applied to values within the allowable product design tolerance. There are also many other cases where there are subsequent assembly steps that correct the fastener discrepancy downstream prior to sale.

However, there have been a few cases at RMS where if the wrench could have been proven absolutely to have been used on particular products, the products would have been considered nonconforming because the product drawing tolerance would have been violated. Instead, the engineer could only speculate that the wrenches probably were used, due to their proximity to the assembly area, and had to make a decision whether or not to screen potentially affected products. Complicating matters, due to the lengthy calibration interval, the potentially affected products included all products built since the previous known good calibration many months prior, and nearly all of these products had already been sold and delivered to the customer. At this point, because of the costs involved with product recalls and screening, if the engineer wanted to recall previously sold products for screening, he would have to convince the program manager that there was a definite need and there were definitely nonconforming products in the field. Unfortunately, the backward system prevents the engineer from definite knowledge of the facts of the case and the decision to recall product caused by the use of out of tolerance torque wrenches remains very difficult to make.

This project was borne out of the obvious and pressing need to change the RMS Fastener Torque Control System from one that only identifies torque wrench out of tolerance conditions after the wrenches have been used for many months on production hardware, to a Fastener Torque Control System that identifies torque wrench out of tolerance conditions at the point of use during assembly.

CHAPTER 3

RESEARCH AND FINDINGS

The Year 2001 RMS NOTC data is stored in hardcopy format in binders by the NOTC Administrator in the Metrology Department. The Administrator also maintains a database of NOTC data in Excel spreadsheet format. I was given permission to conduct research into this data after the completion of Year 2001 and was able to read every single NOTC (hardcopy) and take notes on all relevant detail. A copy of a blank NOTC Form is included as Appendix A.

From the NOTC hardcopies the author was able to read every investigation result or "disposition" and was able to identify a trend among the various dispositions. The dispositions generally fell into the following categories:

A. Not used on production hardware during this calibration cycle

B. Out of Tolerance condition exceeds wrench tolerance but does NOT exceed product design tolerance

C. Out of Tolerance condition exceeds wrench tolerance and DOES exceed product design tolerance, but was dispositioned Use As Is via Engineering Evaluation

D. Wrench used only for interim torque

E. Suspect product screened

1. Out of Tolerance fasteners found and reworked
2. Out of Tolerance fasteners NOT found

F. No suspect product screened – any anomaly would have been discovered later

G. All suspect product expended prior to screening effort

H. Wrench not used for "acceptance"

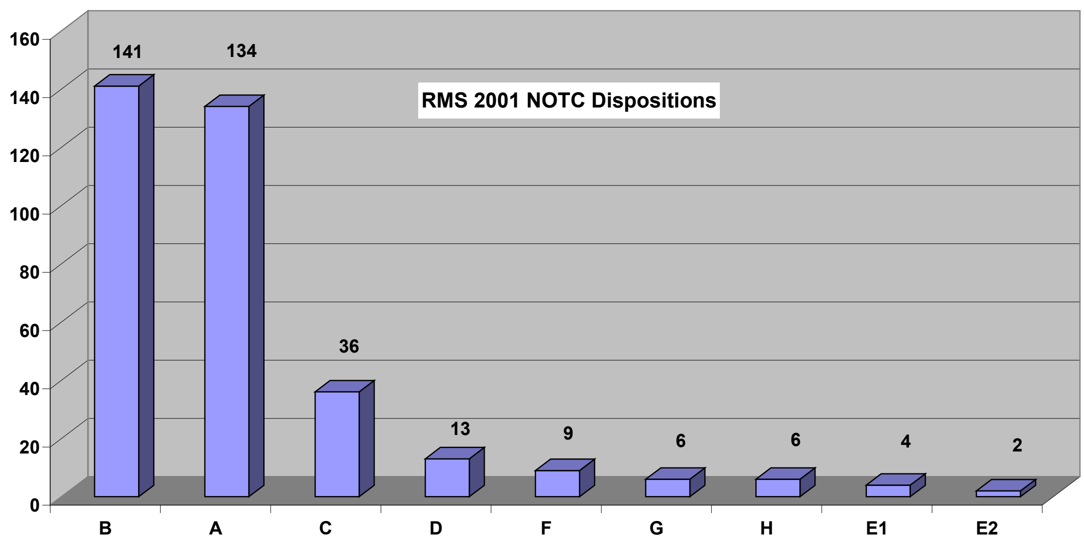

Figure 1

From the Excel spreadsheet I was able to determine average age at NOTC closure, responsible programs and people, number of NOTCs completed past due, and other numerical data made simpler with the sorting capability of the Excel spreadsheet format.

Based on this research into the NOTC data from Year 2001 and from personal experience as a Quality Engineer in the NOTC review process, it this author's contention that the RMS Fastener Torque Control system is "backwards" in that we only know a torque wrench is out of tolerance months after it has been in production use. When a torque wrench out of tolerance condition is discovered, the notification system, Notice of Out of Tolerance Condition (NOTC), is a slow and out-dated 3-ply paper process. Because of the backwards nature of the system and the length of time between removing a wrench from the production floor and the subsequent receipt of a NOTC, the investigation often begins well after the potentially affected hardware has been delivered to the customer, complicating an adequate engineering evaluation.

Once the programs receive the NOTCs, the NOTC investigations and

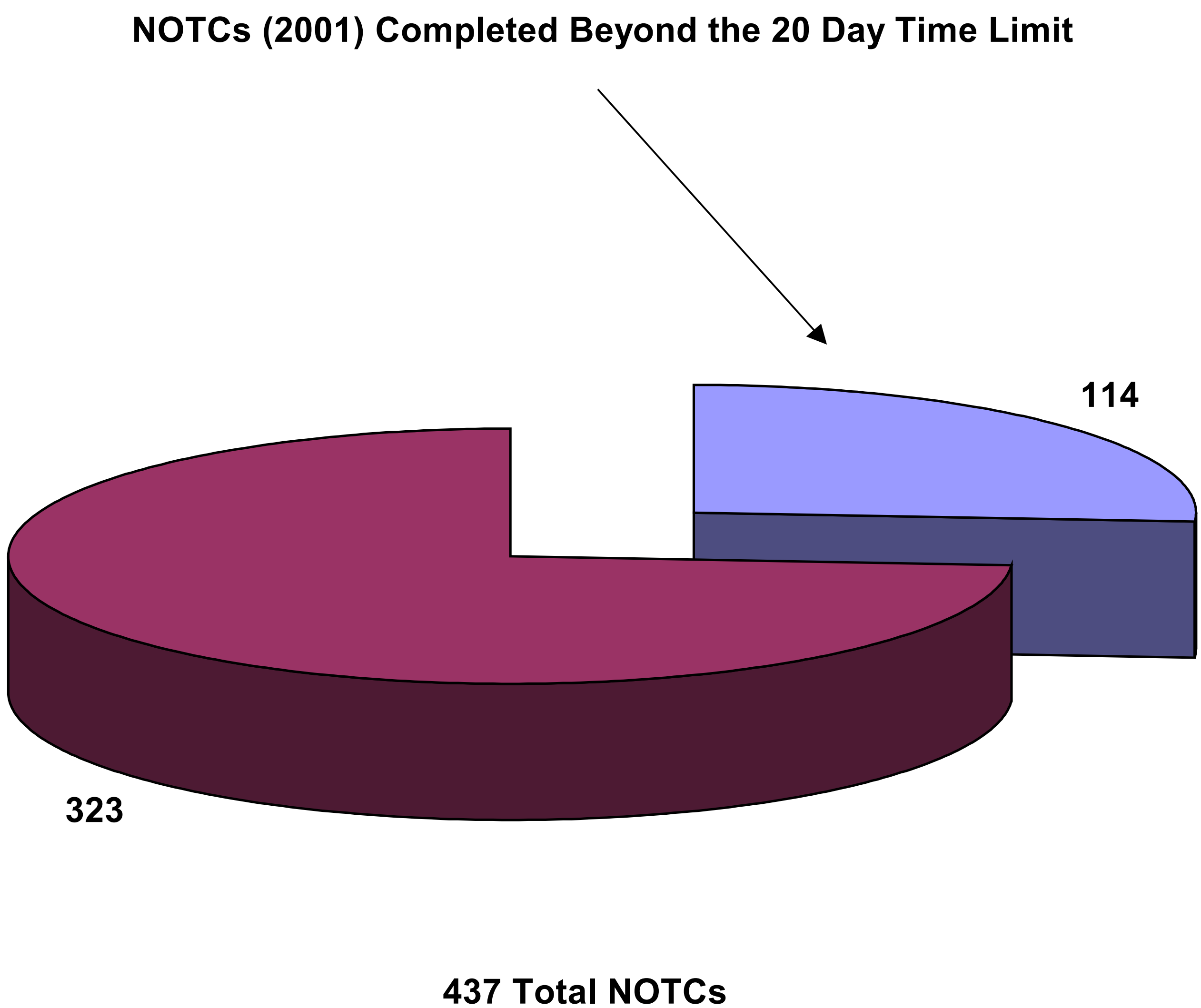

Figure 2

The NOTC dispositions occasionally show poor engineering judgment and sometimes are performed by non-engineers. For example, one of the dispositions was (paraphrase) "No impact to delivered hardware. All hardware is tested prior to delivery." However, the testing referred to was functional testing at ambient temperature and not subject to vibration. Consequently, the testing would not have (by design) identified fasteners that were over- or under-torqued, and was

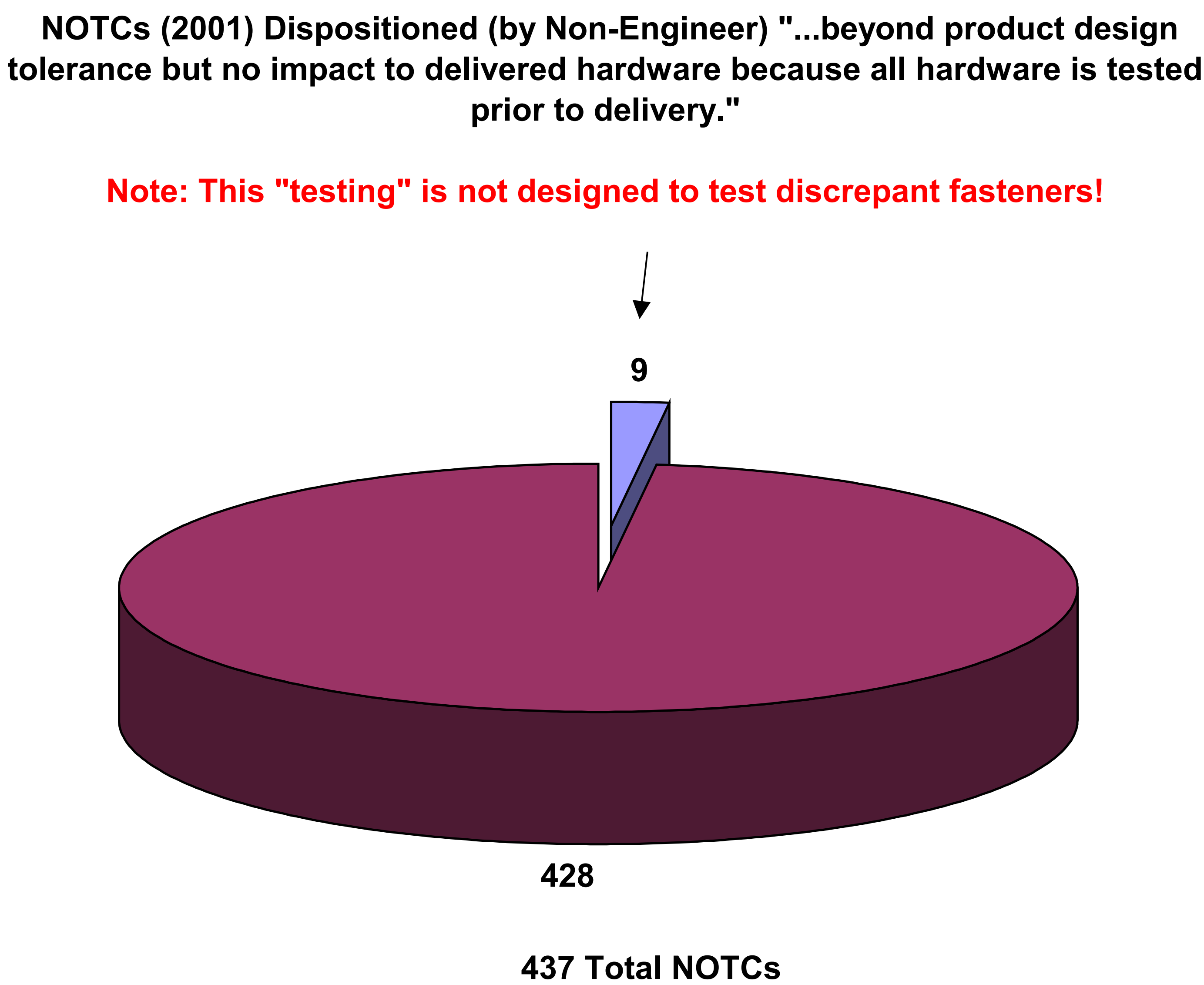

Figure 3

The torque wrench calibration system itself is equally flawed. Wrenches are assigned a calibration interval based on the history of the wrench in the form of a Reliability Factor (RF). In a few cases, the RF for particular wrenches is listed at greater than 250 days, yet these same wrenches fail calibration one-third of the time. Each weapons program using one of these wrenches stands a 33% chance of receiving a NOTC every calibration cycle and will have to investigate whether or not hardware produced over the previous 250+ days (most likely already delivered to the customer) was jeopardized.

The torque wrench design tolerance is also an area of concern. Currently, when a torque wrench exceeds its set value by +/-4% (hand-driven tools) and the wrench is considered out of tolerance, a NOTC is issued. However, most weapon fastener design tolerances at RMS are +/- 10% or greater, and in 2001 nearly one-third of all torque wrench NOTCs were investigated and dispositioned as falling into the zone between wrench and product design tolerance.

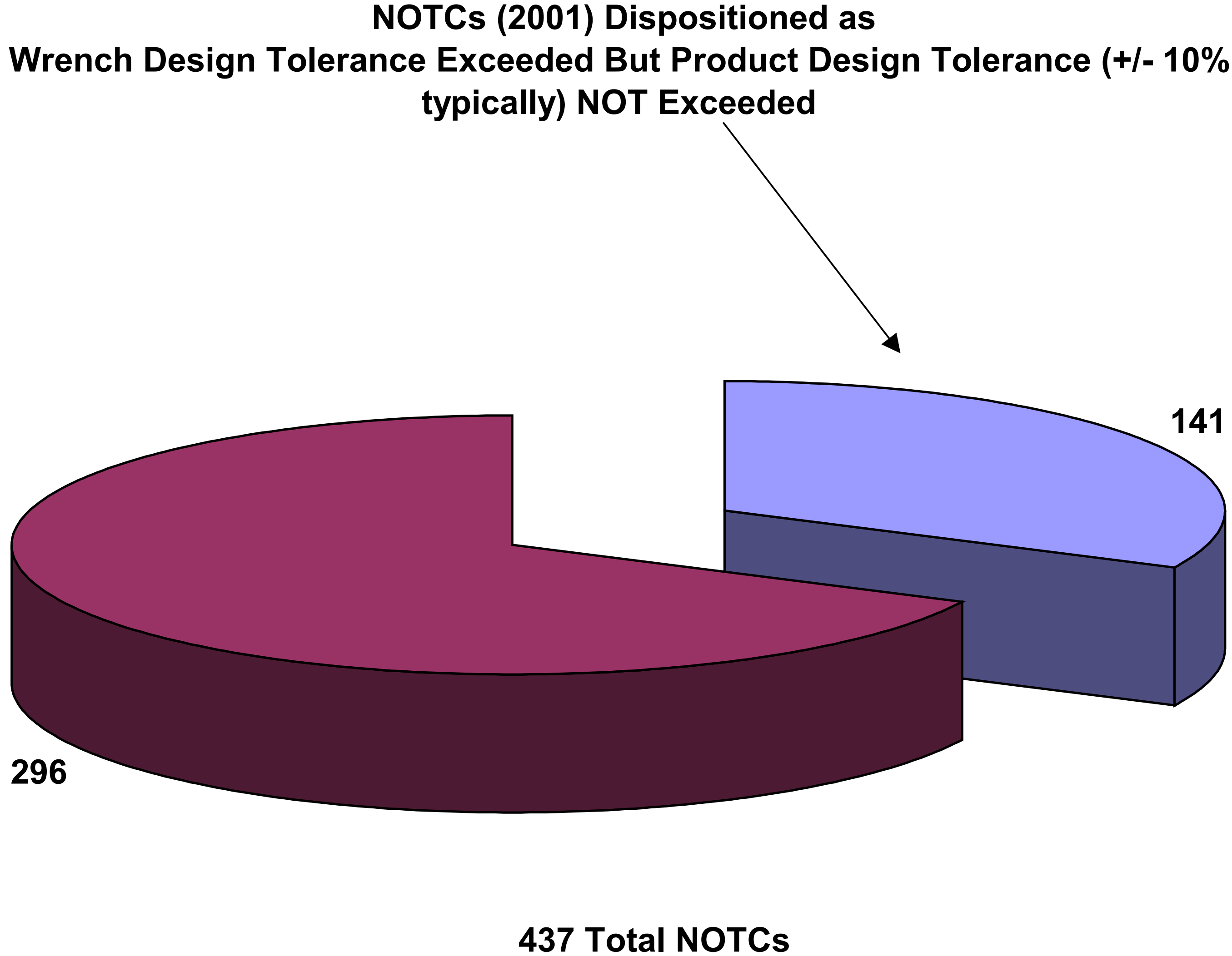
NOTCs (2001) Dispositioned as
Wrench Design Tolerance Exceeded But Product Design Tolerance (+/- 10% typically) NOT Exceeded
141
296
437 Total NOTCs

Figure 4

If this wrench tolerance was expanded to more closely match weapon design tolerances a significant percentage of NOTCs and the associated costs of investigating and administering them would be eliminated.

Another area of concern that is inherent to the current “backwards” system of Fastener Torque Control is that the 2001 NOTC data reveals that 134 of the 437 NOTCs (30.7%) were dispositioned as “Not Used for Production” during the calibration interval in question. That phrase can mean several different things, including that the wrench was left in a drawer for the entire calibration interval and degraded on its own though lack of use or by being left set at a value other that zero in the case of an adjustable torque wrench. It could also mean that the wrench was used only to fasten test fixtures which were later removed and was not used in any permanent way on the product itself. However, since RMS does not require assemblers to document which torque tool was used on which particular missile or particular fastener set, there is no evidence to prove the wrench was NOT used on production hardware. The issue here is that our culture assumes innocence until proven guilty, but in a critical manufacturing environment it makes better engineering sense to prove to ourselves that a product is conforming. The evidence we rely on to prove guilt in these 134 cases is testimony of the workforce, and often the incident we are investigating is 6 months in the past. It is unlikely that an assembler will remember whether or not a particular wrench was pulled out of a drawer and put into use anytime during the previous six months, so the testimony may not be reliable.

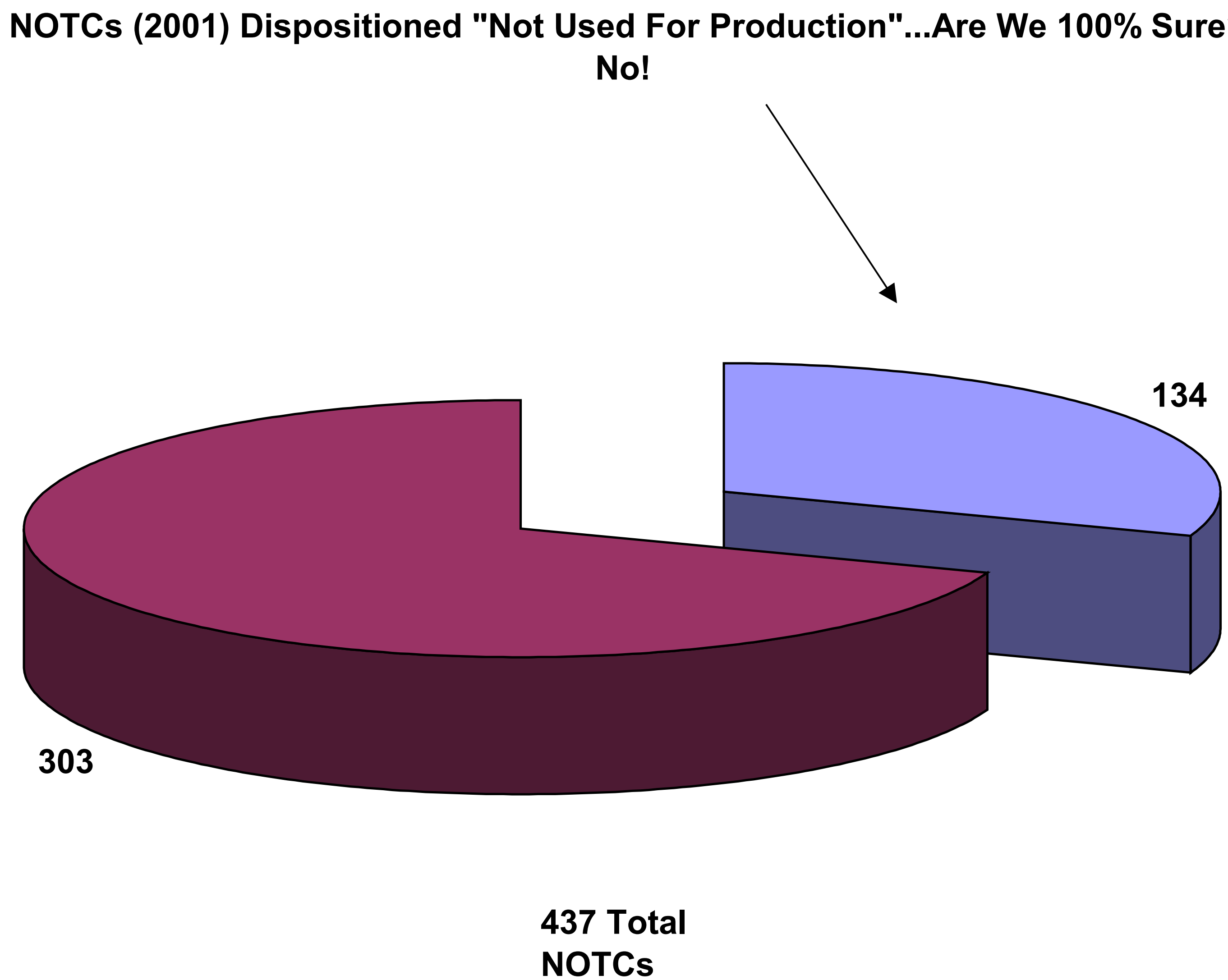
NOTCs (2001) Dispositioned "Not Used For Production"...Are We 100% Sure?
No!
134
303
437 Total
NOTCs

Figure 5

One last area of concern is that 57 of the 437 NOTCs (13%) issued in 2001were dispositioned as "Hardware Jeopardized" in some way or another if one combines categories C, F, G, E1 and E2. In cases where the investigator determines that hardware has been jeopardized, essentially that it is possible or even likely that some fasteners on products built and delivered previously are non-conforming to drawing requirements, the investigator needs to generate a Non-Conforming Material Document and convene a Material Review Board. The Material Review Board, consisting of 2 engineers and a quality engineer, will determine whether or not the defect will adversely affect the fit, form and function of the end item product. If not, the Board will disposition the defect as "Use As Is" and no action is required other than administrative. If the Board determines that fit, form or function of the end item product is adversely affected, the Board will disposition the Non-Conforming Material Document as "Rework", requiring recall of all affected product for rework to meet drawing requirements. Based on the 2001 NOTC Disposition documentation during the research, it was clear that many of the "Use As Is" dispositions contained no documented evidence that a Material Review Board convened to make the determination. It appears instead that a single engineer made the determination, which violates RMS Procedures.

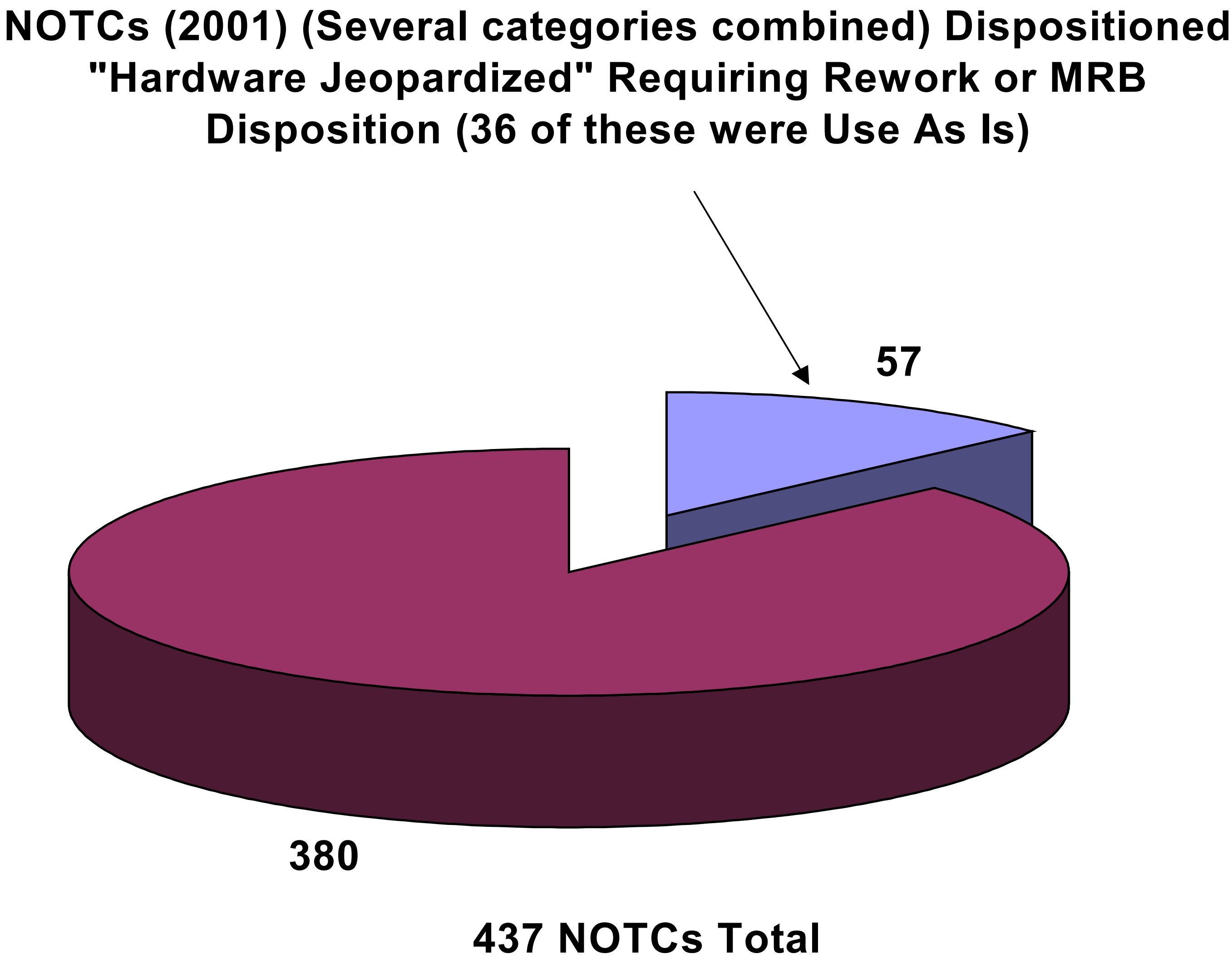
NOTCs (2001) (Several categories combined) Dispositioned "Hardware Jeopardized" Requiring Rework or MRB Disposition (36 of these were Use As Is)
57
380
437 NOTCs Total

Figure 6

A summary of the more interesting 2001 Torque Wrench NOTC data is listed below:

- 12,551 torque wrench calibrations were performed by Metrology in 2001
- 437 NOTCs (3.5%) were issued in 2001 with due dates falling within 2001
- 114 NOTCs (26.1%) were not completed within the initial allotted time frame (20 days)
- 141 NOTCs (32.3%) were issued for wrenches exceeding design tolerance (+/- 4%), although the wrenches were used on products with a fastener design tolerance of +/- 10% or more.
- 36 NOTCs (8.2%) were dispositioned as exceeding both wrench and product design tolerances, yet the hardware was deemed "Use As Is" with only rare mention or linkage to an engineering MRB process. In some cases it appears that non-engineers make the engineering disposition "Use As Is". Further, a non-engineer states in a number of NOTC dispositions that there is "no impact to delivered hardware since all hardware is tested several times prior to delivery", although the testing referred to is at ambient temperatures, not under vibration, and not geared towards discovery of fastener discrepancies.
- 57 NOTCs (13.0%) were dispositioned as "Hardware Jeopardized" and required either rework or MRB action.

CHAPTER 4

A REAL-TIME FASTENER TORQUE CONTROL SOLUTION

Ideally, manufacturers should shift the discovery of out of tolerance conditions from the end of a manufacturing interval to the beginning, in essence a "real-time" system. In this way, they can repair or replace out of tolerance torque tools before they are used to create nonconforming products. The following is a description of a system designed to prevent the use of out of tolerance torque wrenches in the manufacturing area of a small, one line manufacturing facility like some of those at RMS.

The basic concept behind the design identified above is that torque wrenches will be monitored at the point of use and repaired or replaced prior to producing discrepant hardware when they *trend* towards *product* out of tolerance conditions. Currently, manufacturers, including RMS, wait until the end of the calibration interval to determine when a wrench is out of tolerance. This up front awareness will eliminate the need for periodic calibration of torque wrenches, eliminate the NOTC system for torque wrenches (in the case of RMS), and eliminate discrepant hardware recalls for out of tolerance fasteners.

This "real-time" method of fastener torque control is to adjust and calibrate each torque wrench as usual to NIST Standards, but to install torque transducers to each torque wrench in the production area and connect those to monitors that will display and log the exact torque values applied to each fastener.

The values will be automatically plotted using Statistical Process Control software, like Quantum SPC by ASI-DataMyte, and when the torque wrenches degrade to a point where the torque values approach the control limits, an alarm will indicate the wrench is in need of adjustment and re-calibration.

ASI-DataMyte Quantum SPC Software:

Figure 7

Figure 8

The NOTC report process will be eliminated because there will be no out of tolerance conditions. The periodic calibration of torque wrenches will be unnecessary because wrenches will be proven "good" at every use until actual degradation to the point which they will be repaired and re-calibrated "as needed" instead of "as scheduled." Of course, for a system like this to work properly, close control of the transducers will be required so that they never degrade to an out of tolerance condition.

Envisioned ProcessFlow

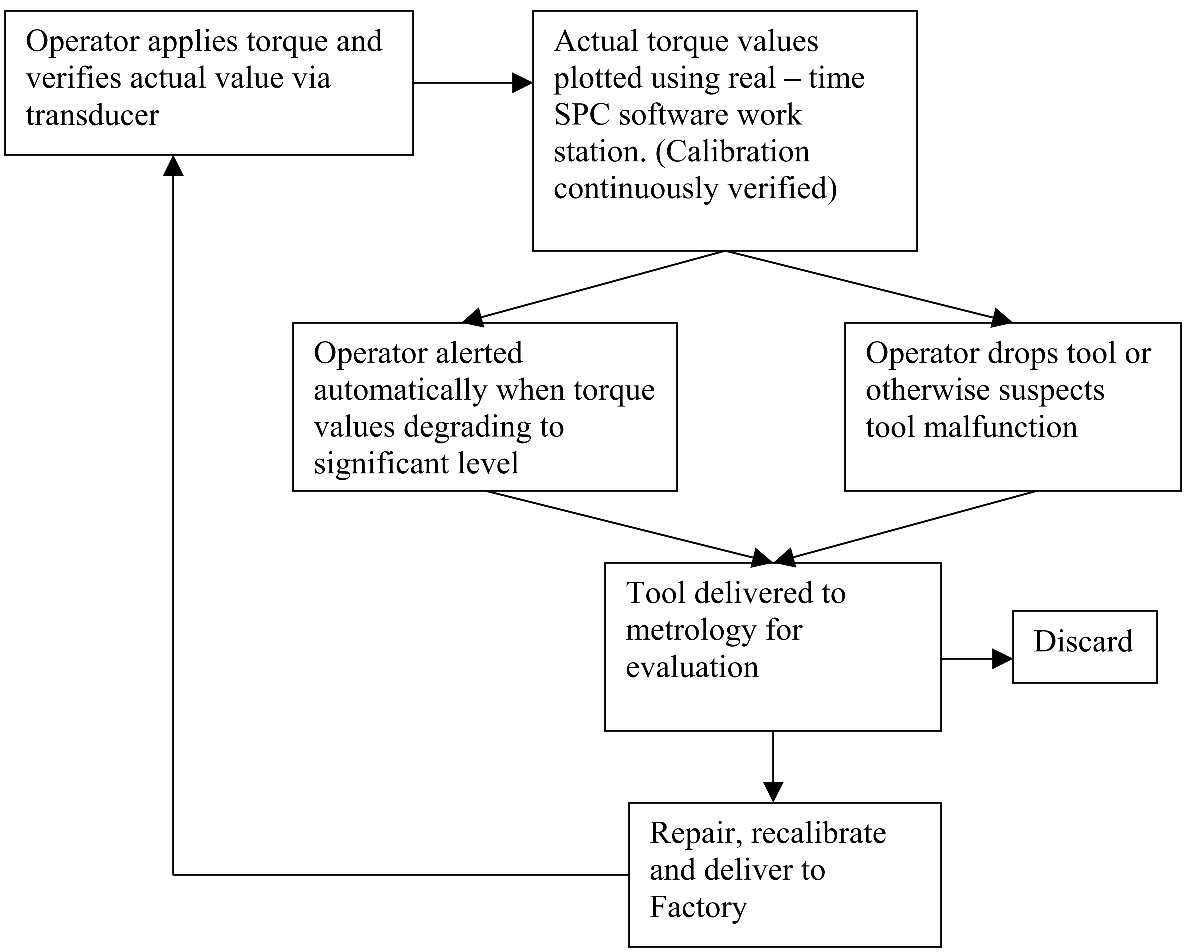

Figure 9

Currently, no commercially available system exists that fits this exact description. This ideal system must meet several design criteria OR "customer requirements" to help attract interest from the assembly force engineering groups that will be required to use the tools that make up the system. The currently available components do not meet these requirements fully, as the figure below illustrates:

Currently Available "Leading Indicator" Fastener Torque Control Systems

Strong Relationship = 3 Medium = 2 Weak = 1

Customer Requirements	Configurable Display Software	SPC Software Package	Windows-Based Highly Rated Software	Wireless Transmission System	Industrial Grade Components	Compact Design	Medium Grade PC Compatible	Dedicated Server	Large Database Staorage Capability	Low Power Adjustable Frequency	Minor Set Up Activities	ASI-Datamyte 501	Mountz, Inc. Wizard	S/R PTV FM System
	Product Requirements											Benchmarks		
Applied Torque Displayed Instantly	3	2	1									X	X	X
Data Points Plotted on SPC Chart Instantly	2	3	1											X
User-Friendly	1	2	3	1			1	1	1		3			X
Must Not Encumber the Assembler				3	1	2				1				X
Able to Withstand Factory Environment					3							X		X
Base Station Must Fit at Current Work Stations						3						X	X	X
Must Utilize Existing PC Work Stations							3					X	X	X
Networked For Remote Monitoring								3				X	X	X
5 Year Database Storage of Plotted Points								2	3			X	X	X
Wireless Transmissions Must Not Violate Safety Restrictions				3						3				
Must Be Nearly Transparent to Assembler				1						1	3			X
Units														
Target Value														
Technical Difficulty														
	Product Target and Benchmarks													

Figure 10

The system must provide real-time verification data to the assembler so he / she knows the fasteners are being installed according to the design tolerance. The system must not add additional encumbrance to the assembler, who is already working around wrist straps for ESD protection, pneumatic and electrical power lines, and other trip hazards. The system must require very little assembler interface so he/she can focus on normal, routine assembly tasks. The system must be user-friendly and the steps must be intuitively obvious so that the assemblers do not have to spend very much time in the data collection and verification process. Lastly, the system must be able to withstand the normal wear and tear encountered in an industrial manufacturing facility.

The current offerings from nationally known vendors do not meet the criteria described above, especially in the area of real-time verification. The systems currently available are more of a satellite data-logging system with a follow on data transfer to a main database of information. Hand held or belt-clipped units, like the ASI-DataMyte 501 Data Collector shown on the ASI-DataMyte website, and the Mountz, Inc Torque Mate Plus and Wizard, shown in the Mountz, Inc. MC12 Catalog, only allow the user to gather torque data in the handheld unit.

ASI-DataMyte 501:

Figure 11

Mountz, Inc. Torque Mate Plus:

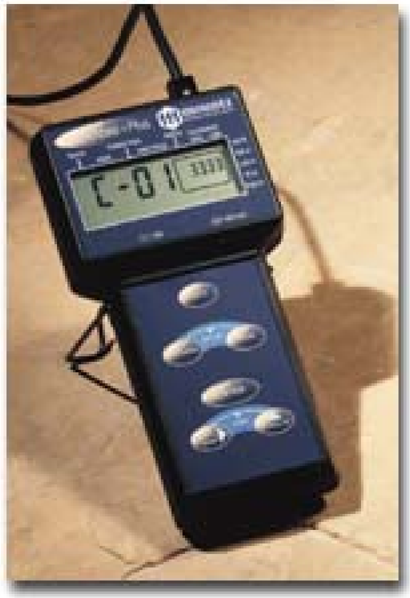

Figure 12

Mountz, Inc. Wizard:

Figure 13

These units gather data that has to be downloaded to a PC at a later time in order to input data to a software package that tells the user whether or not the wrench is in or trending out of tolerance. Handheld units are good for auditing, but do not lend themselves well to real-time verification during assembly. Ideally, the data must be transmitted directly from the transducer to the PC so that the data is plotted real-time on a control chart that will alert the assembler to out of control conditions.

Another area in which the ideal system design criteria cannot yet be met is in the area of non-encumbrance. Wireless technology is offered in some wrench and transducer products and would be the ideal method for transmitting transducer data to a base station on the workbench, which would fulfill the requirement to keep from encumbering the assemblers. However, the technology is only available in a few systems, like the Sturtevant Richmont PTV FM System and the Mountz, Inc. TAAMS series. The TAAMS series is designed to only transmit fastener count data, not fastener torque data so that option falls well short of the requirement. The Sturtevant Richmont PTV FM System appears to meet each of the customer requirements except that the FM transmissions violate the ordnance safety policies at RMS and cannot be used where Class 1.4 Electro-Explosive Devices are stored or assembled, and 1.4 devices are present in nearly all locations at RMS where this system could be used.

Sturtevant-Richmont PTV FM System:

Figure 14

Mountz, Inc. TAAMS:

Figure 15

While it is important in some applications to keep count of the fasteners and ensure the proper number have been installed, the technology to transmit torque data is only available in a system not authorized for use in our factories. In fact, the wrench/transducer offered by Sturtevant-Richmont is able to transmit both torque and count data, unlike the TAAMS, giving an added quality assurance once the FM transmissions obstacle is overcome.

Sinc the ideal system is currently unavailbale for use at RMS, the quote included below is for the Mountz, Inc. system that would function as close as currently possible to the ideal real-time system on the JSOW Missile manufacturing line at RMS:

mountz
the torque tool specialists®

QUOTATION
7182002

Raytheon		Date:	07/18/02
		Contact:	Gary Irvin
		Telephone:	
Tucson, AZ		Fax:	
		E-mail:	glirvin@raytheon.com

Mountz is pleased to respond to your request for quotation on the following quality torque products:

Qty	Model No.	Item No.	Description	Unit Price	Extension
4		065076	Wizard System	$1,995.00	$7,980.00
4		065081	Holster	$28.00	$112.00
1	RTSX10i-H	170036	Rotary Transducer	$3,000.00	$3,000.00
4	RTSX50i-H	170015	Rotary Transducer	$2,765.00	$11,060.00
1	RTSX100i-H	170016	Rotary Transducer	$2,675.00	$2,675.00
2	RTSX200i-H	170017	Rotary Transducer	$3,765.00	$7,530.00
4		065138-W	RTSX Cable to Wizard	$118.00	$472.00
1	SMX25i	071008	Torque Socket Transducer	$1,035.00	$1,035.00
1	SMX100i	071000	Torque Socket Transducer	$950.00	$950.00
3	SMX200F	071001	Torque Socket Transducer	$950.00	$2,850.00
2	SMX500F	071002	Torque Socket Transducer	$1,035.00	$2,070.00
7		770288	SMX Cable to Wizard	$118.00	$826.00
Prices Firm For 30 Days				Total	$40,560.00

FOB:	Shipping Point
Terms:	Net 30 Days with Approved Credit, [Credit Card, COD, Prepay]
Delivery:	

If we can assist you in any way further, please do not hesitate to contact us.

Sincerely,

Mountz, Inc.

Dan Flanigan		Telephone:	303-717-5640
Dan Flanigan		E-mail:	daniel.flanigan@mountztorque.com
Sales Representative		Website:	http://www.etorque.com

Figure 16

CHAPTER 5

AN INTERIM FASTENER TORQUE CONTROL SOLUTION

Until technology increases allow the commercial availability of a true real-time fastener torque verification system at a reasonable cost, as described in Chapter 5, an interim solution to the RMS Fastener Torque Control issue must be explored. This interim system consists of installing a Torque Analyzer / Verifier system on a work bench in the factory area and allowing the assemblers to periodically check the torque tools to ensure they are operating within tolerance.

In the JSOW Factory Area pictured below, the area is small enough to only require a single Torque Analyzer / Verifier system at a single yet central location identified by the red oval with a white X in the middle.

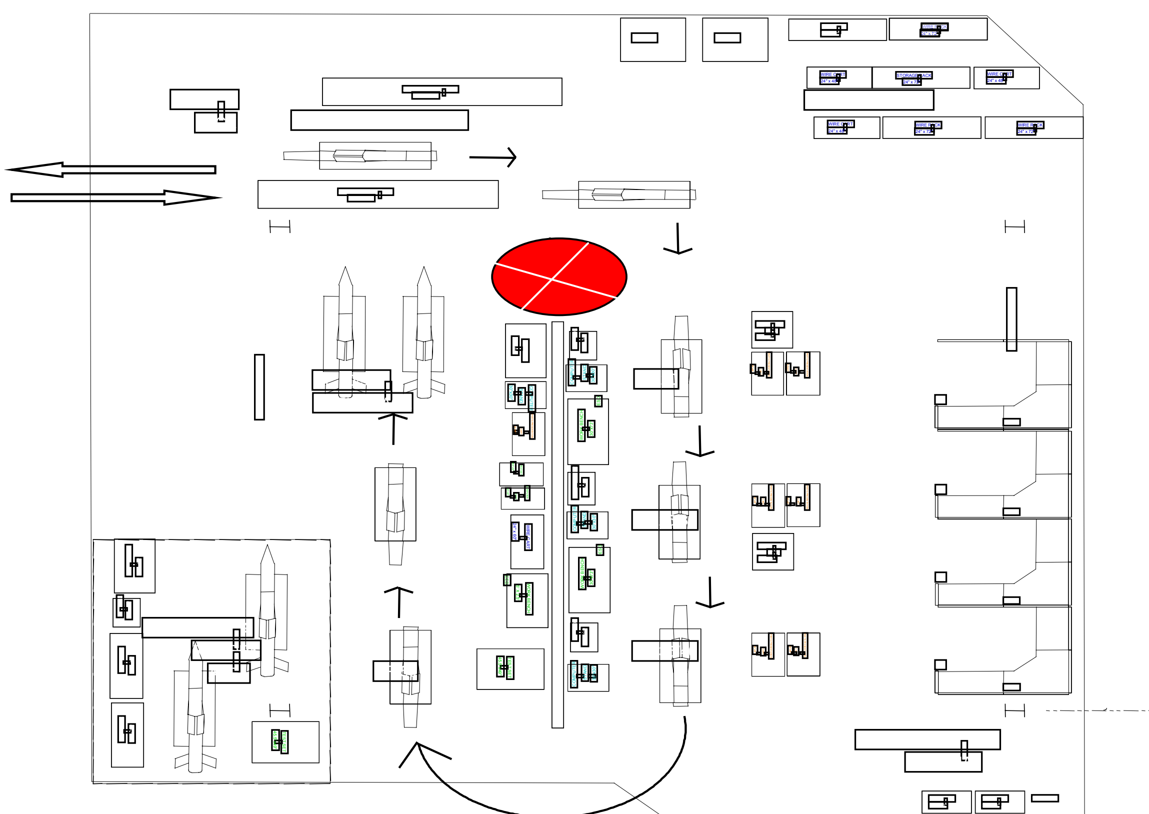

Figure 17

These periodic checks will not take the place of periodic calibration, but will allow the assembler to check much more frequently than the current calibration systems do. Conceivably, the assemblers could verify their torque tools prior to every use, but this seems to be somewhat burdensome because the assemblers have access to tens if not hundreds of tools and could find themselves spending more time verifying than assembling.

Since the goal is to reduce the risk of delivering nonconforming products to customers, it seems that a weekly torque tool verification would be sufficient. A weekly verification plan could be implemented so that once per week the assemblers are asked to verify the function of each of their calibrated torque tools. After this verification activity, any torque tools found to be out of tolerance could be removed from the factory and forwarded to Metrology for verification and repair / replacement. Meanwhile, the products on which the nonconforming torque tools were used could be segregated and reworked prior to reaching the customer. The existing system of periodic calibration with no interim verification process imparts the risk of several months of nonconforming hardware in the customers' hands when the nonconforming torque tool is discovered at the end of the calibration interval. This interim system of weekly verification limits that risk to one week's worth of production and in most cases that production will not have been sold to the customer at the time of nonconforming torque tool discovery.

The Torque Analyzers / Verifiers are commercially available and are, in a lot of cases, the same equipment used by the Metrology Department for periodic calibration. The following is a quote from Mountz, Inc. for a Torque Analyzer / Verifier system to outfit the JSOW Missile factory production line and represents a fairly reasonable cost for the risk mitigation that would result from its use:

mountz
the torque tool specialists®

QUOTATION
5302002DF

Raytheon (Tucson)		Date:	05/30/02
		Contact:	Merle Sievers
		Telephone:	
Tucson, AZ		Fax:	
520-663-8233		E-mail:	mesievers@ratheon.com

Mountz is pleased to respond to your request for quotation on the following quality torque products:

Qty	Model No.	Item No.	Description	Unit Price	Extension
1	TL50i	068072	TorqueLab Analyzer 5 -50 lbf.in	$1,995.00	$1,995.00
1	BMX160z	075220	Torque Reaction Transducer 1 -10 lbf.in (16 - 160 ozf.in)	$1,385.00	$1,385.00
1	BMX100i	075203	Torque Reaction Transducer 10 - 100 lbf.in	$1,110.00	$1,110.00
1	BMX 250F	075208	Torque Reaction Transducer 25 - 250 lbf.ft	$1,400.00	$1,400.00
3		065145-XD5	Cable connectors from BMX to Torque Lab	$118.00	$354.00
1	RDA-100i	063973	Run Down Adapter for BMX 100i	$237.00	$237.00
1	RDA-250F	063982	Run Down Adapter for BMX 250F	$487.00	$487.00
Prices Firm For 30 Days				Total	$6,968.00

FOB:	Shipping Point
Terms:	Net 30 Days with Approved Credit, [Credit Card, COD, Prepay]
Delivery:	

If we can assist you in any way further, please do not hesitate to contact us.

Sincerely,

Mountz, Inc.

Dan Flanigan		Telephone:	303-717-5640
Dan Flanigan		E-mail:	daniel.flanigan@mountztorque.com
Sales Representative		Website:	http://www.etorque.com

Figure 18

CHAPTER 6

ADDITIONAL IMPROVEMENT OPPORTUNITIES

The main focus of this report is to outline the need for and to describe a system of Fastener Torque Control that will prevent fastener out of tolerance conditions at RMS. As described earlier, there are no components commercially available currently to construct a system that meets all of the design criteria. It is anticipated that these components will be developed over time and that at some future point it would make sense to purchase and install the system. An interim system was also described, one in which a weekly verification system could ensure that the torque tools are operating within tolerance, and one in which the risk of delivering nonconforming hardware to customers would be greatly reduced from the current state. However, all of these systems still require some capital investment and would take some time to install. Additionally, these systems are designed to prevent out of tolerance conditions. There are some additional improvement opportunities, discovered during the research for this project, that focus on how RMS functions in cases when the current periodic calibration system identifies out of tolerance conditions, and those are described herein.

The periodic calibration system in place at RMS is such that torque tools are calibrated by the Metrology Department and tagged with a due date for next calibration. The calibration intervals are range from 1 month to 1 year in most cases and occasionally when torque tools are recalled for periodic calibration they are found to be out of tolerance. When this out of tolerance condition is discovered, the Metrology Department issues a Notice of Out of Tolerance Condition (NOTC) to the program that was using the out of tolerance torque tool in its factory area. As late as the first quarter of 2002, the NOTC system was a paper process, so that the Metrology Lab had to fill out the top portion of the NOTC Form and forward it via inter-office mail to the appropriate program (tool-user). After the program assigns an engineer to investigate the impact this out of tolerance torque had on production over the past 1 month to 1 year (potentially), the engineer would fill out the bottom portion of the NOTC Form with his investigative report or "disposition", take appropriate action according to whether or not hardware was jeopardized, and forward the 3-ply form to the Program Quality representative for review. After the Quality representative would review the form and the disposition, he would (hopefully) approve the disposition and forward the form back to Metrology to close out the NOTC Form. A flow-chart of this process is included below:

Previous (1st Quarter 2002) Process

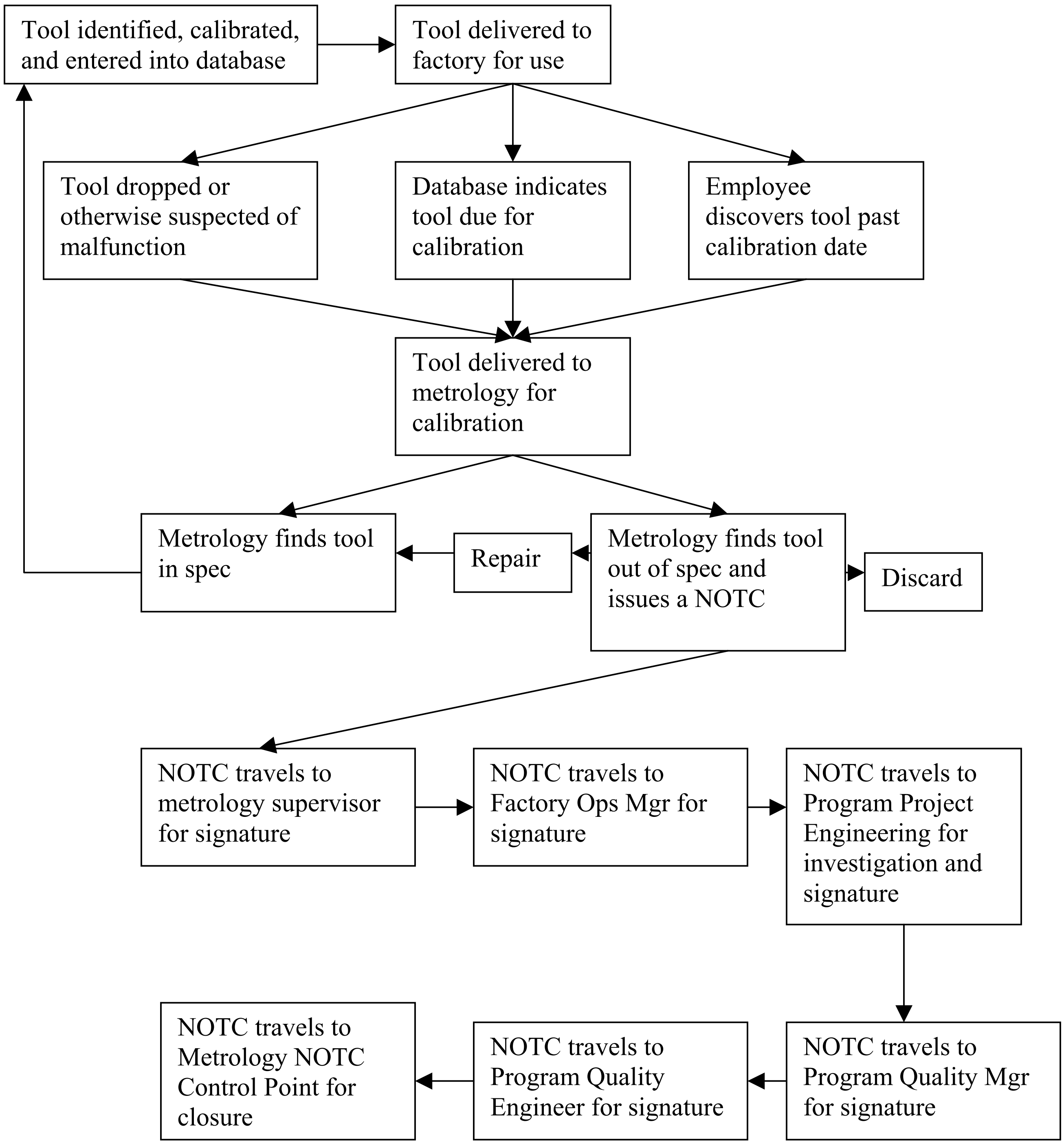

Figure 19

The current process, implemented in the 2nd Quarter of 2002, is based on the implementation of an electronic Notice of Out of Tolerance Condition system, known as the eNOTC System. It is similar to the previous paper process but with some advantages because of its electronic distribution method.

Once a torque tool is purchased it is given an identification tag and entered into the Metrology database of torque tools. The tool is then delivered to the production program that purchased it and entered into the production process. If the tool is subsequently dropped or otherwise becomes out of adjustment, or if the calibration interval expires, the tool is returned to the Metrology Lab for calibration and re-certification. If Metrology determines the tool is still operating within a +/- 4% range of the nominal settings, the tool is returned to the factory floor for production use and is given another calibration due date similar to the previous calibration interval. If the tool is found to be out of the +/- 4% tolerance range, the wrench is either repaired or adjusted back to nominal and returned to the production area with a new calibration due date tag and possibly a reduced calibration interval. Concurrently, an eNOTC is generated and transmitted via e-mail to the responsible program, with copies to the investigating engineer, factory supervisor, and quality representative. The responsible engineer conducts the investigation and completes the eNOTC with appropriate documentation of the program impact resulting from the out of tolerance condition, and forwards the eNOTC to the quality engineer for review and approval. When approved, the quality engineer forwards the eNOTC to the eNOTC Control Point and the eNOTC is closed out.

The advantages of this new system are many, and include speedier routing, automatic tracking of the eNOTC status, and easier monitoring for proper engineering investigations. While not without a few hiccups, this new system is effectively improving the process once out of tolerance conditions are discovered.

Current (2nd Quarter 2002) Process

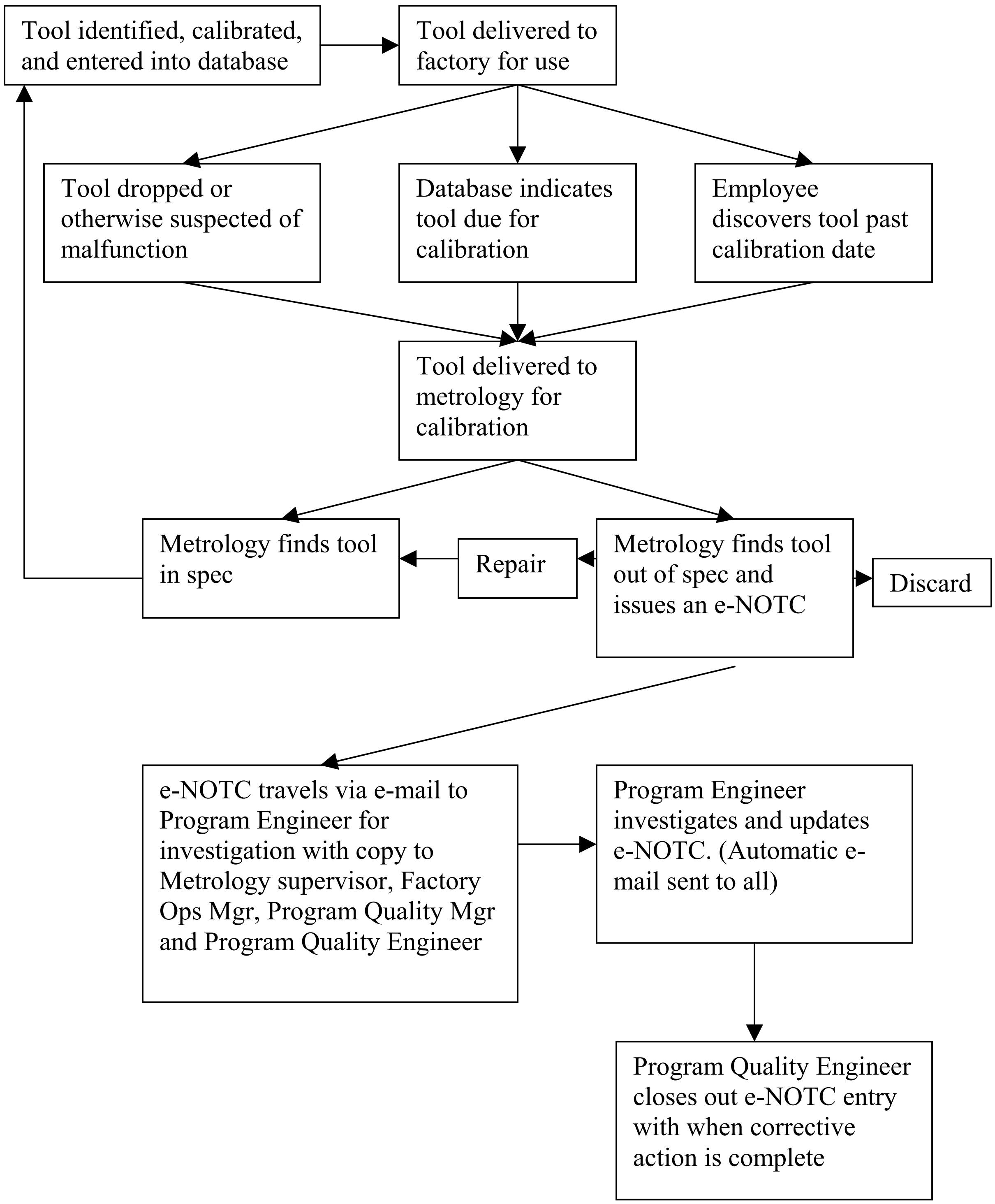

Figure 20

CHAPTER 7

Related Work

During the research and analysis of the RMS NOTC data from 2001, it was determined that approximately one-third (32.3%) of the NOTCs generated were generated unnecessarily. These 141 NOTCs were generated because the torque wrenches (hand-driven) were found out of tolerance by exceeding the Metrology Department standard of +/- 4% from the nominal setting. The NOTCs were distributed to the programs that owned and used the torque wrenches in their respective factory areas, and the engineers responsible for conducting the investigations spent several hours each reading product drawings and identifying fasteners that were possibly fastened with the suspect torque wrenches. After all of the fasteners were identified, the engineers had to determine what negative effects would have resulted if the out of tolerance wrenches were used on these fasteners. In all of these 141 instances, the engineers determined that while the as-found value for the suspect wrenches exceeded the 4% standard, the drawing tolerances for the fasteners on the products were wide enough that the product drawing tolerances were not violated. These investigations that resulted in a "No Hardware Jeopardized " finding were merely a waste of time, and in many cases several hours each were expended in the effort.

Ideally, an out of tolerance notification system should synchronize the torque wrench tolerance standard with the product design tolerances (plus room for natural variation in readings) to prevent “false” notifications that result in unnecessary investigations. Requests to change the +/- 4% hand-driven torque tolerance standard to a more meaningful +/- 10% or +/- 15% tolerance are nothing new to RMS, based on interviews with Metrology Department personnel. Walter Wiley, a Quality Engineer in the RMS Metrology Department provided copies of several memos that were circulated within Hughes Aircraft back in 1990, 1991, and 1996 before Hughes was purchased and consolidated with several other companies into what would become Raytheon Missile Systems. These memos were provided as a result of a discussion involving this author’s inquiry into whether or not expanding the hand-driven torque wrench tolerance from +/- 4% to +/- 10% to eliminate unnecessary NOTC investigations would be poorly or well received within the Metrology Department. Mr. Wiley’s response was that the issue had been raised before, only the tolerance expansion was never adopted for reasons unknown to him.

In one memo, from B.K. Lagasse to K.Craig, (engineers at Hughes) dated February 27, 1990, Mr. Lagasse responds to a previous memo requesting a tolerance expansion stating, “Although concurring with the philosophy of redefining the torque callout format, as stated in the AVO (Avoid Verbal Orders), I would be uncomfortable with increasing the tolerance range beyond +/- 10% at a maximum” (Appendix A). Nearly one year later, another memo from K. Craig to B. Lagasse, dated February 8, 1991, makes a request on the same subject, stating, “Calibration costs can be reduced if the product tolerance is relaxed to plus or minus 15%. At present the tools are rejected if plus or minus 4% of the tool specification is exceeded. A Calibration Data Feedback (CDF) form (NOTC pre-cursor) is issued to the owner of the equipment when the tool is found discrepant. The owner of the tool is to determine what affects to the hardware resulted in use of the defective tool. This requires approximately 4 hours minimum per CDF for the initial investigation. When hardware is impacted by use of the discrepant tool, additional costs are incurred by the responsible program. Note: A greater tolerance on the hardware requirement would reduce the CDFs written, better ensure compliance to calibration specifications, lengthen calibration frequency cycles, and passing customer audits for tools of this type" (Appendix B).

In another memo 5 years later dated June 26, 1996, Mr. Wiley himself proposed an increase in the torque wrench tolerance, stating, "I would like to propose a change to the 4% tolerance applied to torque wrenches. As you know, we have been experiencing a high reject rate resulting in considerable cost to the programs responding to NOTCs. The response to the NOTCs invariably states that the amount out of tolerance was not significant to the production hardware." He also goes on to state that other (Hughes) facilities have expanded the tolerance with no adverse affects, stating "After experiencing the same problems, and evaluating the quality impact to the programs, the Primary Standards Lab in El Segundo increased their tolerance to +/- 10%. The change was effective in 1990 with no significant affect (sic) on product quality to date. I've attached three IDCs documenting their rationale and the benefits expected" (Appendix C).

Clearly there is a commonly held belief among some engineers RMS that the +/- 4% torque wrench tolerance standard should be increased to at or near +/-

10%, though attempts to do so in the past have failed. Since there is no record detailing the decision making process used in rejecting the requests in 1990, 1991 and 1996, this author has formally recommended to the Metrology Department to once again explore the expanded tolerance issue and if it is again rejected, to document the reasons why. At least if the question is asked again in the future there will be documentation that will put an end to the requests. Otherwise, if the request is approved and the standard changed, one would expect to see significant cost savings as a result of many fewer NOTC investigations.

CHAPTER 8

CONCLUSION

Research into the Year 2001 NOTC data at RMS and personal experience as a Quality Engineer in the NOTC review process for the JSOW Program have led this author to believe that there is a clear need for improvement in the Fastener Torque Control System in place at RMS. There are others who share these beliefs, as there are currently at least 2 known projects in other weapons programs at RMS Tucson to explore the use of Torque Analyzers on production lines that have begun as a result of work accomplished in this project. The NOTC data showed that RMS needs a faster system for the Metrology Department to communicate torque wrench Out of Tolerance Conditions to the programs that own the torque wrenches. The eNOTC System was implemented to satisfy this urgent need. The NOTC data shows that too many NOTCs are being generated and reveal that, upon comparison of the as found torque wrench values and the product design tolerances, the product design tolerance was never violated. These investigations waste valuable resources and would never have begun had there been a closer match between the Metrology +/- 4% standard and the standard +/- 10% drawing tolerance standard. The NOTC data also shows that the engineers and non-engineers that conduct the investigations need better guidance because the NOTC dispositions contain some faulty logic that could lead to nonconforming products escaping into the customers' hands. Also, the dispositions have, in many cases, failed to include documented evidence (required by RMS procedure) that a Material Review Board has convened to approve the "Use As Is" disposition in cases where drawing tolerances are violated but the product will still function as designed.

The improvements to the RMS Fastener Torque Control System can be implemented to varying degrees, depending on technology availability and funding availability. Some of the relatively easy improvements have already been implemented, like the eNOTC system and its associated user interface that forces investigators to document their Material Review Board activities in cases of Use As Is dispositions. The e-NOTC system also includes the flowchart or template that leads investigating engineers step by step through a proper and well documented engineering investigation. However, the greatest improvement opportunity will be the implementation of the Real Time Fastener Torque Control System, which allows the assembler to receive immediate feedback as to whether or not the fasteners are being installed with the correct torque value. This real time system will prevent out of tolerance conditions, eliminate the need for periodic calibration of torque wrenches and eliminate the eNOTC system once fully implemented. In the mean time, the improvement opportunity that bears the most fruit for the least amount of capital resources is the installation of Torque Analyzers at production workstations and implementation of a weekly torque tool verification system. This will reduce the risk of nonconforming fasteners to a maximum of one weeks' worth of production, a huge reduction in risk from compared to the current Fastener Torque Control system.

Lastly, one must not overlook the intangible effect a system of greatly improved Fastener Torque Control will have on both the assembly force and the engineering community, the groups who team together the most in bringing products through design, through manufacturing and into the hands of the customers. These people will respond very favorably to being given improved tools and systems that will allow them to increase their product quality and improve their confidence in building the products that they take a great amount of pride in building and selling every day to a very appreciative customer base.

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NOMENCLATURE

AVO – Avoid verbal Orders

ESD – Electro Static Discharge

FM – Frequency Modulation

ISO – International Standards Organization

JSOW – Joint Stand Off Weapon

MRB – Material Review Board

MGR – Manager

NCMD – Non Conforming Material Document

NOTC – Notice of Out of Tolerance Condition

OOT – Out Of Tolerance

OPS – Operations

PC – Personal Computer

PTV – Programmable Torque Verifier

RMS – Raytheon Missile Systems

RF – Reliability Factor

SPC – Statistical Process Control

TAAMS – Torque Activated AM Signal

UAI – Use As Is

Raytheon

Notification Of Out-Of-Tolerance Conditions

18983RMS (8/00)

(Instructions On Reverse Side)

No 13619

I. Measurement And Test Equipment Found Out-Of-Tolerance During Calibration

1a. ID No.	1b. Syn No.	2a. Description (Check One) Electrical ☐ Dimensional ☐
2b. Enter Noun Description	3. Manufacturer	
4. Model No.	5. From T.P.	6. Part No.
7. Operation No.	8. Owning Dept. Name	9. Source Code
10. Equipment Location	11. Calibration Date	12. Previous Calibration Date
13. No. Of Calibrations	14. Reliability Factor	15. Calibration Interval

II. Description Of Out-Of-Tolerance Conditions

16. Procedure Used For Calibration

17. Paragraph/Step/Detail	18. Specification	19. Value Found

Calibrated By →	20. (Print) First Name	Last Name			
Approved By →	21. (Print) First Name	Last Name	22. Source Code	23. Extension	24. Date
Forward To →	25. (Print) First Name	Last Name	26. Mail Station	27. Extension	28. By (Date)

III. Using Activity Report ■ See Attached

29.

Investigator →	30. Investigator Signature	31. Source Code	32. Extension	33. Date

IV. Quality Review

Forward To →	34. (Print) First Name	Last Name	35. Mail Station	36. Extension	37. By (Date)
Approved By →	38. Quality Review Signature		39. Source Code	40. Extension	41. Date
Forward To →	42. NOTC		43. Mail Station 811	44. Extension 43755	45. By (Date)

Distribution: White - Metrology Department NOTC Control Point;
Canary - Program Quality Assurance Manager; Pink - Project/Functional Manager

46. Date Rec'd (Metrology Use)

INTERDEPARTMENTAL CORRESPONDENCE

HUGHES

To: K. Craig
Org: 79-12

c: S. Goldenberg
G. N. Morrison
A. L. Lena
T. Curry

Date: 27 February 1990
Ref: 722631/1318

Subject: Comments on Torque Callout AVO

From: B. K. Lagasse
Org: 72-26-31

Bldg: E01 MS: D102
Loc: EO Phone: 616-0919

REFERENCE: AVO, "Screw Fastener Torque Change Request-Engineering Design Tolerances and Manufacturing Tools", Craig to Lagasse, dated 08 February 1991.

I have reviewed the referenced AVO and I am in general agreement, with one exception: I strongly urge that the stated tolerance level of 15% be reduced to no more than 10% (i.e., mean +/-10%). Current producibility practice is to show a high-low range of recommended torques (e.g., 20-22 in-lb), and, in general, the ranges incorporate an implied "tolerance" of +/- 5%. Because the torque call-out is governed by the maximum allowable torque, the effect of increasing the tolerance band would be to reduce both the "mean" and "minimum" value of torque, thus increasing, by a substantial amount, the resultant bolt preload range.

In structural analysis, it is always desirable to have the smallest possible bolt preload range, to give the maximum flexibility in fastener choice (size, number, strength, type of insert, etc.). Increasing the bolt preload range limits this flexibility. To be sure, in many situations, this aspect may not be significant; however, there are definitely designs where minimum possible bolt preload range is crucial, and can drive the design configuration.

Although concurring with the philosophy of redefining the torque callout format, as stated in the AVO, I would be uncomfortable with increasing the tolerance range beyond +/- 10% at a maximum.

B. K. Lagasse

B. K. Lagasse, Scientist/Engineer
Structural Mechanics Department
Product Analysis Laboratory

/blo

TO: BRUCE LAGASSE 72-26 EO E1 D102 60919
FROM: KEITH CRAIG 79-12-80 EO E4 M137 60183
Keith Craig
2/8/91

SUBJECT: SCREW FASTENER TORQUE CHANGE REQUEST-ENGINEERING DESIGN TOLERANCES AND MANUFACTURING TOOLS

We (reference John Barr, Jim Somers, Ted Curry, and Keith Craig) request a change in the torque requirements on engineering drawings.
We request that torque values be specified as a nominal value with a plus or minus tolerance. This tolerance to be equivalent to plus or minus 15% of the nominal value.
In addition, we would like to understand what affects, if any, to the hardware would result?

The methods commonly used to specify torque requirements on engineering drawings today are as follows:

1. (SN) TORQUE [Description] [(Item)] (Value 1) TO (Value 2) (Unit) reference standard engineering note # 077

2. Torque to (value) plus or minus (value)

3. Requirements vary from 4 to 20% (see figure 1).

If this requested change is agreed to we will request a change to standard engineering note # 077. It may also be necessary to issue a laboratory technical bulletin to establish the plus or minus 15% tolerance as a standard.

SUGGESTED CHANGE TO:

1. (SN) TORQUE [Description] [(Item)] TO (Value) plus or minus 15%
IE: (SN) TORQUE Description (Item) TO 10 inch pounds, plus or minus 1 1/2 inch pounds. See figure 4, suggested change to standard engineering note #077.

The above change is requested for the following reasons:

1. Preliminary investigations to determine the repeatability of mechanical torque limiting hand tools results in a value of

approximately plus or minus 10% (plus or minus 3 sigma). The data distributions do not appear normal, shifting runs occur, probably due to changing frictional force patterns within the mechanism (see figures 2 and 3).

2. Air operated torque wrenches, limiting type, click type, and adjustable type tools are generally used to support high production rates. In areas where the larger direct reading type tools cannot be used due to access or the inability to see the dial. These types of tools are used on almost all current product lines. Modern low inertia design pnuematic or electric torque drivers may be needed for high rate production and suppliers quote plus or minus (15) percent repeatability (6 sigma).

3. The "largest quality problems associated with the calibration of tools" are torque tools. This problem would be reduced from approximately 75/1000 tool failures to 6/1000 tool failures for click type torque tools and less than 1/10,000 tool failures for direct reading dial type torque tools, provided the engineering requirement is plus or minus (15) percent.

4. "Statistical Process Control" may approach the 6 sigma level for torque tools/product torque requirements if the changes requested can be approved. This level of quality is directly supportive of the requirements identified in the Contractors Performance Certification Program, $(CP)^2$.

5. Calibration costs can be reduced if the product tolerance is relaxed to plus or minus 15%. At present the tools are rejected if plus or minus 4 % of the tool specification is exceeded. A Calibration Data Feedback(CDF) form is issued to the owner of the equipment when the tool is found discrepant. The owner of the tool is to determine what affects to the hardware resulted in use of the defective tool. This requires approximatley (4) hours minimum per CDF for the initial investigation. When hardware is impacted by use of the discrepant tool, additional costs are incurred by the responsible program. NOTE: A greater tolerance on the hardware requirement would reduce the CDFs written, better ensure compliance to calibration specifications, lengthen calibration frequency cycles, better ensure compliance to calibration specifications, and passing customer audits for tools of this type.

AVOID VERBAL ORDERS

HUGHES

Subsidiary of
GM Hughes Electronics

TO: Joe Cartier cc: R. Kalal
M. Mileski
J. Nuechterlein

ORG: 5D5600

DATE: 26JUN96

SUBJECT: Torque Calibration Tolerance

FROM: W. Wiley
ORG: 5D8910

BLDG: 811 **M/S:**
LOC: TU **EXT:** 44452

I would like to propose a change to the 4% tolerance applied to torque wrenches. As you know, we have been experiencing a high reject rate resulting in considerable cost to the programs responding to NOTCs. The response to the NOTCs invariably states that the amount out of tolerance was not significant to the production hardware.

After experiencing the same problems, and evaluating the quality impact to the programs, the Primary Standards Lab in El Segundo increased their tolerance to ±10%. The change was effective in 1990 with no significant affect on product quality to date. I've attached three IDCs documenting their rationale and the benefits expected.

I would like to propose a similar change from ±4% to ±10% here in Tucson. I expect there will be some applications where this would exceed the planning tolerance and we would have to allow for exceptions. Would you please arrange a meeting with the affected program assembly engineers where we could present this proposal and seek their concurrence.