Measurement Systems Analysis (MSA)

INSTRUCTION GUIDE

3/8/2017

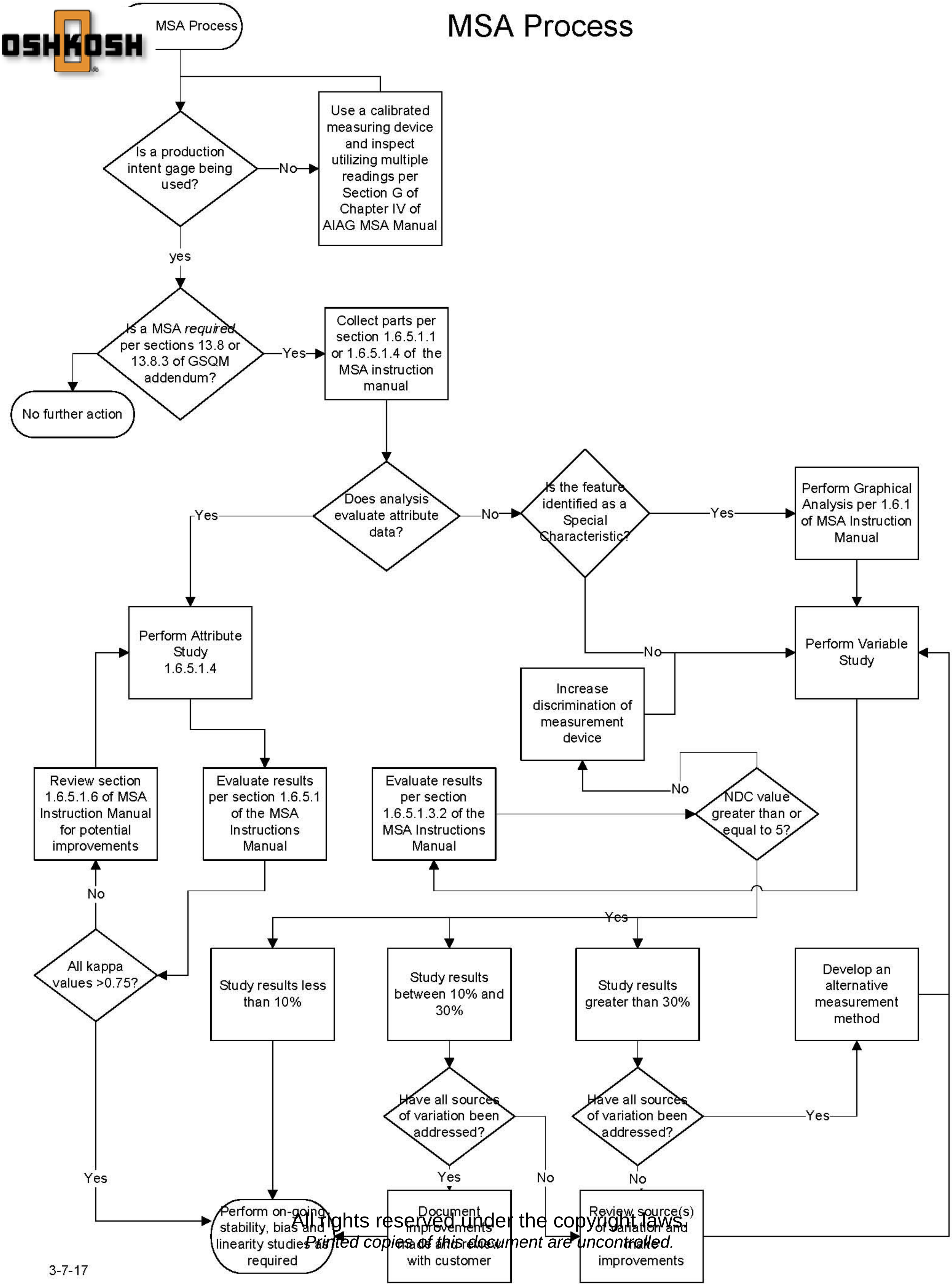
This guide contains three components:

1. The **MSA Flowchart** is intended to assist in determining the next steps in fulfilling the MSA requirements, addressing the various types of measurements that may be encountered. The flowchart will direct the participant to various locations in the instruction guide, to assist in fulfilling the requirements for their particular situation.

2. The **MSA Procedures** is a comprehensive body of knowledge that is intended to cover the various MSA requirements that may be encountered.

3. The **MSA Report** is intended to serve as a means for a MSA participant to document all of the inputs that may have influenced the output (results) of the study. It may assist in determining the root cause(s) if a MSA component fails to deliver the desired results. The last column is intended to provide some additional guidance for the participant on potential future action.

MSA Process



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Measurement Systems Analysis (MSA)

1 General

1.1 The purpose of MSA is to quantify the amount of accuracy and variation that exists in the measuring process

1.2 MSA will assist in enabling the supplier to distinguish acceptable from unacceptable product, improve processes, and comply with Oshkosh requirements

1.3 This guide is intended to support the information contained in the Automotive Industry Action Group (AIAG) MSA Reference Manual.

1.4 Definitions

1.4.1 **Bias** – The difference between the observed average of measurements and a reference value. Bias is evaluated and expressed at a single point within the operating range of the measurement system.

1.4.2 **Kappa** -- Statistical measure of inter-rater agreement for qualitative (attribute) items, taking into account the agreement occurring by chance.

1.4.3 **Linearity** – The difference in bias errors over the expected operating range of the measurement system.

1.4.4 **Stability** -- Addresses the necessary conformance to the measurement system standard or reference over the operating life of the measurement system.

1.5 Gage Requirements

1.5.1 The gage shall be calibrated in accordance with a documented calibration procedure

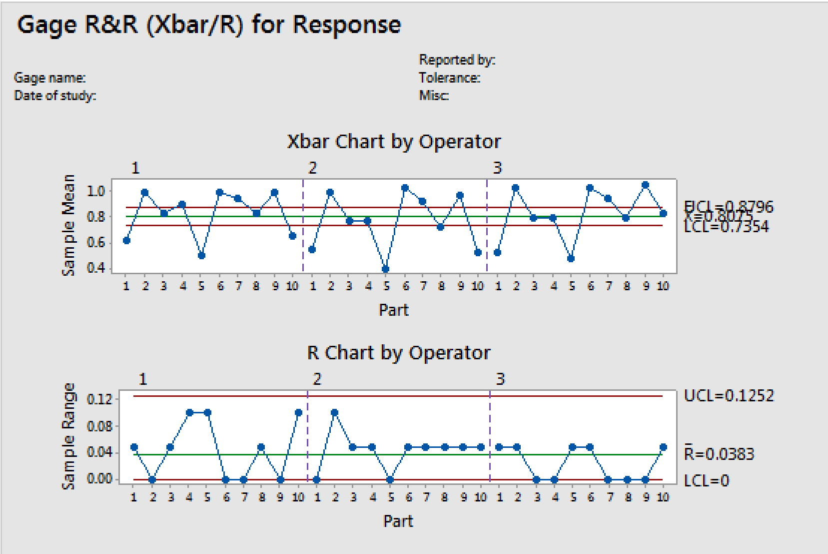
1.5.2 Graduations on the measurement device should be one-tenth of the tolerance range or smaller (for example of a micrometer can measure to the nearest 0.001, it must not be used to measure a feature with a tolerance of less than 0.010). For critical characteristics this could restrict the one-tenth rule to the process range rather than the tolerance range.

1.5.3 Measurements should be recorded to one decimal place smaller than the tolerance. (For example if the tolerance is 0.010 the measurements should be reported to a minimum of three decimal places- x.xxx).

1.5.4 Analog devices should be recorded to ½ the smallest graduation. For example if the smallest scale graduation on the caliper dial is 0.001”, then the measurement results should be recorded to 0.0005”.

1.6 MSA Components

1.6.1 **Graphical Analysis of Results**: This analysis should be evaluated prior to any other statistical analysis. A template for this can be found in the PPAP workbook "GR&R X&R".



1.6.1.1 Interpretation of Range chart:

1.6.1.1.1 The range control chart is used to determine whether the process is in control. The ranges of multiple readings by each appraiser on each part are plotted on a standard range chart including the average range and control limits.

1.6.1.1.2 If all ranges are in control, all appraisers are performing the measurement task in similar way.

1.6.1.1.3 If one appraiser is out of control, the method used differs from the others.

1.6.1.1.4 If all appraisers have some out of control ranges, the measurement system is sensitive to appraiser technique and needs improvement to obtain useful data.

1.6.1.2 Interpretation of Average chart:

1.6.1.2.1 The averages of measurements by each appraiser by each part are plotted by appraiser.

1.6.1.2.2 This plot will assist in determining consistency between appraisers.

1.6.1.2.3 Approximately 50% or more of the averages should fall <u>outside</u> the control limits.

1.6.1.2.4 If less than 50% fall outside the control limits then either the measurement system lacks adequate resolution or the sample does not represent the expected process variation.

1.6.2 Stability

1.6.2.1 Study design/analysis:

1.6.2.1.1 Obtain sample(s) and establish the Reference Value relative to a traceable standard. Depending on the focus of the study it may be desirable to have samples at the low end, middle, and high end of the specification.

1.6.2.1.2 On a periodic basis measure the sample(s) 3 to 5 times. The sample size and frequency should be based on understanding of the measurement system. Some factors to consider are calibration cycle, time between repairs, operating condition stress, environment changes etc.

1.6.2.1.3 Plot the data on and Xbar and Range control chart in time order.

1.6.2.1.4 Analyze the control chart to identify if there are any points out of control. Identify cause of out of control point(s), make correction and continue to monitor

1.6.3 Bias

1.6.3.1 Study design:

1.6.3.1.1 Control chart analysis should indicate that the measurement system is stable before the bias is evaluated.

1.6.3.1.2 Obtain a sample and establish its reference value relative to a traceable standard. If one is not available, select a production part that falls in the mid-range of the production measurements and designate it as the master sample. Note: The same part can be chosen if a stability study was completed.

1.6.3.1.3 Measure the part a minimum of 10 times in a controlled environment (gage room), and compute the average of readings. This average is used as the “reference value”.

1.6.3.1.4 Enter data into template

1.6.4 Linearity

1.6.4.1 Study design:

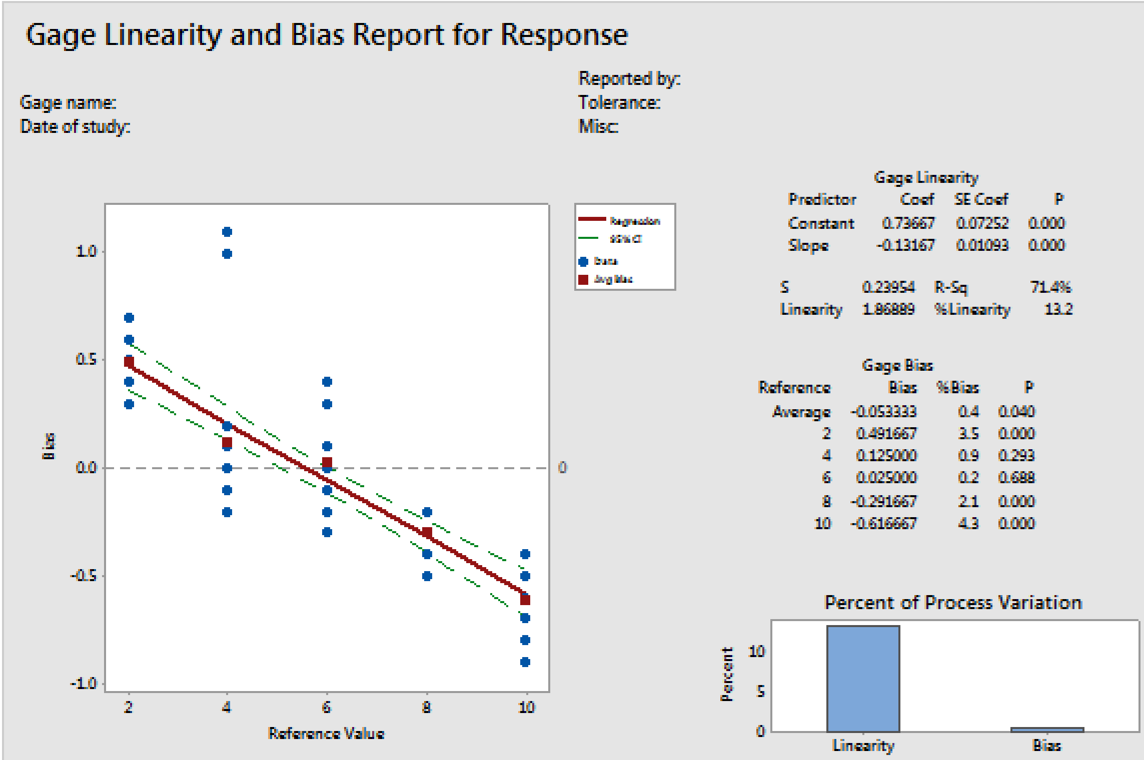
1.6.4.1.1 The collection of samples for this study expands on the collection used for the Bias study. Whereas the method used for the bias study choses a part from the mid-range of the production measurements, the linearity study expands this collection to include a minimum of 5 parts from the entire range of the production measurements.

1.6.4.1.2 Enter data into template

1.6.4.2 Study Results:

1.6.4.2.1 For the Minitab study results below (5) parts were chosen that represented the expected range of measurements. Each part was measured by layout inspection to determine its master measurement, and then one operator randomly measured each part 12 times.

1.6.4.2.2 Total Variation Study Variation from a Crossed Gage R&R study using the ANOVA was used as the input Process Variation (14.1941).



1.6.4.3 Interpretation of Linearity Results:

1.6.4.3.1 Because the R^2 value is high (71.4%), we can see that the relationship between the master part measurement and bias is close to linear. Therefore it is reasonable to assess linearity for this data set.

1.6.4.3.2 However since the % linearity is relatively large (13.2%), this indicates a problem. As can be seen from the graph, smaller parts tend to measure too high, while larger parts tend to measure too low.

1.6.4.3.3 A slope close to zero (horizontal line) indicates there is no linearity problem, while a slope that is not close to zero (vertical line) indicates a linearity problem. The greater the slope, the worse the linearity.

1.6.4.4 Interpretation of Bias Results:

1.6.4.4.1 The average bias of (-0.05333) and %bias (0.4) indicate that there is some variability due to bias. Also the p-value is 0.040. Because the p-value is less than the chosen level of significance (a-level), typically set at 0.05, we reject the null hypothesis that bias equals 0.

1.6.4.4.2 Possible causes of bias and linearity errors:

1.6.4.4.2.1 Instrument not calibrated properly at both the high and low end of the operating range

1.6.4.4.2.2 Error in one or more of the master part measurements

1.6.4.4.2.3 Worn instrument

1.6.4.4.2.4 Characteristics of the instrument design

1.6.5 Gage Repeatability and Reproducibility

1.6.5.1 Gage study design requirements

1.6.5.1.1 Variable method

1.6.5.1.1.1 Choose a minimum of 10 parts, 3 appraisers and 3 trials for the study. These parts should be chosen randomly from current production representative parts. Identify (number) each of the parts. There are factors that could impact the number of measurements taken. These could include:

1.6.5.1.1.1.1 Criticality of the feature measured- for instance, critical features may require additional measurements to increase the degree of confidence in the results. Additional parts are preferred, over additional appraisers or replicates.

1.6.5.1.1.1.2 Part configuration or availability-large/bulky parts or low volume parts may dictate fewer samples and more trials

1.6.5.1.1.1.3 There are some measurements where the appraiser to appraiser effect (reproducibility) can be considered negligible. These may include instances where a measurement device is loaded and secured by an automatic device. If there is any uncertainty in regard to this, multiple appraisers should be used in the initial study.

1.6.5.1.1.2 For critical features, a work instruction should be developed that provides specifics on how to perform the measurements. These specifics could include orientation of part, pressure applied to measurement device, mastering frequency of measurement device.

1.6.5.1.1.3 The appraisers should be selected from those that would normally perform this type of inspection.

1.6.5.1.1.4 The inspections should be made in random order. The appraisers should be unaware of which numbered part is being inspected.

1.6.5.1.1.5 Neither appraisers nor measurement devices should be changed during the duration of the study

1.6.5.1.1.6 Enter the results into Oshkosh worksheet labeled “GR&R” or a comparable template that is able to calculate using the tolerance or ANOVA method.

1.6.5.1.2 GR&R Var (Tol): used for measurements that are not identified as critical

Measurement Unit Analysis					% Tolerance (Tol)		
Repeatability - Equipment Variation (EV)							
EV	=	$R \times K_1$	**Trials**	**K1**	% EV	=	100 (EV/Tol)
	=	4.267 x 0.8865	2	0.8865		=	100(3.782/13.333)
	=	3.782	3	0.5907		=	28.37
Reproducibility - Appraiser Variation (AV)							
AV	=	$\{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2}$			% AV	=	100 (AV/Tol)
	=	{(8.500 x 0.5236)^2 - (3.782 ^2/(10 x 2))}^1/2				=	100(4.369/13.333)
	=	4.369				=	32.77
		Appraisers	**2**	**3**			
n = parts	r = trials	K_2	0.7087	0.5236			
Repeatability & Reproducibility (GRR)					% GRR	=	100 (GRR/Tol)
GRR	=	$\{(EV^2 + AV^2)\}^{1/2}$	**Parts**	**K_3**		=	100(5.779/13.333)
	=	{(3.782^2 + 4.369^2)}^1/2	2	0.7087		=	43.34
	=	5.779	3	0.5236	*Gage system needs improvement*		
Part Variation (PV)			4	0.4464			
PV	=	$R_P \times K_3$	5	0.4032	% PV	=	100 (PV/Tol)
	=	58.167 x 0.3145	6	0.3745		=	100(18.293/13.333)
	=	18.293	7	0.3534		=	137.20
Tolerance (Tol)			8	0.3378			
Tol	=	Upper - Lower / 6	9	0.3247	ndc	=	1.41(PV/GRR)
	=	(225 - 145) / 6	10	0.3145		=	1.41(18.293/5.779)
	=	13.333				=	4
					Gage discrimination low		

1.6.5.1.3 GR&R Var ANOVA: used for measurements that are identified as critical

Anova Report	Standard Deviation (σ)	% Total Variation	% Contribution
Repeatability (EV)	0.21	23.8%	5.6%
Reproducibility (AV)	0.23	25.9%	6.7%
Appraiser by Part (INT)	0.00	0.0%	0.0%
GRR	0.32	35.2%	12.4%
Part-to-Part (PV)	0.84	93.6%	87.6%

Note:

Tolerance = 6.00 Total variation (TV) = 0.9

Number of distinct data categories (ndc) = 3

Gage discrimination low

1.6.5.1.3.1 Study Results: GR&R Percentage

GRR Percentage	Decision	Comments
Under 10 percent	Generally considered to be an acceptable measurement system	Recommended, especially useful when trying to sort or classify parts or when tightened process control is required.
10 percent to 30 percent	May be acceptable for some applications	Decision should be based upon, for example, importance of application measurement, cost of measurement device, cost of improvement, repair or rework. Should be approved by the customer
Over 30 percent	Considered to be unacceptable	Every effort should be made to improve the measurement system. This condition may be addressed by the use of an appropriate measurement strategy; for example using the average result of several readings of the same part characteristic in order to reduce final measurement variation.

1.6.5.1.3.2 Interpretation of Results:
1.6.5.1.3.2.1 If repeatability is large compared to reproducibility, the possible causes may be:
1.6.5.1.3.2.1.1 The instrument needs maintenance
1.6.5.1.3.2.1.2 The gage may need to be redesigned to be more rigid
1.6.5.1.3.2.1.3 The clamping or location of gaging needs to be improved
1.6.5.1.3.2.1.4 There is excessive within-part variation

1.6.5.1.3.2.2 If reproducibility is large compared to repeatability, the possible causes may be
1.6.5.1.3.2.2.1 The appraiser(s) need to be better trained in how to use the measurement device
1.6.5.1.3.2.2.2 No work instruction is available to define a standard work procedure
1.6.5.1.3.2.2.3 The part is not being measured in a consistent location

1.6.5.1.3.3 Study Results : Number of distinct categories (ndc):
1.6.5.1.3.3.1 This statistic indicates the number of categories into which the measurement process can be divided. This calculated value should greater than or equal to 5.
1.6.5.1.3.3.2 If this value is less than 5, it may indicate a lack of discrimination as noted in 1.2.2. The solution may be to use a measurement device that has a resolution to be at most 1/10th of the total process six sigma standard deviation instead of the

traditional rule which is that the apparent resolution be at most 1/10th the tolerance spread.

1.6.5.1.4 Attribute method:

1.6.5.1.4.1 Choose a minimum of (30 parts for the study). Between 40% and 60% of the parts should be “Good” parts and the remaining should be “Bad” parts, as determined by an expert or other measurement method.

1.6.5.1.4.2 Identify (number) each of the parts.

1.6.5.1.4.3 For critical features, a work instruction should be developed that provides specifics on how to perform the measurements. These specifics could include orientation of part, pressure applied to measurement device, or distance and lighting to be used for visual assessments.

1.6.5.1.4.4 The appraisers should be selected from those that would normally perform this type of inspection.

1.6.5.1.4.5 The inspections should be made in random order. The appraisers should be unaware of which numbered part is being inspected.

1.6.5.1.4.6 Enter the results into Oshkosh worksheet labeled “GR&R ATT (Risk)” or a comparable template that is able to calculate a kappa value.

1.6.5.1.5 Interpretation of Results:

1.6.5.1.5.1 Values of kappa greater than 0.75 indicate good to excellent agreement; while values less than 0.40 indicate poor agreement.

A * B Crosstabulation

			B 0	B 1	Total
A	0	Count	17	3	20
		Expected Count	4.2	15.8	20.0
	1	Count	2	68	70
		Expected Count	14.8	55.2	70.0
Total		Count	19	71	90
		Expected Count	19.0	71.0	90.0

B * C Crosstabulation

			C 0	C 1	Total
B	0	Count	18	1	19
		Expected Count	4.2	14.8	19.0
	1	Count	2	69	71
		Expected Count	15.8	55.2	71.0
Total		Count	20	70	90
		Expected Count	20.0	70.0	90.0

A * C Crosstabulation

			C 0	C 1	Total
A	0	Count	18	2	20
		Expected Count	4.4	15.6	20.0
	1	Count	2	68	70
		Expected Count	15.6	54.4	70.0
Total		Count	20	70	90
		Expected Count	20.0	70.0	90.0

Kappa	A	B	C
A	-	0.84	0.87
B	0.84	-	0.90
C	0.87	0.90	-

DETERMINATION	
A x B	Good Agreement
A x C	Good Agreement
B x C	Good Agreement

1.6.5.1.6 Potential Action required:

1.6.5.1.6.1 If any of the appraiser comparisons determine that the agreement is less than 0.75 then the following items should be considered:

1.6.5.1.6.1.1 Are the risks of disagreement acceptable?

1.6.5.1.6.1.2 Do the appraisers need better training or a standardized procedure to follow?

1.6.5.1.6.1.3 Are the standards for good and bad objective and well understood?

1.6.5.1.6.1.4 Could the testing environment be improved?

DEFENSE SEGMENT INSTRUCTION GUIDE

Measurement Systems Analysis Report/Checklist

General Study Information

Item #	Item	Response	Study Comments	Comments Regarding Response
1	Supplier Name			Information only
2	Oshkosh part number, and drawing revision			Information only
3	Date(s) of Study			Information only
4	Location of Study			Information only
5	Gage type, model, serial number			Information only
6	What is the date of the last calibration of the measurement device?			If the last calibration is near due date, or previous calibration records indicate adjustments have been made, this could be a source of variation
7	What is the frequency of calibration?			If the last calibration is near due date, or previous calibration records indicate adjustments have been made, this could be a source of variation
8	Is there a documented calibration procedure for the device?			If there is not a documented procedure, this could indicate a source of variability
9	Was the measurement device recalibrated during the study? If so, record when in study it was recalibrated			It is preferred if device is not recalibrated during study, however if necessary, this could represent a source of variation.
10	Is the general location that study was performed the same as where production parts would be measured?			If locations were different (e.g. measurements for study were done in a lab, but measurement of production parts is done in an area that is not temperature controlled, poor lighting, etc., this

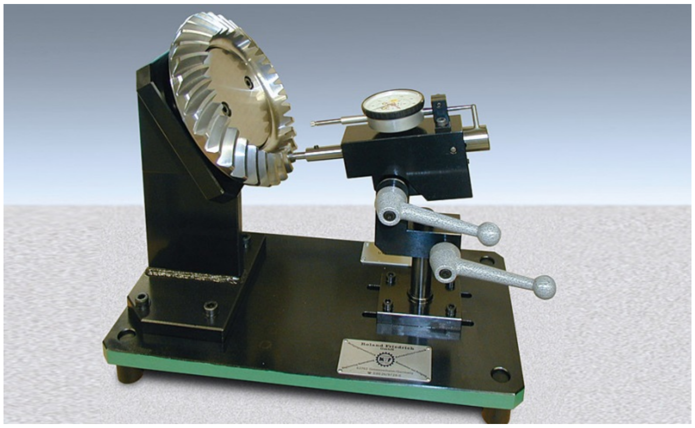
				could be a source of variation
11	Is there a work instruction that provides detail as to how part is to be measured?			If there is no work instruction, there is a greater chance for appraiser to appraiser variation
12	Has it been confirmed that appraisers are following work instruction as described?			Work instruction must be followed in detail to minimize appraiser to appraiser variation
13	List all appraisers that participated in study			Information only
14	Who designed the study? Did they review design recommendations in instruction manual?			Could be a source of variation if recommendations not followed
15	Who administered the study? Did they review design recommendations in instruction manual?			Could be a source of variation if recommendations not followed
16	Were parts presented to the appraisers in a randomized order?			If parts were not randomized there is a chance for other variables such as bias or learning to impact results.
17	Is feature measured identified as a special characteristic? If so, include X bar and R chart			Reminder that x bar and R chart is required for special characteristics
18	Were there any changes to appraisers or measurement devices during the course of the study?			Since the appraisers and measurement devices are being evaluated, they must remain constant throughout the study

Documentation of Target Values and Results of Data Analysis

Item #	Item	Specification (Target Values)	Actual	Comments Regarding Response
19	What is total tolerance on feature being measured?			Verify that tolerance sited matches the drawing tolerance; there are instances for a GD&T callout where the tolerance block tolerance may be incorrectly used.
20	Are the graduations on the measurement device 1/10th or smaller of the total tolerance?			This can impact the ability of measurement device to pass the NDC requirement
21	How many decimal places is the measurement recorded to?			This may contribute to lack of discrimination on the gage or instances where a measurement is being truncated
22	Does the above value satisfy the rule that the measurement must be reported to one decimal place smaller than the tolerance?			If no, this may contribute to lack of discrimination on the gage or instances where a measurement is being truncated
23	For analog devices is measurement being recorded to ½ the smallest graduation?			This can impact the NDC value if measurement is rounded to the full graduation, or may cause additional variation if appraiser attempts to estimate to the nearest tenth graduation, for example
24	How many points in range chart are outside control limits?	=0		action must be considered if there is a point outside control limits, reference instruction guide
25	What percentage of data	>50%		action must be

	points in “averages” chart fall outside the control limits?			considered if this is not satisfied, reference instruction guide
26	GR&R % Total variation	≤10%		action must be considered if this is not satisfied, reference instruction guide
27	GR&R % Total tolerance	≤10%		action must be considered if this is not satisfied, reference instruction guide
28	Number of distinct categories (ndc)	≥5		action must be considered if this is not satisfied, reference instruction guide
29	If any of the above specifications were not attained describe the improvements implemented to improve			
30	What is the overall recommendation of measurement system? (fully approve, approve conditionally)			This provides a clear indication from the supplier’s perspective whether they believe the measurement system is acceptable based on the results.
31	Sign and date			Increases accountability

Include photo of measurement tool as applied to part



Recommendations for Improvement (include what, who, when)

Planned activity	Who is responsible?	Estimated completion date
e.g. Replace calipers, rerun study	*John*	*3/1/19*

Maintenance of System (document activities to be taken on an ongoing basis to maintain control)

Activity Planned	When	Who is responsible?	Is activity noted in control plan?
e.g. ongoing stability study (measure master sample 5 times per week)	*Tuesday, first shift*	*Operator*	*yes*
e.g. develop a process such that only operators/appraisers that have passed a Gage study are eligible to inspect parts			