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Gage R&R, standing for Gauge Repeatability and Reproducibility, forms a key technique of the Six Sigma methodology, a disciplined approach focused on eliminating defects and variability in processes. In industries where precision is paramount, the accuracy and reliability of measurement systems are critical.Gage R&R is a key statistical tool designed to evaluate and ensure the effectiveness of these measurement systems. It aims not just to measure but to illuminate the variability within the system, encompassing both the measuring instrument and the human operators. By quantifying this variability, Gage R&R helps distinguish between true process variation and measurement error, providing a clear view of the process's actual performance. This distinction is vital, as it impacts the accuracy and reliability of data used for decision-making in Six Sigma processes.Gage R&R stands for Gauge Repeatability and Reproducibility, is an important part of the Six Sigma methodology, which is a disciplined and data-driven approach to eliminating defects and variation in processes. Gage R&R is a key method in manufacturing and industrial businesses, where precise measurements are important, and the reliability and accuracy of measurement systems play an important role. In Short, Gage R&R is a statistical tool designed to evaluate the effectiveness of measurement systems. Purpose of Gage R&RThe primary use of Gage R&R is to be able to quantify the amount of variability within the measurement system itself. When collecting data on the amount of variation in the output of a process, there are two key points to consider. The true process variation and the amount of variation observed, there can often be a gap between these with poor measurement systems. The method does not only consider the measuring instrument or gauge but also the human factor, e.g. the operators handling the measurement instrument or gauge.This method aims to analyze and understand different sources of variation in measurements and distinguish between inherent process variation and measurement error. By Isolating the variability that can be introduced by the measurement system from both the gauge and operator, Gage R&R is able to provide insights into how much total process variability is due to the measurement system rather than the process itself. Understanding this and being able to address guage variation is key in Six Sigma to ensure accurate data collection and analysis is used in decision-making processes with accurate and reliable data.Gage R&R, a critical tool in Lean Six Sigma, is composed of two main components: repeatability and reproducibility. These components help in understanding and quantifying the variability in the measurement system.RepeatabilityRepeatability is the variation in measurements taken by the same operator using the same measuring instrument under the same conditions over multiple trials. It essentially evaluates the consistency of the measurement instrument.Key aspects include:Consistency Over Time: It checks if the instrument gives consistent results over a period.Instrument Precision: It helps in assessing the precision of the gauge. A high degree of repeatability indicates a precise instrument.Operator's Consistency: Even though it's the same operator, this aspect also subtly checks the operator's ability to consistently use the instrument in the same manner.ReproducibilityReproducibility, in contrast, looks at the variation in measurements when different operators use the same gauge under similar conditions. It involves human factors in the measurement process, such as:Operator Differences: Different operators may have slightly different techniques or interpretations when using the same gauge.Training and Experience: The level of training and experience of each operator can influence reproducibility.Human Error Variability: It helps in quantifying how much of the measurement variability is due to human error or differences.The first step of a Gage R&R study involves identifying parts, operators and trials.Part SelectionThe goal is to select a range of parts collectively representing the entire range of measurements the process encounters. It is important to include parts at the lower and upper limits of the tolerance range, as well as those in the middle. Importantly, the parts chosen should represent typical parts processed, not outliers or exceptions.ExampleFor example, you might end up with a set of 15 piston rods for the Gage R&R study:5 rods at the lower tolerance limit (e.g., length at 99.5 mm for a tolerance range of 99.5 mm to 100.5 mm)5 rods in the middle of the tolerance range (e.g., length at 100 mm)5 rods at the upper tolerance limit (e.g., length at 100.5 mm)This selection ensures that the Gage R&R study will provide insights into the measurement system's performance across the full spectrum of parts that are typically encountered in the production of piston rodsBy including parts from the lower, middle, and upper ranges of the tolerance spectrum, the study will accurately reflect the measurement system's capability in real-world production scenarios.Operator SelectionWhen selecting operators, you should consider operators that have different levels of experience and skill. This is to best replicate the real-world scenario where different individuals interact with the measurement system. Ideally, operators who are regular users of the gauge should be selected to ensure the study reflects routine conditions.Trials DeterminationFor the study, you should also decide on the number of measurements each operator will take on each part. This number should be sufficient to capture variability without being excessive.This number could differ from study to study, but the balance should be between the number of trials necessary for detailed data and the practical limitations of time and resources. Step 2: Data CollectionMeasurement ProcessThe data collection step is the measurement process. A facilitator of the study should set out the parts in a randomized order, and each operator should measure each part multiple times. This should be done in such a way that the operator will not remember the measurement of the part the first time and just repeat the same measurement from memory. These measurements should also be taken under conditions that closely resemble the actual production environment. For example, if it is a production line that only allows 5 seconds to take a measurement, the simulated process should have the same time limitation. Other conditions include using the same measurement equipment, the same level of lighting, and even PPE if that impacts the ability to take measurements.Systematic RecordingWhen the measurement process is being conducted, there should be an independent facilitator keeping an accurate record of each measurement result and which part the result corresponds to. This data will form the basis of the entire study. For this, we should ensure to record the data in a way clear analysis can be conducted later such as using a table like the one below:Part IDTrial NumberOperator A ResultOperator B ResultOperator C ResultAppraised MeasurementLower Limit199.5999.6899.6799.6Lower Limit299.6199.6299.5699.6Lower Limit399.5099.5899.6199.6Middle Range1100.06100.0699.98100.0Step 3: Data AnalysisDecompose VariabilityNext, we need to conduct a statistical analysis using either statistical software or manual methods to decompose the total observed variation. This decomposition usually identifies the variation due to the differences between parts, the variation due to the measurement device's repeatability, and the variation due to different operators which is reproducibility. This step should help to identify what are the key elements of the measurement system that are contributing the most to the overall variability.Quantify ContributionsFurther analysis can be done to calculate the percentage of total process variability attributable to the measurement system. This involves comparing the gauge and operator variability to the total variability observed.Based on these percentages, an understanding can be made about the adequacy of the measurement system. The higher the percentage indicates a need for improvement in the gauge, the measurement process or operator training. Gage R&R results provide insight into the reliability and accuracy of a measurement system. These results are typically expressed as a percentage, representing the proportion of the total process variation attributed to the measurement system. This variation is divided into repeatability (variation due to the measurement instrument) and reproducibility (variation due to different operators).Understanding the Percentage ResultsLess than 10%: If the Gage R&R percentage is below 10%, it suggests that the measurement system introduces relatively little variation compared to the total process variation. This is generally considered acceptable, implying that the system is reliable and does not significantly contribute to the overall process variability.Between 10% and 30%: A Gage R&R result in this range suggests a moderate level of variation due to the measurement system. In this scenario, the acceptability of the system depends on the specific requirements of the process and the criticality of the measurements. For example, in highly precise manufacturing processes, even a small level of measurement system variation might be unacceptable. Conversely, in less critical applications, this level of variation might be tolerable.Over 30%: This result indicates that a significant portion of the process variability is due to the measurement system. Such a high level of variation is generally considered unacceptable, indicating that the measurement system is unreliable and could lead to incorrect conclusions about the process.Based on the findings from the Gage R&R study, specific actions can be undertaken to enhance the measurement system:Training for OperatorsConsistency and Technique: Operators might need training to standardize their measurement techniques. Inconsistent methods among different operators can lead to significant reproducibility issues.Awareness of Best Practices: Training sessions can also include best practices for handling and using measurement instruments, which can reduce operator-induced variability.Calibration or Maintenance of GaugesRegular Calibration: Regular calibration of the measuring instruments is crucial to maintain their accuracy over time.Preventative Maintenance: Routine maintenance can help in identifying and correcting issues before they affect measurement accuracy.Revising Measurement Procedures or Replacing the SystemProcedure Review: Sometimes, the measurement procedure itself might be flawed or outdated. Reviewing and updating these procedures can help in reducing measurement variability.System Replacement: In cases where the measurement system is fundamentally unreliable (as indicated by a high Gage R&R percentage), replacing it with a more accurate system might be necessary.Gage R&R studies offer invaluable insights into the measurement system's contribution to overall process variability. By interpreting these results, organizations can determine the reliability and adequacy of their measurement systems. A low Gage R&R percentage indicates a reliable system, while higher values signal the need for improvement. Addressing these findings through operator training, gauge calibration, or procedure revisions ensures the collection of accurate and reliable data.Ultimately, Gage R&R not only underscores the importance of precision in measurement systems but also guides continuous improvement efforts in Six Sigma practices. By isolating and addressing measurement system variability, organizations can make more informed decisions, leading to enhanced process control and product quality.Peruchi, R.S., Balestrassi, P.P., de Paiva, A.P., Ferreira, J.R. and de Santana Carmelossi, M., 2013. A new multivariate gage R&R method for correlated characteristics. International Journal of Production Economics, 144(1), pp.301-315.Thanks for your feedback! Gage Repeatability and Reproducibility are often referred to as Gage R&R. It's a method to assess the repeatability and reproducibility of a measurement system. In other words, Gage R&R studies are carried out to discover how much of the process variation is due to the measurement system. Measurement System Analysis (MSA) is a tool for analyzing the variation present in each inspection, measurement, and test equipment type. It is the system used to assess the quality of the measurement system. A gage, in this context, is a tool for measurement. A gage could be simple, like calipers and rulers. Or it could be a complex piece of machinery. It could even be a piece of software. Gage R&R focuses on two key aspects of measurement: Repeatability: Repeatability is the variation between successive measurements of the same part or trait by the same person using the same gage. In other words, how much variation do we see in measurements taken by the same person, on the same part, using the same tool? Reproducibility: Reproducibility is the difference in the average of the measurements made by different people using the same instrument when measuring the identical characteristics on the same part. In other words, how much variation do we see in measurements taken by different people on the same part using the same tool? Looking at these two metrics helps us to understand variation in our measurements. When we understand it, we can combat it. Gage Repeatability and Reproducibility measure the amount of variability in measurements caused by the measurement system itself. Then, it compares this variability with the total to determine the actual variability of the measurement system. Gage R&R is very important when new workers are assigned; new tools are used, or any significant process changes. Don't like Ads? Neither do I. If you're a member, just log in to avoid ads. If you're not a member, what are you waiting for? Sign up here! For example, imagine a situation where our performance metrics show a serious problem in our manufacturing process. We spend a lot of time and money trying to fix it and improve the performance of a process. But we'd have noticed serious measurement variations if we'd spent some time looking at gage repeatability and reproducibility instead. The problem wasn't in the process at all; it was in the measurements. Checking this first would have saved time, money, and stress. Variation is made up of part and gage variation.Image from Bo-ci-an under CC-BY-SA 3.0. Based on the available data and data type, there are basically three types of Gage R&R available: Crossed Gage R&R Select crossed-gage R&R when each operator measures each part, and it must have a balanced design with random factors. It is used for non-destructive testing. Nested Gage R&R Select nested gage R&R when only one operator measures each part. It is used for destructive testing. Since it is not crossed with other factors, it is called nested gage R&R. It must have a balanced design with random factors. Expanded Gage R&R Select expanded gage R&R when we need to include more factors (maximum of eight) than operator and part. Typically crossed and nested deal with only two factors (operator and part). Design can be balanced or unbalanced. There are basically three methods that exist to perform Gage R&R: Range method Average and range method Analysis of variance method Range Method: The range method will provide a quick approximation of measurement variability but does not compute the measurement system repeatability and reproducibility separately. Average and Range method: The Average and Range method quantifies the measurement system's variability and provides repeatability, reproducibility, and part variation. Only crossed Gage R&R can be performed with the Average and Range method. Analysis of Variance method: It is the most widely used and accurate method for measurement system repeatability and reproducibility. It also quantifies the variability of the interaction between the operator and the parts. Gage R&R (crossed, nested, and expanded) can be done with the ANOVA method. Ensure the gages used in the study are properly calibrated before collecting measurements. Record a variety of measurements taken by multiple appraisers (operators) on the same parts using the same gage. For each measurement, be sure to note: The part being measured The person (appraiser) taking the measurement The specific gage used When all measurements have been recorded, analyze the data to identify sources of variation. For example, for Operator A and Part X: Range: Max − Min = 0.33 − 0.29 = 0.04 Mean: (0.29 + 0.31 + 0.33 + 0.32) / 4 = 0.3125 Repeat this process for each combination of operator and part. For Operator A: Mean of Ranges: (0.04 + 0.04 + 0.04) / 3 = 0.04 Mean of Means: (0.3125 + 0.2875 + 0.2875) / 3 = 0.2958 Repeat this process for each operator. Total Mean Range ($\bar{R}$): (0.04 + 0.02 + 0.01) / 3 = 0.0233 Range of Operator Means ($\bar{x}diff$): 0.2991 − 0.2958 = 0.0033 Formula: $EV = \bar{R} \times k1$ $\bar{R}$: 0.0233 Subgroup size: 4 (number of trials) Number of combinations (g): 3 parts × 3 operators = 9 d2 (from table): 2.080 k1: 1 / 2.080 = 0.480 EV: 0.0233 × 0.480 = 0.0112 Formula: $AV = \bar{x}diff \times k2$ $\bar{x}diff$: 0.0033 n (number of parts): 3 r (number of trials): 4 g (number of combinations): 9 d2 (from table): 1.718 k2: 1 / 1.718 = 0.5820 Note: If the calculated AV is negative (e.g., due to rounding or statistical artifacts), set AV = 0. Add the squared values of EV and AV, then take the square root: Total Gage R&R = $\sqrt{EV^2 + AV^2}$ According to the Automotive Industry Action Group (AIAG), %GRR guidelines are as follows: Less than 10%: Acceptable 10%–30%: May be acceptable depending on application and cost Greater than 30%: Not acceptable Example: If Total Gage R&R = 1.12%, the system is in the green zone and considered acceptable for most applications. To measure Gage R&R using the ANOVA method, follow these guidelines: Use a minimum of 10 parts for accuracy and robustness. Select two technicians (or more) to perform the measurements. Each technician should measure each part 2 or 3 times. Three measurements per part per technician are typically recommended. Measurements should be collected in random order. Compute the overall average of all measurements: $\bar{\bar{x}}$. Let: t = number of technicians (appraisers) r = number of trials or replications p = number of parts This is the sum of squares based on the squared deviations between each technician's average and the overall average: $SSTechnician = p \times r \times \Sigma (\bar{x}Technician - \bar{\bar{x}})2$ This is the sum of squares based on the squared deviations between each part's average and the overall average: $SSPart = t \times r \times \Sigma (\bar{x}Part - \bar{\bar{x}})2$ The total sum of squares represents the squared deviation of each individual result from the overall average: $SSTotal = \Sigma\Sigma\Sigma (xijk - \bar{\bar{x}})2$ Or alternately: SSTotal = SSTechnician + SSPart + SSTechnician×Part + SSEquipment This reflects variation due to measurement equipment. It's the sum of squared deviations of individual trial results from the average for the same technician and part: $SSEquipment = \Sigma\Sigma\Sigma (xijk - \bar{x}ij)2$ This represents variability from interactions between technicians and parts. It's calculated as the remainder after subtracting other components from the total: SSTechnician×Part = SSTotal − (SSTechnician + SSPart + SSEquipment) The number of distinct categories is a metric. In gage R&R, the goal is to identify the measurement system's ability to detect a difference in the measured characteristic. It represents the number of non-overlapping confidence intervals that span the range of product variation. Number of distinct categories = (Standard deviations for parts / standard deviation for gage) * √2 So, the number of categories depends on the ratio of the variability in the measuring parts and the variability in the measurement system. According to the Automotive Industry Action Group (AIAG), the number of distinct categories should be greater than 5 for an adequate measuring system. >=5: Adequate measuring system   =2:   Data can be divided into two: say Low and High   =3:   Data can be divided into three: say Low, Medium, and High   30%), that provides insight about the types of parts being selected. It's telling us that the measurement tool cannot effectively decipher if the part is good or bad, because too much measurement system variation is showing up between specifications. I hope the answers to these common questions help you next time you're doing Gage R&R in Minitab! The Gage R&R Statistic is usually reported as either a percent of tolerance, or as a percent of the total process variation. Calculate the Gage R&R Statistic easily with our QA-Calibrate gage calibration software, our SPC IV Excel statistical process control software, or our Green Belt XL lean six sigma software. When expressed as % Tolerance, Gage R&R indicates the relative usefulness of the gage system for determining part acceptance. Tolerance, calculated as the Upper Specification Limit minus the Lower Specification Limit, indicates the amount of variation that is permitted between all parts produced. As gage system error increases relative to the tolerance then the chances increase that: 1. parts whose true value is outside specifications could be measured as being within specifications and subsequently accepted for use, and 2. parts whose true value is within specifications could be measured as being outside specifications and subsequently rejected as unfit for use. When expressed as % Process Variation, Gage R&R indicates the relative usefulness of the gage system for use in control charting and process capability analysis. The calculation of statistical control limits and the estimate of process capability require a sound estimate of the process variation. Subgroups plotted on a control chart are also subject to measurement system error. As measurement error increases, so does the chance that: 1. Subgroups from a controlled process will be determined to be out of control, and 2. Subgroups from an out of control process will be determined to be from an in-control process. Typical recommendations for Gage R&R, expressed as ether % Tolerance or % Process Variation, are: 0 to 10%: Acceptable 10-30% Marginal Over 30%: Unacceptable The Discrimination Ratio is also useful is determining the suitability of the gage to estimate real process variation. See also: Interpreting a Repeatability Control Chart Interpreting a Reproducibility Control Chart Repeatability Reproducibility Analysis for an example analysis Learn more about the Quality Improvement principles and tools for process excellence in Six Sigma Demystified (2011, McGraw-Hill) by Paul Keller, or his online Green Belt certification course ($499). Page 2 The following is an excerpt on Six Sigma implementation and the Six Sigma steps from Six Sigma Demystified (2011, McGraw-Hill) by Paul Keller. Reducing unnecessary movement as part of a value stream analysis incorporates a Lean concept known as the 5S process, which comes from the Japanese words used to create organization and cleanliness in the work place [Seiri (organization); Sieton (tidiness); Seiso (purity); Seiketsu (cleanliness); Shitsuke (discipline)]. The traditional 5S have been translated into the following 5S process, which are perhaps better definitions for English-speaking companies (ReVelle, 2000): Sort: eliminate whatever is not needed. Straighten: organize whatever remains Shine: clean the work area Standardize: schedule regular cleaning and maintenance Sustain: make 5S a way of life Common outcomes from 5S implementation include: Reduced movement Reduced search time Increased effective use of floor space Improved inventory management Reduced accidents Improved working conditions [Note: In the Six Sigma Demystified text, I present a useful means of quantifying each of the 5S parameters, so their status can be benchmarked and tracked over time. One critical perspective of 5S that I feel compelled to offer is that, contrary to what is apparently a common perception, implementing 5S in itself is not a serious effort at implementing Lean. 5S is a very small aspect of an effective Lean strategy. See also Lean Thinking. Learn more about the Lean Six Sigma principles and tools for process excellence in Six Sigma Demystified (2011, McGraw-Hill) by Paul Keller, in his online Lean Six Sigma DMAIC short course ($249), or his online Green Belt certification course ($499). If the measurement system outputs variable data - or numerical measurements (example: 0.0021, 0.0023, 0.0019 ...) - then we use a Variable Gage R&R study. Common measurement systems with variable data output include Micrometers, Calipers, CMMs, Height gages, Dial indicators, Temperature probes etc. A Variable Gage R&R study typically requires 10 parts that represent the production range, 3 operators who normally perform the measurements, and 2-3 trials per operator per part, resulting in 60-90 total measurements. The study analyzes the variation from two sources: repeatability (equipment variation - the same operator measuring the same part multiple times) and reproducibility (operator variation - different operators measuring the same part). Results are typically expressed as a percentage of either the process variation (%TV) or the tolerance range (%Tolerance), with acceptance criteria of less than 10% for critical characteristics. This analysis helps organizations determine if their measurement system can adequately distinguish between parts and reliably monitor their process. Variable Gage R&R studies are sub-classified into: Crossed Gage R&R: In the most commonly used method, the study is crossed i.e., each operator measures each part or sample multiple times. We'll explore this method for the rest of this guide. Nested Gage R&R: In some cases, it is not possible for each operator to measure each part or sample multiple times (e.g. destructive tests), requiring a nested study in which each operator measures a different set of parts (i.e. the parts are "nested" under the operator). Six Sigma Black Belt: No problem. Six Sigma Green Belt: Yup! Any Six Sigma belt exam from ASQ, IASSC, Villanova, university, or company-specific: Absolutely. Contrary to what you might think there are plug-and-play formulas for reaching these goals. Repeatable and scalable formulas. They aren't complicated. But they are hard to find. My name is Ted Hessing and I am the creator of Six Sigma Study Guide. At Six Sigma Study Guide I've reverse engineered and tested dozens of test preparation strategies. I've turned the most effective strategies into detailed step-by-step instructions for you. Step 1: I research and test everything. Step 2: You get the best strategies. For example… I discovered one new test strategy formula. I shared it with the members of this site and a few months later I learned it produced a huge increase in the likelihood of whether a Six Sigma exam candidate would pass their exam or not. It has resulted in hundreds of people passing their certifications exams is projected to help 100s more this year. The best part? It takes a really short amount of time to implement. The formula isn't hard. It's not complicated. But if you don't constantly research and test new things you'll miss out on strategies like this that can easily increase your chance of passing the exam. That's why Six Sigma Study Guide is here. Every month I email out a way to prepare for your exam, apply Six Sigma techniques to at your job, and other ways to deliver amazing real-world results and improve your career. Just enter your email address below and I'll email the strategies I'm testing right now (publishing in a few weeks) along with the studying strategy I mentioned above. Get Your Free Six Sigma Studying Strategy. One statistic that is directly affected by specification limits is the %tolerance statistic, which compares the tolerance with the study variation. Ideally, the tolerance should amply encompass the study variation, ensuring the variability due to Gage R&R and part-to-part variation do not push the process output beyond the specification limits. When a process has two specification limits, the tolerance equals the difference between them, and %Tolerance equals the study variation of a given variation source divided by this tolerance. However, this method is invalid when you provide a single specification limit. Hi, I am conducting a GR&R studies on my measuring equipment and the results are as follows: The % tolerance is 31.11 and the number of distinct categories is 9. Is this gage acceptable? What does the %tolerance tells us about this gage? Please help. Thanks. The ndc = 9 says that the gage is good for process control, that is the gage can distinguish 9 distinct levels within the process variation. The percent tolerance of 31.1% is just over the maximum of 30%. This means that the gage is marginally unacceptable for inspection purposes. Now, a bigger question: To get an excellent ndc and bad P/T ratio can mean one of two things: 1) Your process variation is much greater than your tolerance (i.e., process is not capable). or 2) Your selection of parts for the study greatly exceeds the normal process variation, which inflated the ndc numbers. Your sample parts should reflect the spread of actual process variation. Gage Repeatability and Reproducibility studies (Gage R&R) are a type of Measurement Systems Analysis (MSA). The typical Gage R&R acceptance criterion is that the total measurement variation of a process is less than 30 percent of the process tolerance, but more rigorous applications or more established measurement systems might be acceptable only when the measurement variation is less than 10 percent of the process tolerance. The total measurement variation comes from two sources: Repeatability: variation from the measurement device is measured by comparing measurements by the same person using the same device on the same part. Reproducibility: variation from different people is measured by comparing measurements by different people using the same device to measure the same part. Why are Gage R&R studies important? Gage R&R studies are usually a precursor to other Lean Six Sigma analyses. Gage R&R studies verify that the measurement system is good enough for you to trust the conclusions of your data. For example, if you want to be able to use a control chart to monitor when the mean diameter of a bearing changes, you need to be confident that any changes you see are because of changes in the process, not because the measurements are inconsistent. If you cannot trust your measurements, then you can't use your data to make decisions or process improvements. Because we comprise the variation of the measurement system from two parts, we generally describe the outcomes of a Gage R&R study that shows the variation as being too large as pointing out one of two problems: 1. Demonstrate that the tool needs improvement When the measurement system variation is high because of high repeatability, we say that the measurement tool itself is too inconsistent. The tool might need to be calibrated more often, might need repair, or might need to be replaced with a more precise tool. 2. Demonstrate that the operators need more consistency When the measurement system variation is high because of high reproducibility we say that the differences from one operator to another are too great. The temptation is usually to blame the least consistent operators in the study, but when the operators represent a random sample from the available operators, the interpretation is different. The operators in the study are representative of all operators, so when we see operators differences in the Gage R&R study, we expect that variation to represent all of the operators. Improving training for everyone, making the measurements easier to take, or verifying that the operators are all using the same process are possible steps that follow a study where the reproducibility is too high. Who performs Gage R&R studies? Although Gage R&R studies have strong roots in automotive manufacturing, they have become a fundamental tool. Gage R&R studies have found their way into nearly every industry where there's measurement uncertainty. Consider these Gage R&R example applications: In a hospital, T. Erdmann et al. use a Gage R&R study to assess measurements of patient temperatures. Mithun Sharma et al. use a Gage R&R study to assess measurements of burst strengths of shower cartridges. Dominik Krumm et al. use a Gage R&R study to assess measurements of bending stiffness of athletic footwear. The more complex the measurement system is, the more important it is to be sure the data are trustworthy. Anytime measurement variation can exist, it's worth making sure that it's small. How to perform Gage R&R - the process A typical Gage R&R study involves the following, which determines the number of measurements: At least three people At least ten parts At least two measurements by each person of each part. Note that the preceding numbers are all minimums. The more variability you expect to find from a source of variation, then the more measurements you'll need in order to get a good estimate of that variability. For example, if you expect that it's hard for people to get the same measurement, then you'll take more than two measurements by each person on each part. You might need to make adjustments based on your situation, but these are the general steps: Randomize the order that people will take the measurements in. Randomize the order that each person will measure the parts in. Have each person measure the parts in the assigned order. Repeat steps 1-3 for as many measurements as you plan. How to perform Gage R&R - the software While you'll find many templates that make it easy to do Gage R&R calculations by hand, these days it's more common to use software. A Gage R&R analysis in Excel typically replicates the most traditional calculations. A Gage R&R analysis in a statistical software package, like Minitab Statistical Software, comes with additional insights into the measurement process. Gage R&R Excel Begin with a data collection form that lets you record the measurements. A variety of forms exist, but the essential quality is that they put the measurements in a place that makes it easy to calculate the averages and ranges for measurements by a person of one part and of the measurements of a part by different people. Get your Gage R&R worksheet! You can follow along with this Gage R&R Excel sample worksheet. Calculate values from the measurements Record the measurements for each part in separate columns in a single row for each person and each set of measurements. Calculate the average of the measurements in each column for a person and a part. Calculate the range of the measurements in each column for the same person and the same part. Calculate the average of the averages for each person from step 2. Calculate the average of the ranges for each person from step 3. Calculate the average of all the measurements for the same parts. Calculate the range of the averages from step 6, RPart. Verify that the measurement system is in-control Calculate the averages of the ranges from step 5, $\bar{\bar{R}}$. Calculate the range of the averages from step 4 across all of the people, $\bar{X}$Range. Determine the upper and lower control limits for the ranges with the following Gage R&R formulas: $LCL = \bar{\bar{R}} * D4$ $UCL = \bar{\bar{R}} * D3$ $\bar{\bar{R}}$ is from step 8. D3 and D4 are constants that depend on the number of sets of measurements, given in the following table: Number of sets of measurements D3 D4 2 0 3.267 3 0 2.574 4 0 2.282 5 0 2.114 6 0 2.004 7 0.076 1.924 8 0.136 1.864 9 0.184 1.816 10 0.223 1.777 If any of the current range measurements are outside of these control limits, then the measurement system isn't in control. Stop and correct the measurement system before you estimate the variation. Estimate the variation from different sources Use the Gage R&R formula for variation from repeatability $Repeatability = \bar{\bar{R}} * K1$ where K1 depends on the number of sets of measurements, given in the following table: Number of sets of measurements K1 2 4.565603 3 3.041937 4 2.501214 5 2.214101 6 2.03236 7 1.904586 8 1.808922 9 1.734007 10 1.673164 Use the Gage R&R formula for reproducibility $Reproducibility = \sqrt{(\bar{X}Range * K2)2 - (Repeatability2/(nr))}$ where $\bar{X}$Range is from step 9, repeatability is from step 11, n is the number of parts, and r is the number of sets of measurements. K2 is a constant that depends on the number of people who take measurements. People K2 2 3.65 3 2.70 4 2.30 5 2.08 6 1.93 7 1.82 8 1.74 9 1.67 10 1.62 Use the Gage R&R formula for the total variation from the measurement system: $R\&R = \sqrt{Repeatability2 + Reproducibility2}$ Use the Gage R&R formula for the variation among the parts in the study $VariationParts = RPart * K3$ where RPart is the value from step 7. K3 has the same values as K2, but the determining number is the number of parts, not the number of people. Calculate the total variation and the percentage from each source Use the Gage R&R formula for the total variation $Total\ Variation = \sqrt{(R\&R)2 + (VariationParts)2}$ where R&R is the value from step 13 and VariationParts is from step 14. Divide each source of variation by the total variation to find the percentage from each source. Divide R&R by the process tolerance to decide whether the measurement system meets the Gage R&R acceptance criteria. Gage R&R Minitab Minitab performs calculations for you, so the results are much faster to produce than in Excel. Create a data collection sheet Minitab sets up a Gage R&R worksheet for you so that you can see how to arrange the data in Minitab. The worksheet also shows the random order for measuring the parts. Choose Stat > Quality Tools > Gage Study > Create Gage R&R Study Worksheet. Enter the number of parts that represent your process. Enter the number of operators for your study. Enter the number of replicates, which is the number of sets of measurements. Produce the results After you enter your measurements in the correct cells, Minitab completes the calculations for you. Choose Stat > Quality Tools > Gage Study > Gage R&R Study (Crossed). In the Part numbers field, enter the column that identifies which part was measured in that row. In the Operators field, enter the column that identifies which person took the measurement in that row. In the Measurement data field, enter the column that contains the measurements. If you have a process tolerance, click Options. Enter the tolerance in Upper spec - Lower spec. Click OK in both dialog boxes. Gage R&R interpretation Whether you've done Gage R&R yourself or in a software like Minitab, the basic results have the same interpretation. Minitab provides a full graphical report. Minitab output The table output in Minitab shows results where the variation in the measurement system is almost all from repeatability. The variation from the measurement system is about 3 percent of the process tolerance, which indicates a usable measurement system for most applications. The components of variation graph illustrates the values from the table. The yellow bar that is less than 10 percent on the y-axis shows that the measurement system is adequate. The remaining pieces of the output show the following: S chart by operators The S-chart shows whether the measurement system is in-control. You can trust the results from the rest of the study if the S-chart is in-control. Xbar chart by operators The example Xbar chart is out-of-control. The out-of-control situation is good because it means that the measurement system is able to distinguish the different parts in the study. Measurements by parts The measurements by parts graph provides insight into whether measurement variation is higher for some parts than others. Measurements by operators The measurements by operators graph provides insight into the variation among people. Parts * operators interaction The parts * operators graph shows whether the measurement variation for some parts is different from operator to operator. Excel output The Excel calculations show that the total Gage R&R represents a small proportion of the tolerance. Because the % of tolerance is less than 10 percent, the measurement system is adequate for the process. Ready for more? The Gage R&R study described in this article is usually used for non-destructive testing that looks at the two most common sources of variation for a measurement system. The method is also appropriate only for measurement data as opposed to attribute data that count how often something occurs, like a particular type of defect. You can learn more about different types of measurements and how to assess their measurement systems in the Measurement Systems Analysis course from GoSkills. You can see a free preview of the Gage R&R Methodology Section that's well worth watching. After that, you'll be eager to learn more about how you can make a Gage R&R study work for you. Prepare to get certified in Lean Six Sigma Start learning today with GoSkills courses Start free trial