Prioritisation of Measurement System Analyses

at the Airbus plant in Stade, Germany

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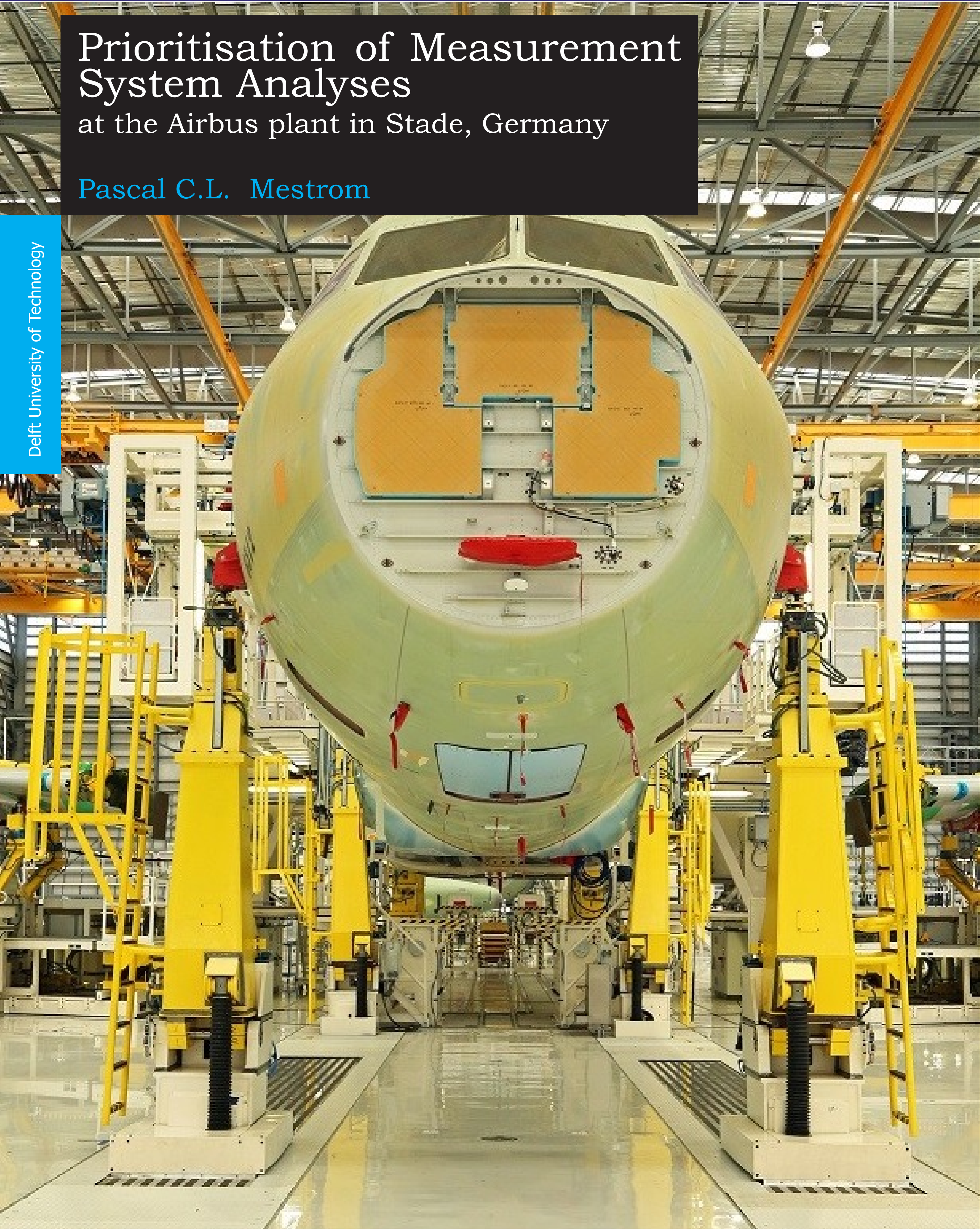

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Challenge the future

Prioritisation of Measurement System Analyses

at the Airbus plant in Stade, Germany

by

Pascal C.L. Mestrom

in partial fulfillment of the requirements for the degree of

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TO MY WONDERFUL PARENTS, for their everlasting interest and belief in me;

TO MY SIBLINGS, RIK & JOLIEN, for their mental encouragement and appreciated distractions;

TO THOSE ON THE BACKGROUND, for being there with the little things which are so often so easily forgotten, yet remain important.

Declaration

I hereby declare that except where specific references are made, and except for this declaration, the contents of this Master of Science Thesis are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This thesis is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and the acknowledgements.

Pascal C.L. Mestrom
Delft, December 2019

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Abstract

The thesis project concerns the development of a methodology to connect data, from the Airbus department in Stade, with each other and find relationships between them which lead to a prioritising tool with which justifiable decisions can be deduced in order to plan which *Measurement System Analysis (MSA)* to conduct next, focusing on cost effectiveness.

Therefore, the main content will revolve around studying and analysing relevant literature and connecting this with the actual data, as present at Airbus, to arrive at a functional tool.

As such, the main aim and objectives concentrate around developing a thorough understanding of the relevant data and discovering how they relate with one another and with costs. Aim would be to find a causal relationship, which is then subsequently also verified and validated.

The main findings are expected to give the relationships between the data, e.g. that a certain improvement of *X%* in MSA leads to *Y%* better C_{pk} (Process Capability Index. Adjustment of C_p for the effect of non-centred distribution) and as such *Z%* reduction in *Cost of Non Quality (CNQ)* per process.

As Airbus is in a tough competition with Boeing and other aircraft manufacturers, finding ways to be more cost effective is very useful. Especially now with the population of the earth rapidly growing and the use of aircraft for travel becoming more readily available/affordable for everyone, the amount of aircraft that need to be in the worlds fleet is expanding even more. As such, the rate of construction of aircraft is rising tremendously and improvements in recurring costs are ever more valuable. Even though the work is dedicated to Airbus processes, the methodology as developed for the prioritisation tool should be generalisable to also be applicable for other situations and as such give a worthwhile contribution to the body of knowledge: How these data relate with each other and how this knowledge/information can be turned into practical improvements.

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Nomenclature

Greek Symbols

μ	Mean
σ	Standard deviation
6σ	Set of tools and techniques to improve a process

Sub- and superscripts

C_p	Process Capability
C_{pk}	Centralised Process Capability

Acronyms & Abbreviations

ANOVA	Analysis of Variance
ASM	Aerospace Structures & Materials
BIPM	Bureau International des Poids et Mesures
CD	Control Device
CIPM	Comité International des Poids et Mesures
CNQ	Cost of Non Quality
CP	Control Plan
CTI	CriTical Item
DES	Discrete Event Simulation
DMAIC	Define Measure Analyse Improve & Control
DPMO	Defects Per Million Opportunities
EVOP	EVolutionary OPeration
FAL	Final Assembly Line
FFD	Fractional Factorial Design
FFE	Fractional Factorial Experiment
FMEA	Failure Modes & Effects Analysis
GR&R	Gage Repeatability and Reproducibility
GTA	Grounded Theory Approach
HIP	Harmonised Inspection Planning
HO	Head Of
HTZ	Herstellerteilezeichen, Manufacturer Part Number
IC	Inspection Characteristic
IP	Inspection Planning
ISO	International Organization for Standardization
JCGM	Joint Committee for Guides in Metrology
KC	Key Characteristic
KPI	Key Performance Indicator
LSL	Lower Specification Limit
MANOVA	Multivariate ANalysis Of VAriance
MANCOVA	Multivariate ANalysis of COVAriance
MC	Monte Carlo

MDA	Multiple Discriminant Analysis
ME	Manufacturing Engineering
MPM	MSA Prioritisation Matrix
MQR	MSA Quality Review
MS	Measurement System
MSA	Measurement System Analysis
NC	Non Conformity
NDC	Number of Distinct Categories
PCA	Principal Component Analysis
PPS	Practical Problem Solving
QC	Quality Control
QDS	Quality Department Stade
QI	Quality Inspector
RCA	Root Cause Analysis
SAP	Systems, Applications & Products in Data Processing
SHA	StakeHolder Analysis
SMART	Specific Measurable Achievable Reasonable Time constraint
SOD	Severity Occurrence Detectability
SPC	Statistical Process Control
TPV	TeilProzess Variante, Subprocess variant
USL	Upper Specification Limit
VOC	Voice Of the Customer
VTP	Vertical Tailplane

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1 Introduction

In all large scale industrial manufacturing environments, people have to deal with processes and products which they want to continuously be of an adequate level of quality; the product should lay within the specification bounds. Therefore, these processes get tracked and tested in several ways. One of these methods is by executing *Measurement System Analyses (MSA)*.

The thought behind this is nothing new in itself, there has always been a need to back up statements with verifiable facts. However, a means for making grounded prioritisation decisions, has not been around. In the event of a company having a substantial backlog of MSA which still need to be conducted, it can be worth looking into the exact sequence for executing them, from a financial as well as quality point of view. This is exactly, what will be strived for in this project, as Airbus is in such a situation.

The MSc project has *Measurement System Analyses (MSA)* as a general area of interest, in which the challenges and advancements lay in the understanding of relevant data and the (causal) relations between them. Reviewing the project from an academic perspective, its relevance consists of researching and then determining the (causal) relations between the data. This will add to the body of knowledge and will be applied for the problem statement at Airbus, Stade and could be generalised to be applied at other industries dealing with similar processes.

This leads to the research objective and aim of the thesis: *To come up with a methodology for Measurement System Analysis (MSA) prioritisation, by means of data analysis in the field of C_p, C_{pk}, Gauge Repeatability & Reproducibility (GR&R) and CNQ data for Airbus production processes in Stade.* Around this methodology a tool will be developed to execute said prioritisation. This will help increase the competitiveness of Airbus. Along the way towards this objective, several sub goals are developed and should be executed. To make all of this more clear, it can be put in a research framework and get linked with task blocks.

To reach the project goal, the main research question should be solved, which is: *'Is it possible to develop a prioritisation tool as described in the research objective?'*

To be able to solve this question, two other main questions and several sub-questions are treated first. By solving these (sub-)questions, the problem at hand can be tackled:

1. How does Airbus handle its MSAs currently?
   (a) What is an MSA?
   (b) For which processes are MSAs executed?
   (c) How is prioritisation currently being handled?
2. How do all interested stakeholders feel about (the need for) a MSA prioritisation tool? Which opinions do the distinctive parties have on the core concepts as well as the assumed relationships between them, in regards of the Airbus Stade organisation?
   (a) Who are the stakeholders?
   (b) What is relevant for such a tool, according to the engineering department?
   (c) What is relevant for such a tool, according to the manufacturing engineering department?

   (d) In the eyes of the production department, what is relevant for such a tool?
   (e) In the eyes of the programming department, what is relevant for such a tool?
   (f) What does the quality department mark as important for such a tool?
   (g) What are the main differences and similarities in these opinions, both in terms of problems, as well as envisioned solutions?

3. How do the relevant data relate with each other?
   (a) What is the nature of the data?
   (b) How does CNQ relate with GR&R?
   (c) What kind of a relation is there between GR&R and C_{pk}?
   (d) In which manner does C_{pk} manifest a relation with risk?
   (e) ...

With respect to novelty and innovation, this project can be placed in line with the ongoing trend of switching towards industry 4.0. This is visualised in figure 1.1. Here, the last block shows how data is the new big thing. By means of sensory equipment and feedback loops less and less human handling is required to keep processes running smoothly. Data is used both as in- and output, it oversees processes as well as steers them.

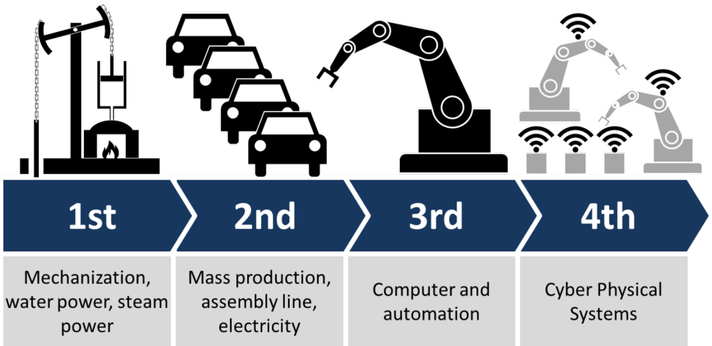


Figure 1.1: The four industrial revolutions [1]

Airbus collects a great amount of data while producing aircraft. With the data present, it would be a shame to not effectively use this data towards optimised processes. As there is no link found between the data at hand, it is a novel and innovative part within the entire industry 4.0 revolution.

The motivation for this research project is twofold. First, Airbus is looking for ways to be more cost effective and had this project envisioned to be carried out. Second, the student completed his internship at Airbus just mere months before the start of this research project and was eager to continue with a thesis at Airbus. With respect to feasibility; the initial investment for the project is rather low, considering Airbus opts for a student to complete the project and the rewards to be gained remain substantial. Furthermore, it fits within the time-constraints of a MSc thesis which ensures that the outcomes will become available in a short amount of time. Next to this, the problem will not only just be tackled, but a knowledge background will be developed too, allowing for swifter resolutions when similar problems occur at a latter point in time.

2

Background Information

It is a known fact that variation and scatter are always present in processes, even for those which are supposed to be constant [11] - e.g. the amount of water in a filled 1L bottle. It is impossible to know exactly by how much this variation occurs. From the second law of thermodynamics it is known that the total entropy - the disorganisation - of an isolated system does not decrease over time. For an ideal case, it can remain constant when the system is in a thermodynamic equilibrium, or is enduring a reversible process. However, for all real processes, the entropy increases. Although a law of physics can not be beaten, its effect can be appeased by forcing the process to be in a state of functional equilibrium through process monitoring and applying adequate adjustments - statistical process control.

This chapter starts with a short history of *Measurement System Analyses (MSA)* which be read in section 2.1, this will then extend further in the next two sections, covering *Statistical Process Control (SPC)* and MSA in some more detail in respectively sections 2.2 and 2.3. Thereafter, a synopsis concerning the executed stakeholder analysis is included in section 2.4. Finally, some findings with respect to a relationship between GR&R and C_pk are presented in section 2.5.

2.1. Early MSA

From this physical nature originates the desire to have a means to control whether a measurement is correct. It allows for accountability and traceability in case something has gone wrong along the way and needs fixing. Examples have been documented, dating back to the ancient Egyptians around 2700 BC, where the length of the pharaoh's forearm would be used as a reference length in construction. [12] Albeit very primitive, effective. Fast forwarding to the end of the 18^{th} century, a reference length for 1 meter was established in Paris, France. First in Marble, later in brass, platinum and a platinum-iridium mixture. All of which had one goal in mind; increasing the precision of the measure of length. So one can clearly say that the thought behind MSAs is nothing new. Regardless of that, it wasn't until the late 1970s when the Bureau of Weights and Measures decided to conceive an international agreement on the expression of measurement uncertainty. They started the development of a more modern and industrial approach, with a first proposal finalised in 1980 and confirmed the year after. It then took another five years to see the ISO Advisory Group on Metrology get entrusted with the preparation of a detailed guideline which got published in 1995 - known as the *"Guide to the expression of Uncertainty in Measurement" (GUM).* [13] [14]

From these initial steps, MSA and SPC evolved and are now embedded deeply in every large company which deals with a lot of measurements. A condensed summary from the literature study [15] on both concepts will now be presented in the following sections, with first SPC in section 2.2 and thereafter MSA in section 2.3.

2.2. Statistical Process Control

To get a better grip on the topic of SPC as a whole, a little breakdown with respect to the structure is used, while researching relevant content. This section starts with subsection 2.2.1 in which SPC is defined. It is followed by subsection 2.2.2 in which *Process Capability*, C_p & C_{pk} are examined. The last subsection is subsection 2.2.3 which is about how Airbus specifically deals with SPC. Particularly, but not limited to, the plant of Stade in Germany.

2.2.1. Statistical Process Control explained

SPC is a methodology, driven by industry standards, with which processes, as present while manufacturing products, are continuously measured and the quality is controlled. [4] As such, it provides for a great tool for managers and alike to keep propelling towards success for their businesses. To continue from this point, one should first determine what exactly a process is.
A process is characterised by the following properties: [2]

- A process receives input
- A process is influenced by actions and characteristics
- These actions and characteristics are interrelated
- A process provides output

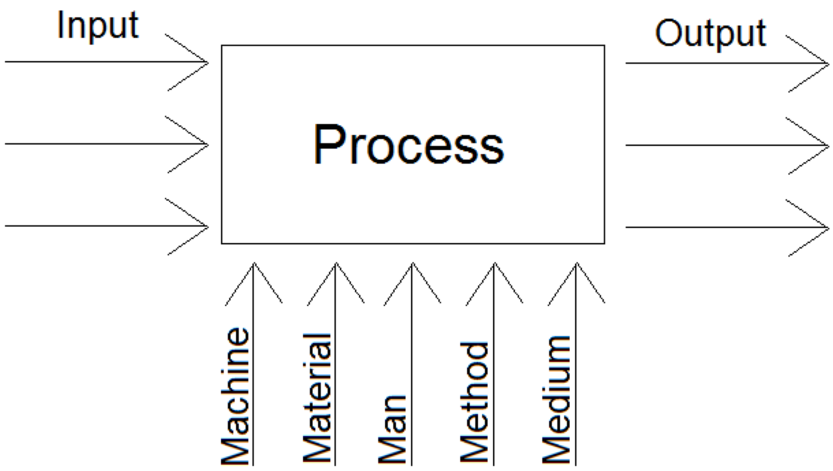


Figure 2.1: In- and output of a process as well as influencing factors [2]

A simplified example, fitting to figure 2.1, would be the assembling of the flaps to the wing. Here, the flaps could be labelled as input, the fully assembled wing with mounted flaps as output and the drilling of holes and then connecting the two with bolts as the influencing factors (which machine used, which personal, which method, etc.). Note that some overlap is possible too, as the bolts for example can be seen as material as well as input. Similarly, certain methods such as vacuum infusion, will make use of consumables in which material is used, e.g. scotch tape, which doesn't become part of the final product - it'll be considered as material.

In case the behaviour of a process can be predicted up to a certain extent, it is said that the process is under statistical control. Nonetheless, the output of a process is not constant, as there are a number of variables which have an impact on the process. These quantities can't be continuously controlled nor influenced in contrary to the input. One can distinguish between two types of influencing variables, which are:

- Random variation
- Systematic variation or variation due to special causes

A stable process is characterised by a well-defined and predictable variation due to natural causes. An unstable process has variation both from natural as well as special causes. Therefore, one can't give trustworthy predictions for the process results.

A goal for a process is to be efficient and effective and as such to allow for predictable results; to achieve high process stability. For a stable process, with predictable output on defined input, SPC can be used; stability is a requirement for SPC as is the use of at least 30 samples. This SPC data is obtained through measurements along the process. Again, as in any process, there is variation present in the process of obtaining measurement values. Therefore, to increase the level of trust in the SPC data, one needs to verify whether the measurements are obtained correctly. This is where the Measurement System Analysis (MSA) process comes in. As it is an important and big topic, it will get further handled in section 2.3.

The better the outcomes of MSAs, the more the SPC data can be deemed to be correct and the more narrow the probability density function of the total variation will be (variation in the process and in the measurements combined; there will be less scatter, the measurements will resemble each other more).

2.2.2. Process Capability

Data, which concerns the quality of the process and product measurements, are acquired in-situ while producing. Consecutively, this data are plotted as graphs accompanied by previously determined control limits. These control limits have been defined by the capability of the process itself, as opposed to specification limits which are set by customer desires.

There are two types of process capability of importance for this research; the *normal* C_p and the *indexed* C_{pk}. In the latter, C_p is corrected for the effect of non-centered distributions.

To properly plan the quality side of operations, it is of the utmost importance that it can be assured that the process at hand will stay within specifications. [7] The main goals of SPC are intertwined with this:

- To ensure the process remains stable
  - Stable processes can be influenced in a planned manner
  - Stable processes behave in a statistically predictable way
- To timely (and adequately) respond on changes
- To influence the processes in a clever and predictable way to keep or increase the quality over time [16]

Process Capability - C_p

This has led to the development of a concept called *'Process Capability (C_p)'* which assesses the quality of a process and gives a quantified prediction thereof. Note: one can only use process capability when the stability of the process has been verified and the distribution of measured values represents a normal distribution. [2] Such a normal distribution corresponds to equation 2.1 and is depicted in figure 2.2. To find out whether the measurement values comply with a normal distribution, they can for instance be checked with an Anderson Darling, or Shapiro-Wilk test. [17], [18] & [19]

$$y = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{2.1}$$

Here and throughout this report μ and σ are the mean and the standard deviation respectively. The mean is the average, which is obtained by adding all the outcomes and dividing by the amount of outcomes. The standard deviation is an indication of the amount of variation over all the outcomes. In this particular graph, they're set to be 0 & 1 respectively.

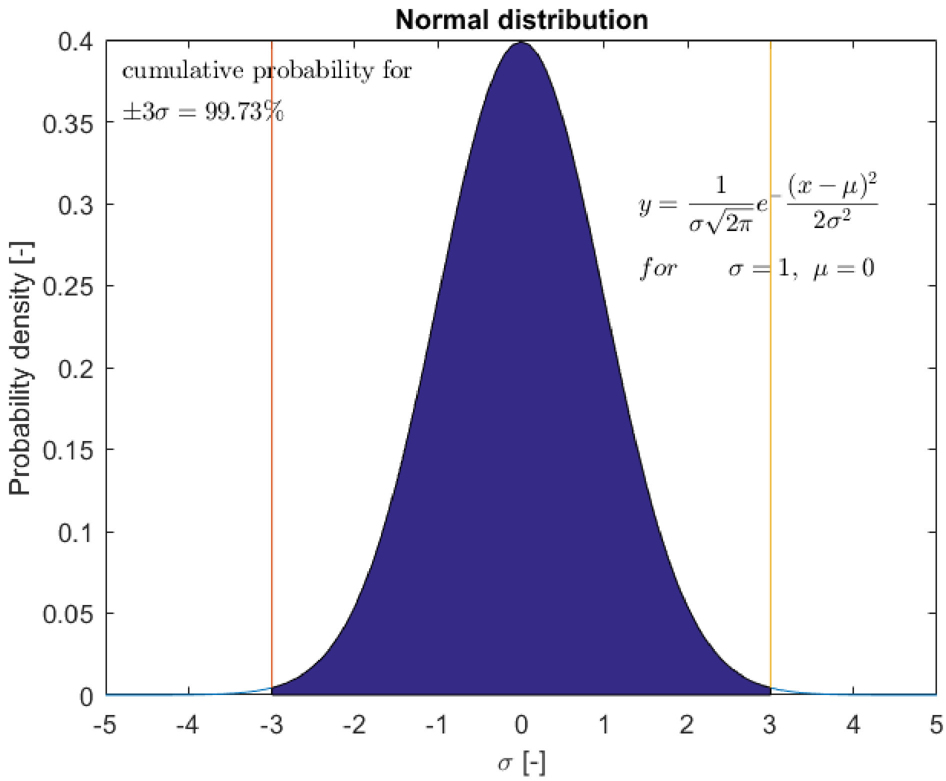


Figure 2.2: Plot of a generic normal distribution, the area underneath the graph is bounded by 3σ and captures 99.73% of the scatter

The assessing of C_p should be done after an MSA has been carried out. As a result, from being able to quantitatively predict the performance of a process, process capability is now widely adopted in quality planning as a major element. Process capability is defined as *"The measured, inherent variation of the product turned out by a process."*. [20] From this definition, a few more words should get defined, to properly stick within the bounds of context.

- Process: It refers to a specific combination of jigs, tools, materials, methods, machines and people, as involved in the production. It is generally worthwhile and enlightening to separate the effects of the variables within the combination and quantify them
- Capability concerns the ability to obtain measurable results over the process
- Measured capability gives reference to the fact that C_p gets quantified from data which are results from work measurements in the process
- When there is product uniformity, due to a process that is in a state of statistical control, it is referred to as inherent capability. In such case, there is no drift over time or any other cause of variation that can be assigned. Another used term for inherent capability is *'instantaneous reproducibility'*

This so called process capability can be captured in a widely adopted formula, which is given in formula (2.2): [4]

$$C_p = \frac{USL - LSL}{6\sigma} \tag{2.2}$$

In this formula, C_p is displayed as a ratio in which the width of the actual process scatter is compared to the width as per customer demand. The actual scatter of the process is represented by six times the estimated standard deviation (σ). This method, in which 99.73% of the scatter is captured, is as such used in calculations as the actual scatter.

Note that this should not be confused with the 6 sigma approach which is well established for lean manufacturing; in this method, at the 6 sigma level, the USL and LSL are represented by ±6 σ from the mean, then even when a shift of ±1.5 σ is present, the process will function well and average about 3.4 *defects per million opportunities (DPMO)*. This can be seen in figure 2.3. [3]

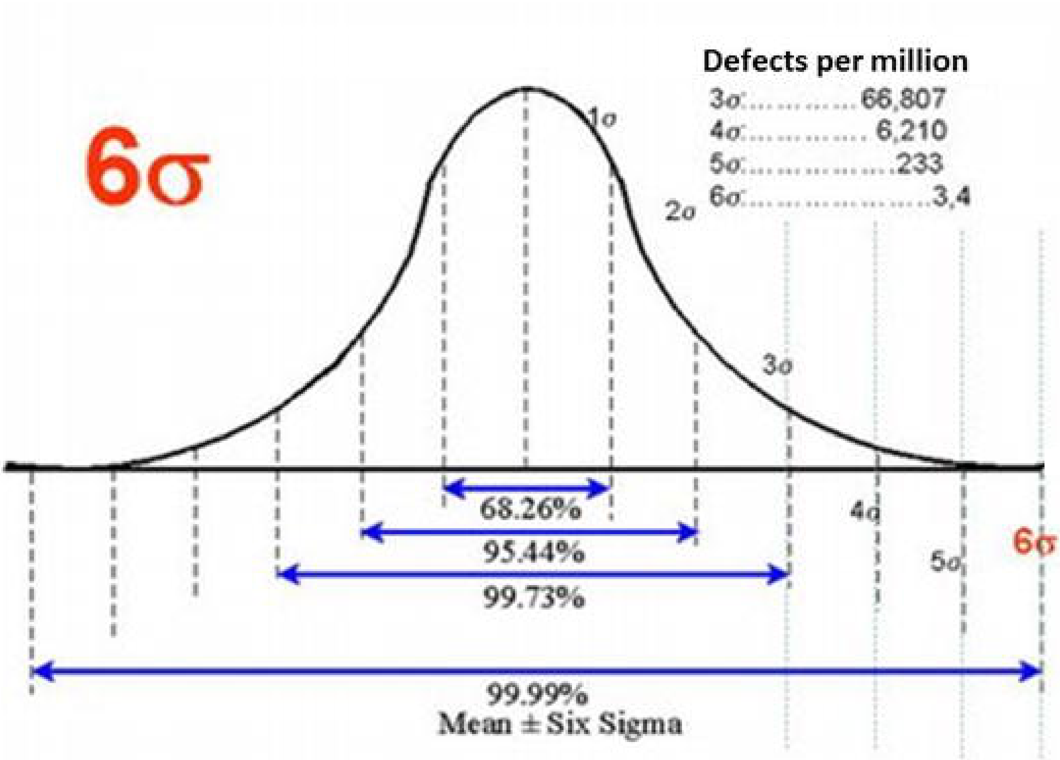


Figure 2.3: Visualisation of the σ levels accompanied by their respective amounts of defects per million opportunities [3]

Note that this holds for a normal distribution, which is being covered here. For a normal distribution, the process is centered at the nominal specifications. The allowable scatter, as per specification/customer demand, is given by subtracting the Lower Specification Limit (LSL) from the Upper Specification Limit (USL); this is the allowable scatter for the particular process.

The process capability can be used in several manners within industry. The most noteworthy are the following:

- To predict how variability has an effect on the examined process. This can be used to put realistic tolerances on specifications
- To select the most appropriate process for a product, adhering to tolerances

- To plan with respect to interrelationship as present among sequential processes. How the precision of a predecessor process can be influenced by a successor process. By quantifying the C_p's of the respective processes, a solution can often be found
- To provide an appraised basis for the establishment of a schedule for periodic process control checks and modifications, if need be
- To assign the machines to those work packages they fit best
- To test theories, related to causes of defects, as noted while going through improvement programs with respect to quality
- To serve as a backbone for the specification of performance requirements, in the field of quality, for procured machines

Referring back to equation (2.2); three distinct groups of outcomes can be obtained, namely:

- $C_p < 1$. This indicates that the scatter of the process is larger than the allowable range. In this case, some of the data will lay outside the specification
- $C_p = 1$. Here the width of the scatter of the process is exactly the same as the width of the specification. There is no room for error
- $C_p > 1$. The preferred situation. The scatter of the process is less than the allowable range for scatter which is marked by the USL & LSL borders. A process with such a C_p is a potential candidate to be selected as the process, as it is fitting within the specification limits, as this will also depend on the location of the average mean

These three cases are further visualised with a set of graphs, as depicted in figures 2.4 till 2.6. Note that all graphs are essentially the same; they have the same shape and size for 6σ. The differences between them are within the specification limits.

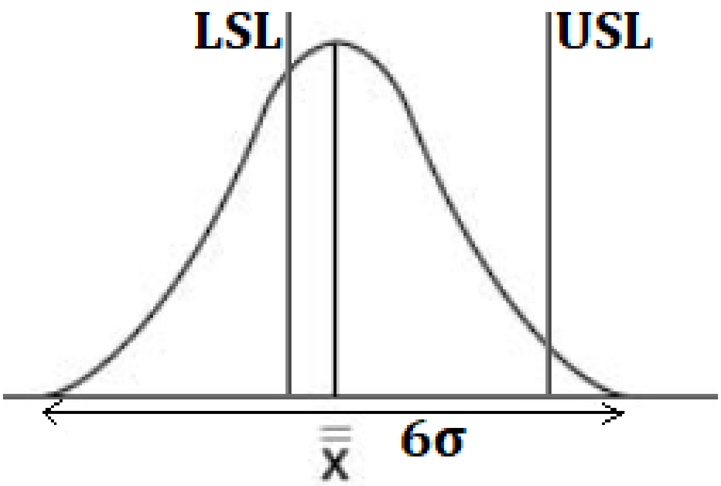


Figure 2.4: Visualisation of a process with a process capability of 0.5 [4]

Note how one can here promptly see, in figure 2.6, that although a process has a C_p which is promising, it might still give a lot of issues. A good chunk of the actual scatter is outside of the specification limits. This lead to the adjustment from C_p to C_{pk}, which is further dealt with in subsection 2.2.2.

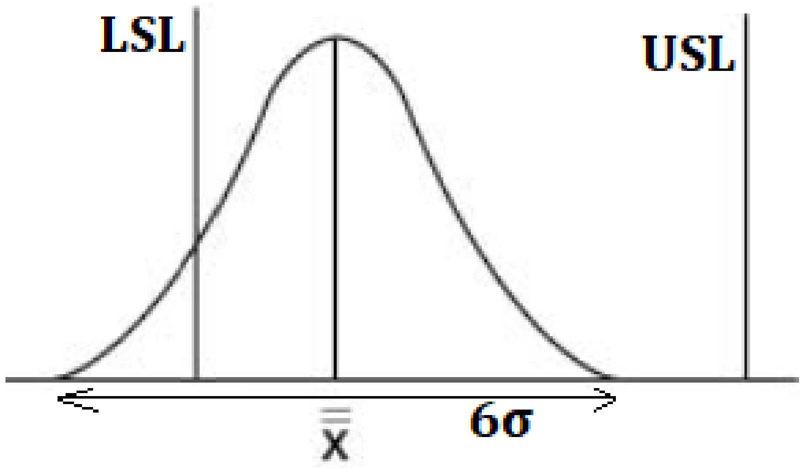


Figure 2.5: Visualisation of a process with a process capability of 1 [4]

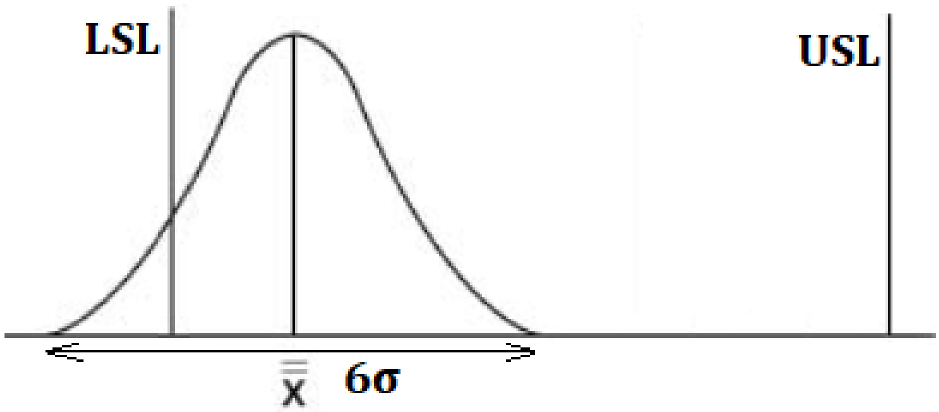


Figure 2.6: Visualisation of a process with a process capability of 1.5 [4]

As a result from the multitude of useful applications of C_p, it is no wonder that the use of C_p is growing. As such, also the execution of C_p studies. To properly conduct such a study and before starting with data acquisition, the purpose for the study should be clarified, as well as other steps needed to assure the purpose gets achieved. More in depth knowledge on executing a C_p study is outside the scope of this thesis, but for the interested reader several sources are highlighted. [21] [22] [23]

In short, the results of the statistical quality data analysis can be summarised in the following four key points: [16]

1. Determining the stability of a process
2. Determination of process capability (C_p)
3. Recognising problem areas
4. Recognition of test reduction potentials

The third point is made easier by the second, which attests to the use of C_p, and the fourth is where the skill of the engineer comes into play, to optimise the process.

Relating this to product specifications, a considerable reason to quantify process capability is to be able to compute a process' ability to stay within product specifications.

To give a view on some typical values for C_p, table 2.1 is provided:

Table 2.1: Table with different values for C_p. [7] *assuming that the process is centred midway between the specification limits

Process Capability (C_p)	Total Product Outside Two-Sided Specification Limits*
0.5	13.36%
0.67	4.55%
1.00	0.3%
1.33	64 ppm
1.63	1 ppm
2.00	0

This table shows the actual meaning behind the C_p value, with respect to production. The importance of a high C_p value can be seen as a function of some variables and / or constants; to name a few:

- The quantity of product which is being produced via this process
- The cost to optimise the process
- The severity of the product falling outside of the specification range
- The (need for) reputation, which respect to quality, of the manufacturer

When for example comparing production processes in car and aircraft industry, the quantity of car components being made will generally vastly overthrow the quantity of aircraft components. As such, a high C_p is of more importance when producing cars. This will therefore support for higher investments for process optimisations.

Process Capability - C_{pk}

Continuing with the centralised version of C_p, it makes sense to get a feeling for its significance. A commonly used analogy comes from parking something in a set space, e.g. an aircraft in its hangar. With the aircraft having width w and the hangar having width 1.5w, the parking should be no problem. Here the walls of the hangar represent the USL & LSL. This situation can be related to figure 2.6. Although the specification width is sufficiently wide to cover the actual scatter, there is still a relatively big chunk of the process variation out of the limits. When however the mean gets centralised, without altering the range of the scatter, the process will be fully within the specification limits (as per 6σ). Once this is done, the C_{pk} is obtained. This can be seen in figure 2.7.

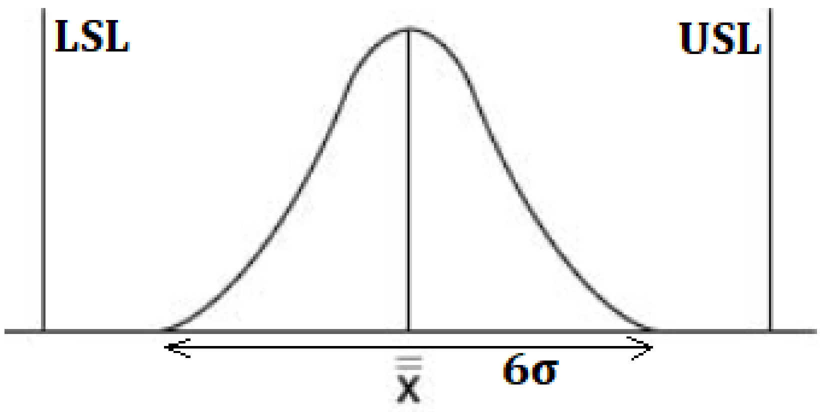


Figure 2.7: Visualisation of a centralised process with a process capability of 1.5 [4]

When it comes to calculating the C_{pk}, another batch of equations show up. Remembering equation (2.2), this needs to get modified to look at the individual parts of the graph separately. Related to the upper and the lower specification limits, this leads to equation (2.3):

$$C_{pl} = \frac{\bar{X} - LSL}{3\sigma}$$
$$C_{pu} = \frac{USL - \bar{X}}{3\sigma} \tag{2.3}$$

By now selecting the smallest value of the two, the C_{pk} is found. Or in equation format:

$$C_{pk} = Min(C_{pl}, C_{pu}) \tag{2.4}$$

2.2.3. The use of Statistical Process Control at Airbus

Airbus is rather comparable with other companies with respect to the use of SPC. The goal is to have the 6 σ scatter of their processes well within the LSL & USL bounds. When the processes then undergo a shift of their mean over time, they will not immediately start giving way worse results. [24]

This gives some freedom to the processes in respect to them undergoing a shift over time and not immediately

As is customary for the use of SPC, processes for which the 6σ scatter is well within specification width are sought after by the firm. This is as such not out of the ordinary when compared with other companies.

What is interesting though, is that Airbus is only working with C_{pk} data now, there is no effort put in extracting information through C_p. It makes sense to have a keen eye on C_{pk} data, as that always leads to checking for the limiting factor, due to the centering which has taken place. As there are a great many of processes at Airbus, which all need to be tracked, a lot of data is being generated. Loads of this data is automatically uploaded and stored in big databases. Data, without any logical way of dealing with it, is just a cluttered mess of numbers. Therefore, to keep checks on what and where they want to improve, they've classified and colour coded the ranges in which their SPC data can lay in the following groups:

- Grey in case there is no C_{pk} data available
- Red for $C_{pk} < 0.67$
- Orange for $0.67 \leq C_{pk} < 1$
- Yellow for $1 \leq C_{pk} < 1.33$
- Light green for $1.33 \leq C_{pk} < 1.67$
- Dark green for $C_{pk} \geq 1.67$

To give an example of how this might look like, with modified data for confidentiality reasons, a picture is inserted as figure 2.8. Although the actual data is edited, the figure is very representative of the figures which are used at Airbus, it as such also shows that there are indeed quite some processes which could, or even should, be improved.

Note that in this figure, *Gage Repeatability and Reproducibility (GR&R)* results are also incorporated, provided they are available. More on GR&R will be explained in section 2.3.

The grey parts in the graph should in reality not be present. All data which is displayed here comes from processes which are tested, verified and validated, otherwise they would not be allowed to be part of the production process of manufacturing aircraft. The cause for these grey entries is data leakage; data is not redirected properly from its stored location, in big data-lakes, to the program which calls upon it to create these graphs. Although this is of course an issue that should get solved, from the companies point of view, it is of no significance for the scientific world as a whole. This issue however comes back in chapter 7 as a recommendation for the future.

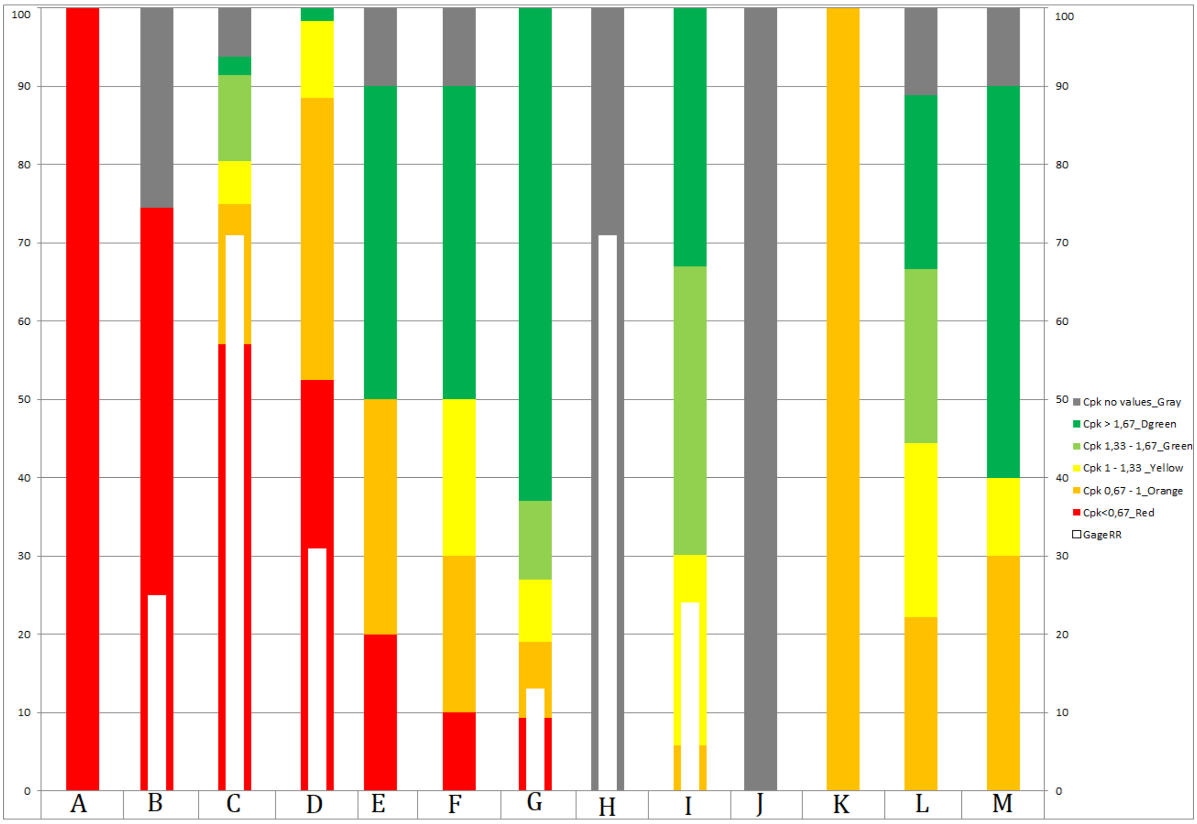


Figure 2.8: Distribution of c_{pk} values for a set of Airbus processes [5]

2.3. Measurement System Analysis

The concept of Measurement System Analysis (MSA) is well established; it is a methodology which is applied in order to measure the amount of variation present in the used measurement device. This allows for quantifying the measurement error as well as reducing the measurement variation as far as possible. After execution of the MSA, potential problems with respect to the measurement device, if any, are exposed. Thereafter, recommendations could be given to facilitate quality improvement by means of alterations with the measurement system.

To obtain a broader knowledge on MSAs and get a better feeling for the needs of a company as Airbus in this field, effort is put into researching several topics. In the first section, the actual use/need for MSAs is discussed. Then in subsection 2.3.2, the steps which are to be taken before an MSA is initiated are inquired into. Thereafter, the types of MSA are further investigated in subsection 2.3.3 and the components of which an MSA is built up in subsection 2.3.4. The last two subsection aim at MSA use at Airbus; in subsection 2.3.5 the current handling of MSAs and an actual execution of an MSA is documented in subsection 2.3.6.

2.3.1. The use of Measurement System Analyses

As was already mentioned in section 2.2, the industrial world is going through continuous changes. The one at hand is *Industry 4.0* and drives quality to ever more demanding standards. When trying to stay on top of those demands, the concept of MSAs kick in.

The concept of Measurement System Analysis (MSA) is well established; it is a methodology which is applied in order to measure the amount of variation present in the used measurement device and the entire system involved in obtaining the measurement values. [25] This allows for quantifying the measurement error as well as reducing the measurement variation as far as possible. After execution of the MSA, potential problems with respect to the measurement device or e.g. the environment in which the MSA is executed, if any, are exposed. Thereafter, recommendations could be given to facilitate quality improvement by means of alterations on the measurement system.

To give some insights on the effects measurement errors actually have upon acceptance decisions, the two options that can occur are evaluated. [7] First, wrong decisions can be made on single products, second on batches that are to be sampled. Next, another division can be made how the classification of the product can be done incorrectly; a unit that is conform regulations is falsely rejected, which is purely a financial risk for the manufacturer. Or conversely, a unit that is not conform its specifications is falsely accepted, which is a client's risk in first line, yet also a manufacturers, as it may have consequences on further orders. The relation between precision, it's definition will be elaborated upon later in subsection 2.3.4, and these errors has already been proven. [26] Further analysis of it will not bring anything in the scope of this thesis and is therefore not proceeded. For the interested reader, more investigations with respect to the effects of inspector errors are referenced in [27] and [28] as well as the probability of rejecting or accepting a process without having GR&R data for that process. [29] This again stresses the usefulness of MSAs, as they prove that measurement errors can have serious consequences.

Variation in the observed measurements is caused by several causes. The relationship between the total variation as observed and those per independent cause, is given as follows in formula (2.5):

$$\sigma_{tot} = \sqrt{\sigma_A^2 + \sigma_B^2 + \dots + \sigma_N^2} \tag{2.5}$$

Evaluating this formula, it is worthwhile to locate which cause is having the biggest impact, in order to direct most effort onto reducing that influence. Note that in essence, the contributing factors are added up, so the more independent factors present, the larger the total variation will be. A first order division can be made in between variation caused by the process and by the measurement system. The first type of variation is of lesser interest with respect to the scope of the thesis, the second is depicted in figure 2.9.

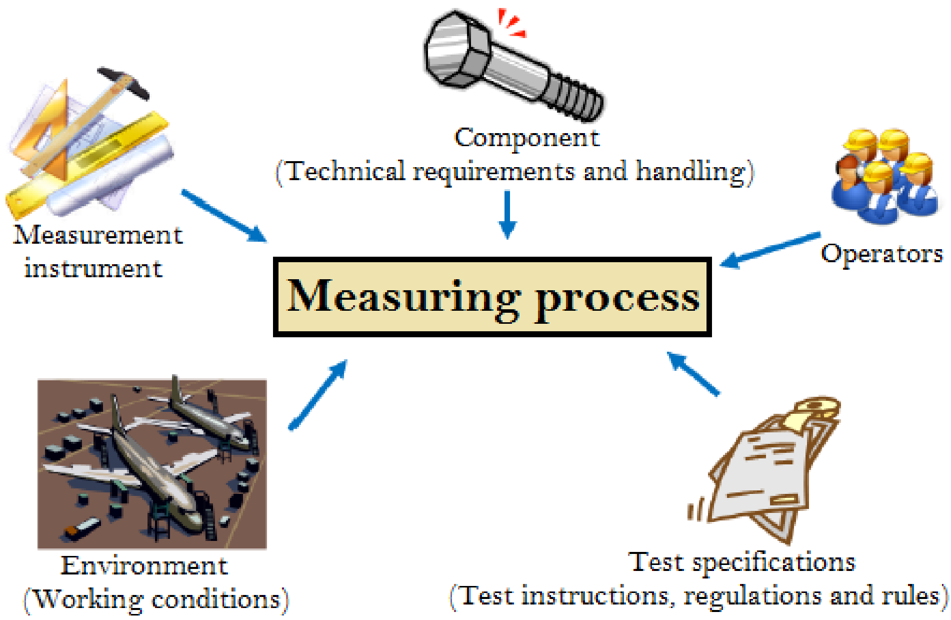


Figure 2.9: Factors which cause variation while conducting measurements [6]

In this figure, five distinct areas, that have an influence on the measurement system, are highlighted.

2.3.2. What proceeds a Measurement System Analysis?

To be able to execute an MSA, one should first determine whether the process is capable of undergoing an MSA which gives meaningful output. [2] Therefore such a process should comply with the following requirements:

- The process should revolve around variable data (e.g. length, width, weight, etc.),
- There should be enough (minimum 30) measurements,

- The data, which is being utilised, should originate from a stable process (be tested on stability),
- This data should approximate a normal distribution (test the data whether it does).

Of course, before embarking on executing MSAs left and right, one needs to find out what is useful to know. [7] One should setup a plan for data collection. What are the right questions to ask? These questions are essentially information seeking and could for example be:

- What is the cause for the problem?
- With which frequency does the problem occur?
- What is the impact of the problem? Relating it to time/money/quality.

What is to be understood, is that good information is always supported by good data; the facts. Nevertheless, just harvesting data does not necessarily lead to obtaining suitable information. Therefore, the main issue is about *"How to obtain useful information?"* instead of *"How to collect data?"* This often stands in contrast to how most companies have huge amounts of data concerning their processes, yet are not able to extract genuinely relevant information out of it. For instance, as will later also turn out to be a problem for Airbus specifically, there is a lot of data available on the costs involved with the processes, but they are lumped together in such a fashion that more variables are into play. As such, the root cause can not easily be distilled out of the data. This stems from the so called practice of *"data diving"* in which organisations look at a great amount of available data, if not all, to educate themselves in whichever way possible about the processes. Even though this tactic can produce useful information, it is not the most efficient one, as a lot of data which will be looked at has no added value for the cause. Planning the data collection while having the end/goal in mind, as described here, is much more effective as well as efficient, provided it is executed properly. To summarise; the generation of information starts and terminates with asking and answering questions:

- First, formulate, as precise as possible, a question that leads to the wanted answers
- Amass data which is relevant for that question
- Carefully analyse this data to come to an answer to that question
- Present the data such that it answers the question in a clear way

Therefore it is paramount, for data collection, to learn to ask the right questions. Data is irrelevant, as long as it doesn't answer a or several questions that are cared about, no matter how accurately it has been obtained by means of well-crafted sampling plans. The process that comes along with this planning is depicted in figure 2.10. Notice how it starts and ends with questions by going forwards and backwards through the same steps. First, questions get defined, then thoughts about how to communicate the answers to these questions are evaluated and what kind(s) of analysis/analyses should be performed. After which the data gets generated, analysed and communicated to answer the questions; leading to information.

This figure can be elaborated upon by connecting it to a sequence of steps that likewise lead to the generation of functional information.

1. Establish the objectives related to the data collection and formulate questions accordingly in specific statements:
    - For which reason is data being collected?
    - What process or product is being monitored to obtain data from?
    - What are the expectations? What is essentially being tested?
    - For which question(s) should the data be beneficial?
2. Make decisions on what to measure, while considering how to communicate and analyse it:
    - What data is needed?

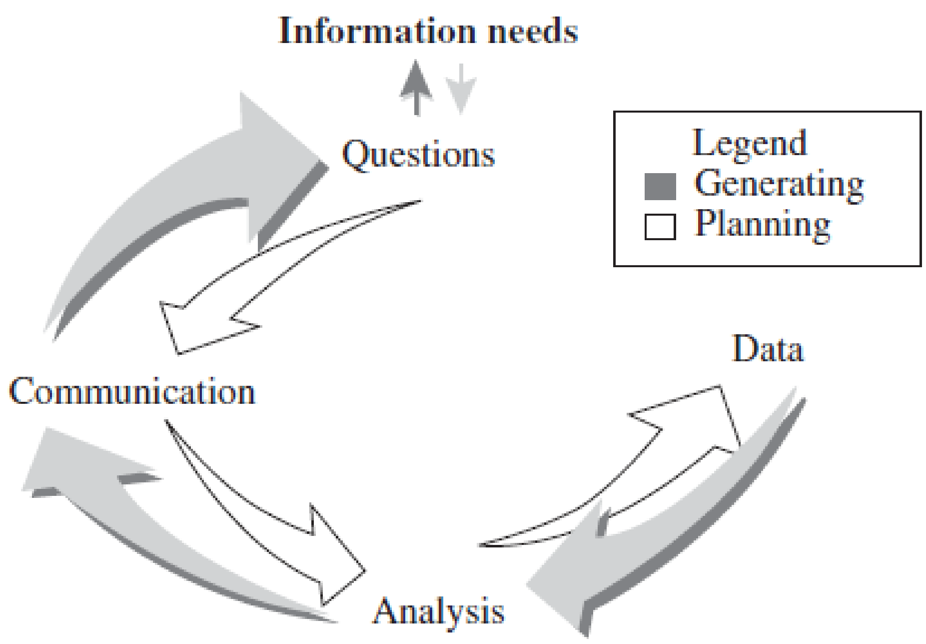


Figure 2.10: The information needs cycle [7]

- What kind of measurement is it? E.g. physical measurements, indices, rankings, ratios, etc.
- What kind of data is it? E.g. qualitative vs quantitative and variable vs attribute data.
- How has each measurement been operationalised? In which operationalising is defined as *'The process of choosing and accurately describing the indicators for complex and/or abstract concepts.'* [30] E.g. is it now clear what is to be measured and how this will be done?
- How will the data be analysed and transferred?
- Are there applicable data from the past available?

3. Decide on how to conduct the measurements (for/on a sample):
    - With which measurement tool will the measurements be made?
    - What kind of sampling strategy is being applied? E.g. simple random or stratified random sampling. [31]
    - How much data is to be collected? Having usefulness in mind; calculate the sample size needed for the required precision of results, the statistical risks that accompany it as well as the variability of the data and the ever present measurement error.
    - What is the actual method of measuring?
4. Collect the wanted data while minimising bias.
5. Come up with comprehensive (physical) locations or times and where or when data can be collected.
6. Pick and educate unbiased operators:
    - Understand these operators and the environment they operate in.
    - How to collect the data from the sources with the least chance for mistakes and minimised effort?
7. Conceptualise, design, prepare and test the methods, forms and instructions for data collection:
    - When reflecting; what further information would be useful with respect to analysis, reference or traceability in the future?

- To confirm accuracy and precision of the measurements, conduct measurement system analyses (MSA).

8. Execute an audit on the collection process and validate the results.
9. Screen and analyse the data.
10. Evaluate the steps that have been taken so far, e.g. the assumptions concerning the sample size. If need be, make corrective actions.
11. Evaluate the problem by means of graphical and statistical techniques.
12. Consider and determine whether more data and analysis is beneficial c.q. required.
13. Ponder over the idea of executing a sensitivity analysis.
14. Evaluate the conclusions as obtained through the data analysis in order to determine whether the original problem has been appraised or whether it has been modified to fit in the framework of the statistical methods.
15. Show the outcomes in a manner which can be read comfortably: Create a (short) report in which the conclusions follow from results that stem from the prime problem, instead of from statistical indexes as used for the analysis. When appropriate, use graphics and keep only the simpler statistical methods in the body of the report, while dropping the complexer analyses in the appendix.
16. Investigate and determine whether the conclusions with respect to this problem apply for other problems as well and whether the data, accompanied by the calculations, could be of any use for other problems.

In the entire process of deciding what information is wanted and how to obtain it, the decision for which sensor to use should also not be forgotten. The sensor, when staying in the context of operational control subjects, is the device or person that actually makes the measurement. To be able to decide on what sensor to use, one should also define how the measurements are to be made, which includes who will make them and when. It goes without saying that a sensor should also be economically feasible and easy to use. Furthermore, as it is an integral part of the measurement system towards delivering data that potentially leads to decisions on the process, it has to be accurate and precise.

Deploying the measurement process, once it has been decided to be useful, leads to the following flowchart, as can be seen in figure 2.11:

2.3.3. What types of Measurement System Analyses are there?

Subjecting the MSA to measurements of a dimensional nature in production processes, the conformity of the product can be evaluated. Next to the obtained information concerning the measured product, the results of these measurements are indispensable to analyse the measuring system as used in the specific production processes. There are three distinct manners of using measurement systems. In the first, the capability of the measurement system is evaluated for one object to be measured by one operator. In the second, there is still only one object, but with several operators and in the third there are several objects and operators. These three cases are also tabulated in table 2.2.

Table 2.2: Three distinct manners of using measurement systems

Case	# of Objects	# of Operators
1	1	1
2	1	More
3	More	More

Note that for case 1, there is only 1 operator. This has an effect on the type of analysis that can be performed; e.g. there is no reproducibility to be evaluated. Reproducibility is further elaborated upon in subsection 2.3.4.

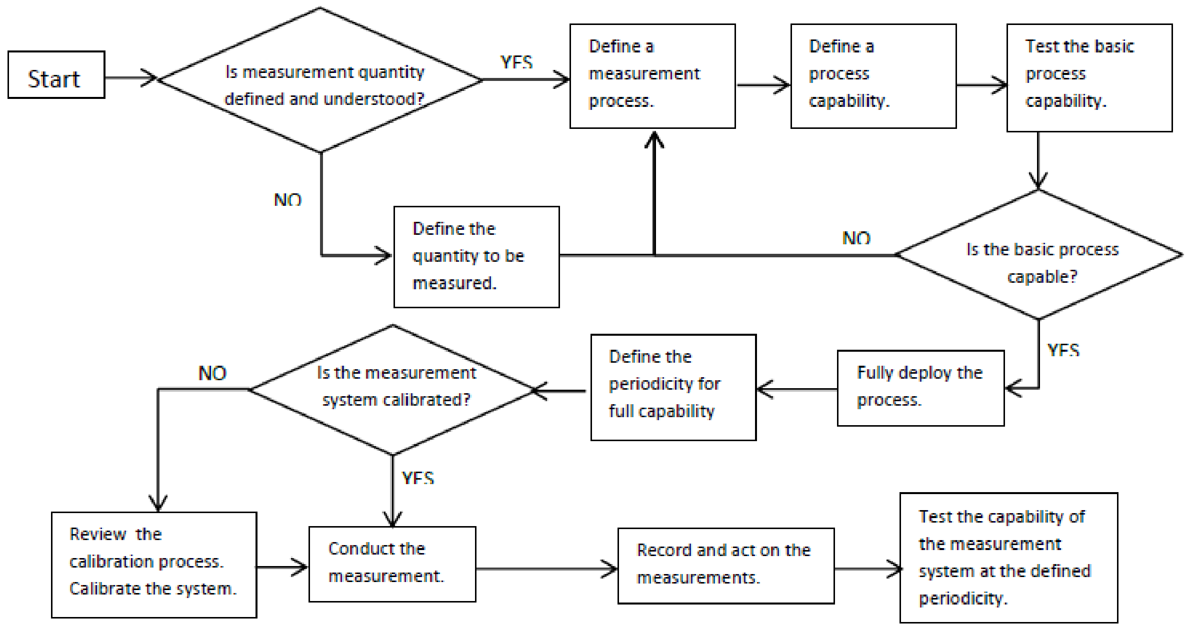


Figure 2.11: A flowchart depicting the key steps which are to be executed when deploying a measurement process [8]

An MSA is often performed with a focus on precision. This leads to the execution of a Gauge Repeatability and Reproducibility (GR&R) study, which is a specific type of MSA. This can also be further divided in nested and crossed evaluations. Alike reproducibility, further clarification about this is given in subsection 2.3.4.

2.3.4. What are the main components of a Measurement System Analysis?

In this subsection, a slightly more comprehensive outline on measurement systems and their analyses is given. Considering that if a measurement system can't be trusted, the data coming from it can't reliably be trusted either. If in the next step these data are used to make decisions upon, these decisions will be flawed too, as per the *'Garbage In, Garbage Out' (GIGO)* principle. [7] [32]
Therefore, it is paramount that the measurement systems which are being used are proper; that they effectively function in the way they're supposed to. When discrepancies in the measurement system become visible upon execution of a measurement system analysis and no actions result from it, the MSA was a waste of money and time. A proper measurement system should comply with a few standards to allow for good process control, the design of new products or the exclusion of perpetuating random variation. These encompass the following:

- Accuracy
  - Bias
  - Linearity
- Precision
  - Stability
  - Repeatability
  - Reproducibility

This decomposition, in which bias and linearity are part of the accuracy and stability, repeatability and reproducibility part of precision, follow the ideas of Juran and are most often followed. [7] There are however also other sources in literature, in which stability is set as part of accuracy, or even where accuracy is seen as a term which covers both trueness and precision. [33] [34] The latter is even adopted by certain branches within Airbus.

To determine the capability of such a measurement system, a measurement system analysis is performed. This is done by running a set of carefully crafted experiments or measurements which quantify the errors in the gauge. These errors exist in the two distinct categories as mentioned before: *accuracy* and *precision* [20] [35]. As the two terms are often used in the wrong manner, they are both explained by means of a graphic and an accompanying table, respectively figure 2.12 and table 2.3. Here a V implies that it conforms with the statement and an X that it doesn't. Note that these terms are relative; what may be judged as accurate or precise by one, might not be for someone else, often depending on the process to which they're subjected. Nevertheless the one is always viewed as more accurate or precise as the other. *Accuracy* gives reference to how correct measured values are; it describes the difference between actual values and what was measured. On the other hand, *precision* refers to the grouping of the measurements to each other; it shows the variation between the measurement values while executing the same measurements. To quote from the international vocabulary book of metrology for the intermediate precision condition of measurement: *'Condition of measurement, out of a set of conditions that includes the same measurement procedure, same location, and replicate measurements on the same or a similar object over an extended period of time, but may include other conditions involving changes. The changes can include new calibrations, calibrators, operators and measuring systems.'* [20] [36] [37] It is a measure of the consistency and reliability.

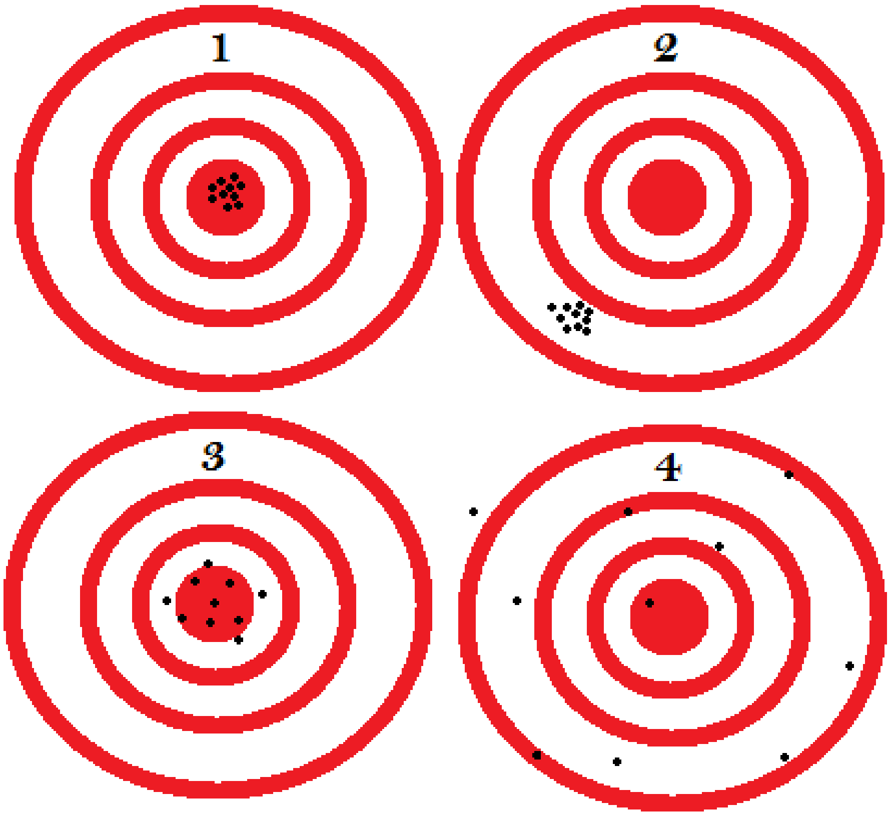


Figure 2.12: Visualisation of precision and accuracy

Table 2.3: Four cases regarding precision and accuracy

Case	Precise	Accurate
1	V	V
2	V	X
3	X	V
4	X	X

In the first category, bias and linearity are placed. Bias is the estimate of a systematic error. The systematic measurement error is a component of measurement error that for replicate measurements varies in a predictable way or is even constant. It is the difference which can be seen between the averaged value as measured and a set reference value. In which the reference value is a pre-set agreed standard. With this reference standard, the measurement system can be calibrated. The bias creates an offset making all measurements wrong by a certain predictable amount. This bias can be clearly seen in the upper right corner of figure 2.12 (2) and is also plotted in figure 2.13. Bias can furthermore be split up in absolute and relative bias. [8] With the first describing the difference as observed for the average measurements and the value of the master average of the exact same part. Whereas the latter is the difference as is observed between the averages of several operators.

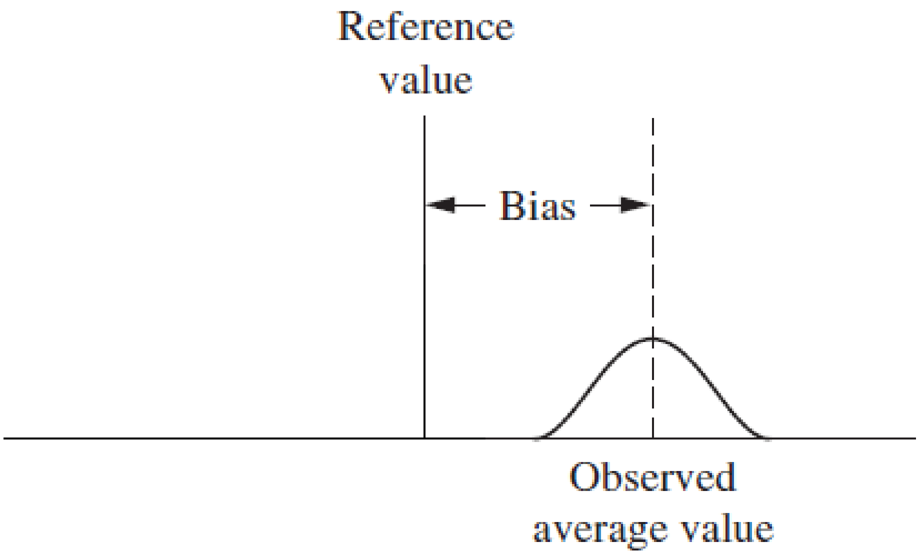


Figure 2.13: Bias; a miss match between the observed average value and the reference value for the measurements of a process [7]

Linearity is a specific kind of bias; it is the bias over a specific range of the measurements. More precise: the operating range of the measurement equipment. This linearity too, is further explained by means of a picture, as can be seen in figure 2.14. Note that on the left hand side picture, a greater bias is present for measurements. Take for example the process of measuring the width of holes; holes with a diameter of about 1mm are more accurately measured, than those with a width of around 10 mm - in this specific example.

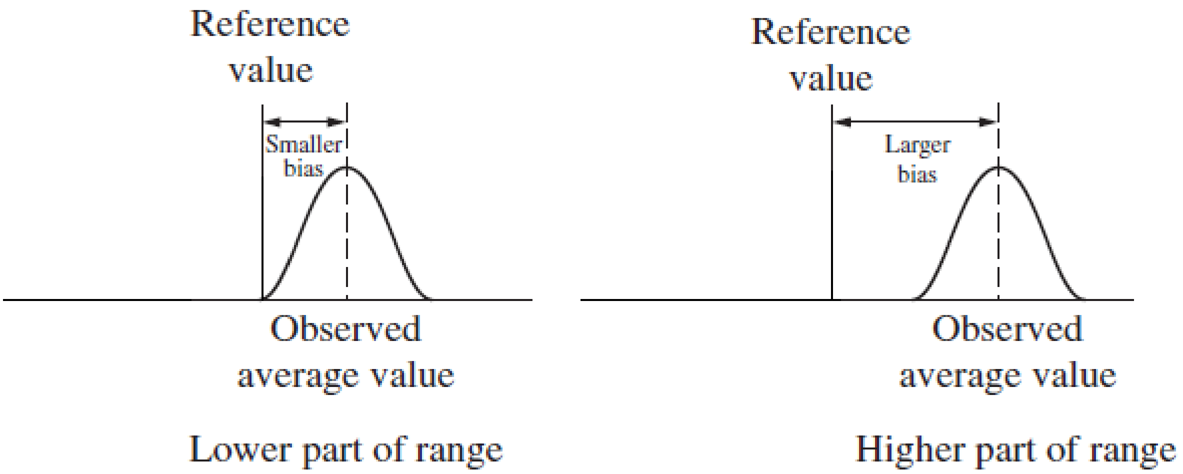


Figure 2.14: Linearity effects as observed within the measurements, at the lower and higher parts, of the operating range of a process [7]

The second category holds stability, repeatability and reproducibility. Here stability is the total variation for a single characteristic, as obtained over the measurements with the same measurement system, on the same part for a prolonged period of time. This stability is depicted in figure 2.15. Note that although the reference value and the overall shape of the distribution remain the same, the entire distribution is shifted to the right and therefore the measurements are off.

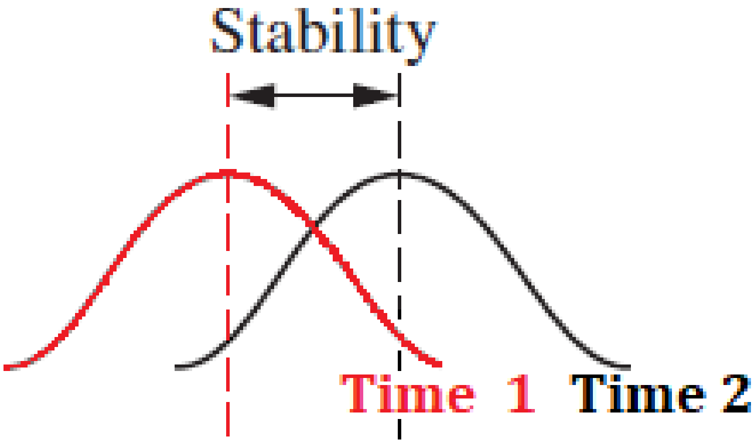
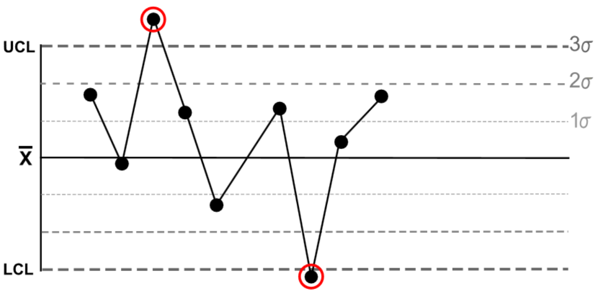


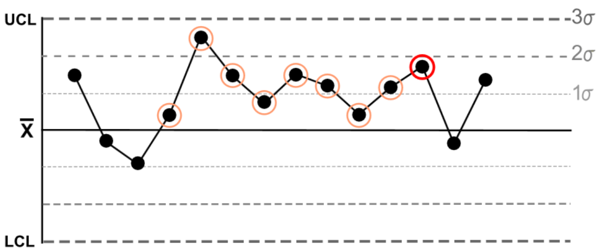
Figure 2.15: Stability effects on the measurements of a process [7]

The main requirement for a process to be considered stable, is that its measurement values stay between the upper and lower limits over time. Next to this, a few other rules should also be taken into account before assuming the process is indeed stable. These rules are applied on a control chart, on which one plots the magnitude of a variable against time. The most noteworthy are defined as the Nelson Rules and given in the following list of 8: [2]

1. There shouldn't be any values more than three standard deviations (σ) away from the mean. Such a occurrences indicate a shift in mean, standard deviation or an outlier. This is visualised in figure 2.16a.



(a) Violation of the first Nelson Rule [2]

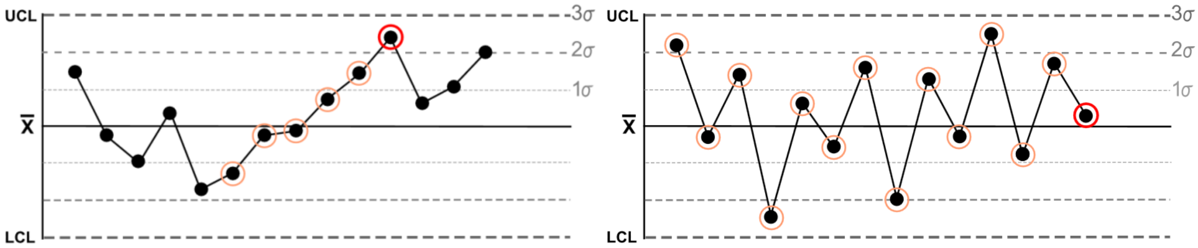


(b) Violation of the second Nelson Rule: [2]

Figure 2.16: Violation of the first two Nelson Rules: (a) values are off by more than three σ, this indicates a shift in mean, standard deviation or an outlier (b) more than eight consecutive values on the same side of the mean, this indicates the existence of bias [2]

2. There shouldn't be more than eight consecutive values on the same side of the mean. Such an occurrence indicates the existence of bias; a shift in the mean. This is depicted in figure 2.16b.

3. There shouldn't be more than five consecutive values going in the same direction, neither up nor down. Such an occurrence indicates the existence of a trend. A visualisation hereof is shown in figure 2.17a.



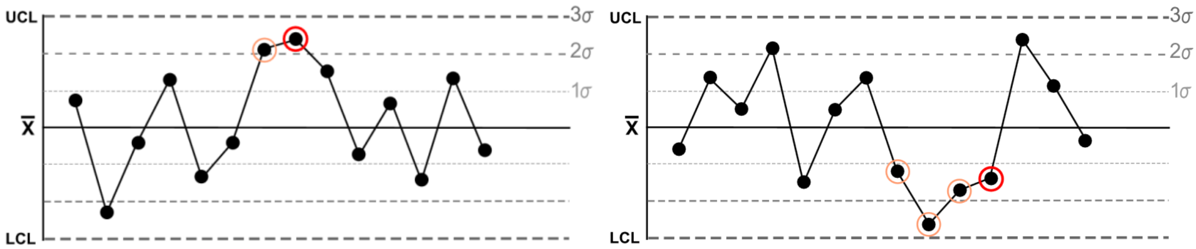
(a) Violation of the third Nelson Rule [2]

(b) Violation of the fourth Nelson Rule: [2]

Figure 2.17: Violations of the third and fourth Nelson Rule: (a) more than five consecutive values in the same direction; indicating the existence of a trend (b) more than 13 consecutive values alternating in direction; a sign that data originates from two different sources [2]

4. There shouldn't be more than 13 consecutive values alternating in direction. Such an occurrence goes beyond normal oscillation from noise. It is a sign that the data originates from two different sources. An example of this rule can be seen in figure 2.17b

5. There shouldn't be more than one out of three consecutive values more than two standard deviations (σ) away from the mean in the same direction. Such an occurrence indicates a medium likelihood for the sample to be moderately out of control. This behaviour is depicted in figure 2.18a.



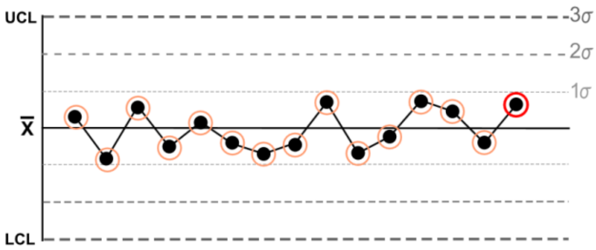
(a) Violation of the fifth Nelson Rule [2]

(b) Violation of the sixth Nelson Rule: [2]

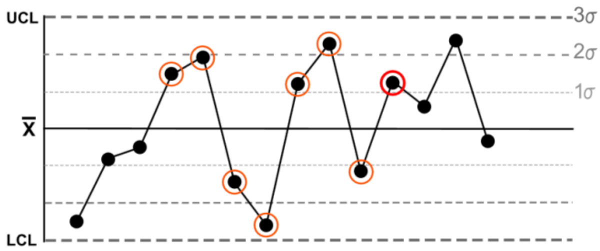
Figure 2.18: Violations of the fifth and sixth Nelson Rule: (a) more than one out of three consecutive values more than two (σ) away from the mean in the same direction; indication of being out of control (b) more than three out of five consecutive values more than one (σ) away from the mean in the same direction; again indication of being out of control [2]

6. There shouldn't be more than three out of five consecutive values more than one standard deviation (σ) away from the mean in the same direction. Such an occurrence indicates a strong tendency for the sample to be somewhat out of control and can be observed in figure 2.18b.

7. There shouldn't be more than 14 consecutive values less than one standard deviation (σ) away from the mean. Greater deviations would be expected. Here, this feat is included as figure 2.19a.



(a) Violation of the seventh Nelson Rule [2]



(b) Violation of the eighth Nelson Rule: [2]

Figure 2.19: Violations of the seventh and eighth Nelson Rule: (a) more than 14 consecutive values less than one (σ) away from the mean (b) more than seven consecutive values more than one (σ) away from the mean [2]

8. There shouldn't be more than 7 consecutive values more than one standard deviation (σ) away from the mean in either direction. Such an occurrence indicates a high probability for the sample to be out of control. In figure 2.19b, an example of such an occurrence is presented.

When a violation of one or more of these rules is observed, the process can be assumed to be under influence of special causes. In case such special causes are present, the likelihood of the process to be stable is very slim. These rules are also applied in statistical programs such as Minitab and of value for the remainder of this document.

When the process is complying with these eight rules and values remain between the upper and lower limits over time, the measurement system is found to be stable. This stability is a requirement to ensure that the process capability (C_p) can be calculated and its data used.

The repeatability, also known as the equipment variation (EV), with respect to the measurements, is evaluated along the repeatability condition of measurement, which is stated in [20]: *'Condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location and replicate measurements on the same or similar objects over a short period of time.'* The repeatability can be captured in a sixsigma approach where it is often visualised as a distribution, as depicted in figure 2.20:

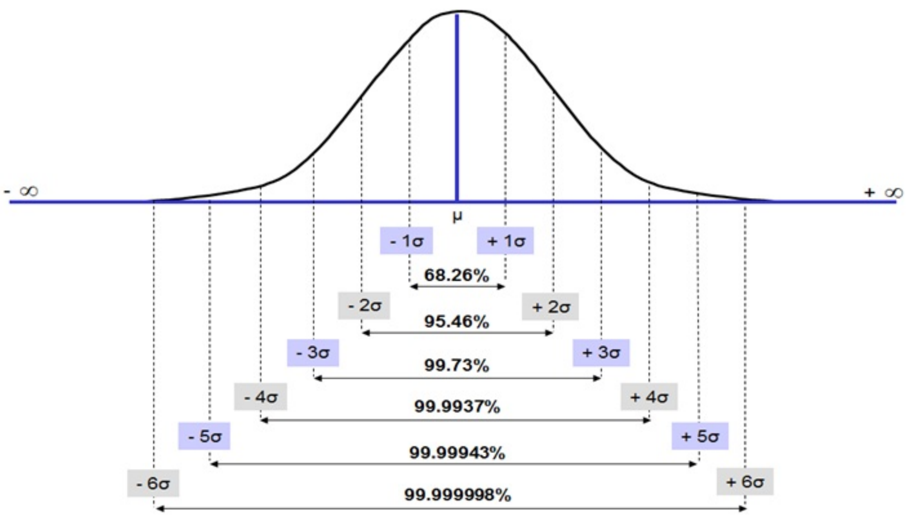


Figure 2.20: Normal distribution with six σ levels [2]

Here the area underneath the graph shows the probability of a measurement being within the upper and lower limits. For example, a measurement hat 68.26% chance to be within $\pm$ 1σ and 95.46% chance to be within $\pm$ 2σ.

Considering repeatability, there are a few common errors that can be present in it. Varying the position of the part or the instrument, are the two main leading causes for errors in measurement with respect to repeatability. Next to these two main causes, less likely errors are:

- Instrument related: poor maintenance or quality of the measuring instrument
- Reference related: poor maintenance or quality of the part used as reference
- Application related: depending on how the operator executes certain tasks, such as his or her technique, calibration, holding (of the device or part)
- Sample related: surface finish, taper, form
- Environment related: humidity, temperature, lightning, cleanliness, vibration, noise, smell
- Operator related: experience, fatigue
- Assumption related: having incorrect assumptions or violating (an) assumption(s)

Likewise, the reproducibility, a measure for appraiser variation (AV), is evaluated along the reproducibility condition of measurement, which is also stated in the International Vocabulary of Metrology: *'Condition of measurement, out of a set of conditions that includes different locations, operators, measuring systems and replicate measurements on the same or similar objects. These different measuring systems may use different measurement procedures.'*[20] It is the variation in the averaged measurements as obtained by different operators who utilise the same measuring device while measuring the same part for the same characteristic. The reproducibility can be perceived more clearly through a picture and is shown in figure 2.21:

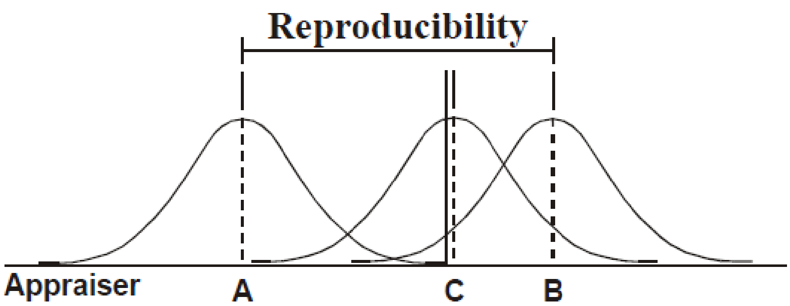


Figure 2.21: Visualisation of the concept of reproducibility by means of three distinct appraisers [2]

Evaluating the scatter of the three appraisers in this figure, operator C has the most desired results, followed by B and finally A. C is most centered around the actual value.

The error sources associated with reproducibility are also very similar with respect to repeatability. Here the focus is on differences between alike conditions, such as using the same type of instrument, just a different production number, while keeping the other factors constant. Or when evaluating different, yet similar, parts while keeping all other influences to be unaltered (same operator, measuring instrument, method, etc):

In case there would be big numerical gaps between the *repeatability* and *reproducibility*, solutions could be found by tackling specific errors and causes:

- Extended training for operators; how to handle, use and read the gauge
- Calibration should be executed properly
- Lack of a jig; a jig could help to increase the consistency in which an operator executes his or her task

- Maintenance of the instrument
- Redesign of the instrument
- Location where the gauge is applied
- A too large amount of variation is present between different samples

With the first three related to *reproducibility* and the latter four to *repeatability*.

Note that in these figures (figure 2.13 through 2.15 and 2.20 & 2.21), for simplicity's sake, only a normal distribution is shown. It is the most common probability distribution; other common ones are the exponential, Weibull, Poisson and binomial distribution. Where the first three are for continuous data; a characteristic which is being measured can have any value and the latter two for discrete data; the characteristic can only take specific values, e.g. integers: 0, 1, 2, etc. For completeness, these five common types are shown in figure 2.22, giving the type, form, probability density functions and applicability of the distributions. All other types of distributions are not further mentioned.

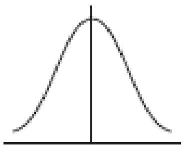
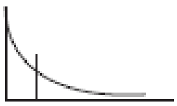
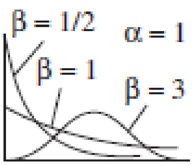
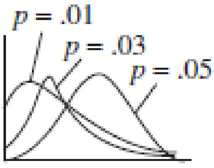
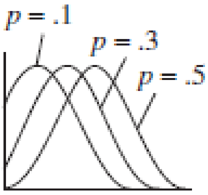
Type of distribution	Form	Probability function	Applicability
Normal		$y = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$ μ = Mean σ = Standard deviation	Applicable when there is a concentration of observations about the average and it is equally likely that observations will occur above and below the average. Variation in observations is usually the result of many small causes.
Exponential		$y = \frac{1}{\mu} e^{-\frac{x}{\mu}}$	Applicable when it is likely that more observations will occur below the average than above.
Weibull		$y = \alpha\beta(X-\gamma)^{\beta-1}e^{-\alpha(X-\gamma)^{\alpha}}$ α = Scale parameter β = Shape parameter γ = Location parameter	Applicable in describing a wide variety of patterns in variation, including departures from the normal and exponential.
Poisson		$y = \frac{(np)^r e^{-np}}{r!}$ n = Number of trials r = Number of occurrences p = Probability of occurrence	Same as binomial but particularly applicable when there are many opportunities for occurrence of an event but a low probability (less than .10) on each trial.
Binomial		$y = \frac{n!}{r!(n-r)!} p^r q^{n-r}$ n = Number of trials r = Number of occurrences p = Probability of occurrence $q = 1 - p$	Applicable in defining the probability of r occurrences in n trials of an event that has constant probability of occurrence on each independent trial.

Figure 2.22: A set of distribution types [7]. The normal distribution is applicable throughout this report

To be able to actually make sensible comments on the accuracy and precision of a certain process, three criteria need to be adhered to, namely:

- The test method should be defined. Within this definition, a step-by-step procedure, the equipment to use, the preparation of the test samples, the test conditions and more should be agreed upon
- All the causes of variability within the system should be defined, amongst others: analysts, material, days, material, laboratories, etc.
- There should be valid SPC, verifiable by control charts, which has stability with respect to accuracy and precision

The main components of an MSA are visualised in figure 2.23 as a chart, to see how these are linked.

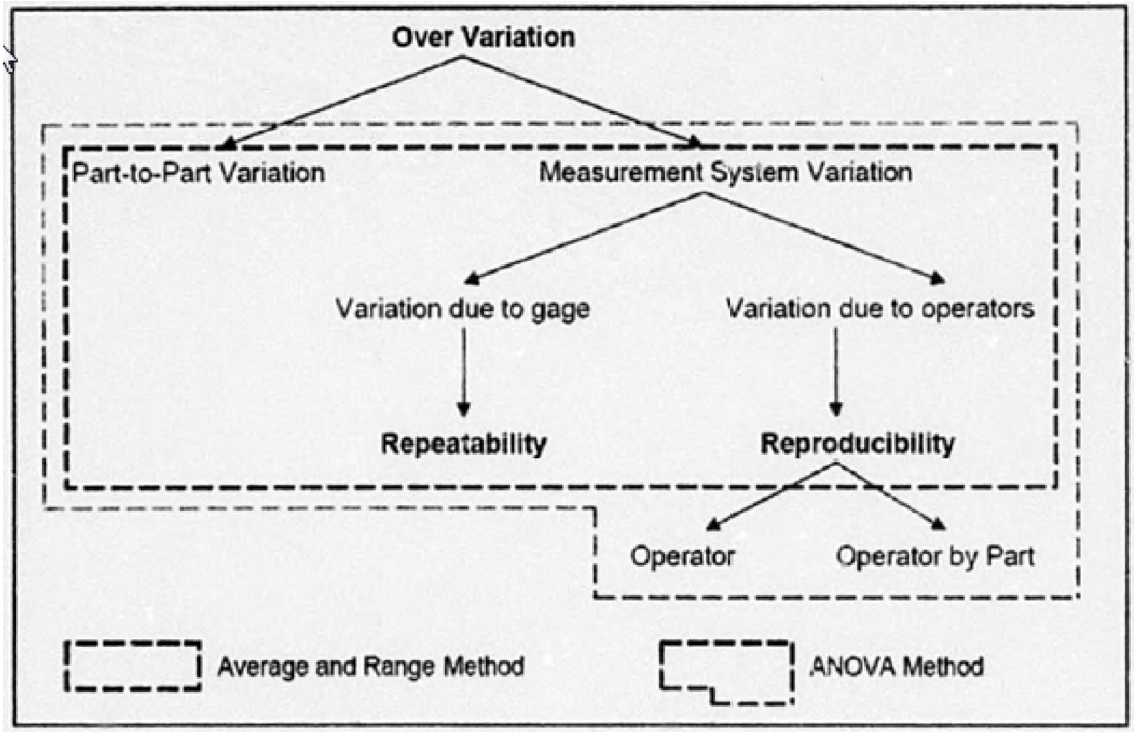


Figure 2.23: A breakdown of the Average and Range method and an extension to the ANOVA method for analysing variation in measurement results. [6]

2.3.5. How does Airbus handle Measurement System Analyses?

As one might expect for a company of the size of Airbus, there are a lot of protocols in effect for all the processes they have running with respect to MSAs. To name a few of the most noteworthy:

- A2019.6: Implement Measurement System
- FM1104083: R&R Report Template
- FM1104084: Gage R&R Planning Template
- FM1243349: Request For Measurement Systems
- FM1303607: Measurement System Work Specification

- FM1306878: Compliance Matrix
- FM1306911: Measurement System Handbook
- FM1306912: Conformity Inspection at Purchaser Site (CIPS)
- M20242_A: Measurement Systems: Proceed with Metrological Confirmation
- M20243_B: Measurement Systems: Qualify and Deploy
- M20244: Measurement Systems: Analyse the Request & Manage Actions
- M7029A: Measurement System Analysis Gage R&R
- RE1108187: Measurement System Analysis GR&R

Note that the starting characters showcase what kind of a file it is; here A, FM, M and RE represent, respectively: Action plans, Templates, Manuals and Requests.

The manuals are to be considered as guides which have to be followed to minimise the risk of errors being made. For instance, the purpose of *M20242_A: Measurement Systems: Proceed with Metrological Confirmation* is: *This Manual describes the activity box "Proceed with metrological confirmation" in order to ensure that measuring equipment and measurement processes are adequate for their intended use and to ensure the achievement of product quality objectives and management of the risk of incorrect measurement results. The metrological confirmation is the set of operations required to ensure that measuring equipment conforms to the requirements for its intended use.* [38]

Having obtained a thorough understanding of MSAs, it is vital to come up to speed with the way how Airbus goes about with them. [6] Airbus initially only analyses the Gauge R&R and in case of the Gauge R&R failing (need <30% for total GR&R and >3 Number of Distinct Categories (NDC) for the MSA to be capable [39]), also looks over the *stability*. The *linearity* and *bias* (*accuracy*) are of no further interest. This makes sense as the processes by Airbus are concerning large volumes of data and as such systematic errors can be corrected for in a reliable way. There is an extensive guide present for the exact roll out of MSAs for Airbus processes. [40] The most important information in this guide is that whenever an MSA is being performed on a process, it should be done in such a way to ensure the highest similarity with how measurements are normally performed. To paraphrase from German: *"The test must be structured in such a way that it takes the 'actual process' into account as far as possible. This means that the set-up of the measuring instruments should be carried out by the examiners who normally perform the set-up, measurements should be made by the personnel who normally take measurements, under the original environmental conditions, following the steps they normally follow, with the measuring equipment that they use on a regular basis, while retaining all the other factors that constitute the regular manufacturing environment (unless obvious causes of diffusion have been identified in the process and must be remedied immediately)."* [40]

Herein there is also a notable difference in what kind of characteristics are being examined. Are variable characteristics being examined, or attributive ones? Variable characteristics can have many different values, e.g. when evaluating height, weight, length, these can all have an infinite amount of values. Attributive characteristics are present or not. For example, a wing box does have Expanded Copper Foil (ECF) to protect against lighting strike for composite material, or it does not (Yes/No). Or a stringer of an A320 rudder is within the upper and lower limits with respect to thickness (i.O. / n.i.O. (in order / not in order)). When attribute characteristics are present, they often hold the ability to be evaluated for variable criteria, e.g. how fine the ECF mesh is, or what the thickness of these stringers of the A320 rudder is.

Depending on the type of characteristic, the most suitable method for evaluating it is selected. This is further structured and visualised in table 2.4.

Table 2.4: Evaluation needs for different types of inspection characteristics

Type of characteristic	What to evaluate	Information
Variable characteristic		e.g. laminate thickness
	Repeatability	Capability of an operator to measure a previously measured value as accurately as possible
	Reproducibility	Capability of all operators to consistently measure a value
	Total Gauge R&R	Measurement system variation as calculated from R&R values
	NDC	Number of Distinct Categories; Amount of measurable intervals within the limits of tolerance
Attributive characteristic		e.g. are there undulations
	% Operator's score:	Capability of an operator to make the same decisions (compare sets)
	Study % Effective score:	Capability of all operators to make the same decisions (compare sets)

Having selected the appropriate type of evaluation, the MSA can be applied, as per regulations. [6] [40] Here Airbus makes use of Minitab, a statistics package which allows for automated calculations and quick creation of graphs, to take the human error in calculations out and leave more time to properly interpret the results. [41]

2.3.6. Airbus: execution of a typical / standard Measurement System Analysis

To give a brief synopsis of the execution of an MSA at Airbus, the following is also part of this literature study. Only the most standard type of MSA application is considered.

The planning

First, the necessity of the MSA needs to be reported, thereafter all the required testing documents and regulations should get collected, read and understood. Next, the measurement process and device should be understood, a flowchart of the actual execution should be drawn up and the following questions should be answered:

- What is being measured?
- Is this a variable or attributive characteristic?
- Which decisions are influenced by the outcome of the measurement system?
- How many operators are involved in performing the measurements and in what degree are they rotating?
- Where are the resulting measurement values being stored and are there any old(er) documents for this measurement?
- When is the measurement (going to be) executed and do the measurement methods match the knowledge as needed for further continuation of the process / product (cycle)?

Consequently, the measurement points / zones should get selected, with a division for variable and attributive characteristics. For the variable characteristics, at least 10 measurement points are needed and they should all lay within the same tolerance range; whereas for the attributive characteristics, at least 20 test zones are required and spread evenly over the number of categories. For both kinds, representative measurement points are needed. This implies that the measurement points should lay well distributed (assuming e.g. that thickness is being measured) over the entire component; places that are easy and hard to reach, with high and low values and more. At least 80% of the interested area should be covered.

Agreements should be made with everyone involved:

- What is an MSA and why are they being performed? This does not imply a review of what the operators have done
- Introduce the measurement points / zones as selected; utilise the experience of the operators
- Document the planning and set appointments
- Create the work package, time for testing included. In short, have it setup in the SMART philosophy: Specific Measurable Achievable Reasonable Time constraint

Such agreements are of vital importance to ensure the least hindrance to repeatability and reproducibility.

The measuring

Three operators measure, anonymously and separate from each other, three times the random measurement points in different order, with the same measurement device, at the points marked by themselves c.q. the measurement zones, just before each measurement run.

The important points herein are the following:

- Three operators: Is a requirement for reproducibility analysis
- Anonymous: Is a requirement for reproducibility analysis
- Separate from each other: To prevent copying from each other
- Measure three times: Is a requirement for repeatability analysis
- In different order: To prevent memorising prevent results
- Same measurement device: To exclude that the scatter is due other measurement devices

While the operators are performing the actual measurements, the responsible for the MSA execution / MSA leader should keep the following in mind:

- To announce the measuring points, c.q. measurement zones as per specified sequence
- To write down the measurement values in his log
- To observe the operators; notice and note down how the operator reads the measurement device, holds the device, measures. Might lead to the discovery of too much freedom in how the operator should operate
- To note suggestions for improvement and comments from the operators

The initial analysis

Once the measurements have been executed and even while they're still ongoing, the first analysis already starts. Here, the outcomes are just casually overlooked to see whether some very unlikely results pop up somewhere - most often indicating human error. Provided they're timely noticed, they can be corrected for right away and new proper results can be obtained.

The analysis with Minitab

After the initial analysis, a more rigorous analysis follows by means of Minitab. The measurement data is first pre-procssed in Microsoft Excel and thereafter fed into Minitab. Once the data is in, the type of analysis which Minitab executes is selected; A crossed Gauge R&R Study. Some further experimental specific data has to be given as input, thereafter Minitab will create a table with results with respect to several sources of variation in the measurement. Next to this table, six distinct graphs are plotted: [42] [43]

1. Dubbed, response by part: relative deviation from actual values, per measurement point (info for reproducibility). Both the individual values per measurement point, as well as the averages are depicted. From this graph one can immediately see whether the measurements are within the tolerance and how much the individual measurements differ from each other. This gives insight on the reproducibility.

2. A scatter plot with the response by operator: the average values as per measurement point per operator (info for repeatability). Optimally all operators produce similar values per measurement point; if this is not the case, systematic errors, e.g. due to different measurement methods, are easily detected,

3. Third is a whisker boxplot, in which the variance and average for the measurement points per operator are shown.

4. An $\bar{X}$ Chart per operator; here the effective resolution as well as the process dispersion of the sample measurement is plotted. For an appropriate resolution, at most 50% of the measurement values should be within the control limits. If this isn't the case, the system is unstable. The resolution of the measuring system is too low in relation to the tolerance.

5. R Chart per operator. This gives the span widths as per operator per measurement point. Best outcome would be when all the measurement points are within the tolerance limits, close to 0 (lower limit) and similar to each other.

6. Bar graph with a breakdown of components of variation. The total Gauge R&R, the repeatability and reproducibility separately and a part-to-part division. A substantial part-to-part variation is necessary to validate that the analysed measurement points represent the entire range for the experiment.

Follow up on results

Depending on the outcome of the analysis, different paths lay ahead. For incapable measuring systems, corrective actions should be composed and executed. Practical Problem Solving (PPS) should commence, at level 1, as per figure 2.24. With increased complexity, more investigative techniques can be applied. Stability of the measurement system should be evaluated. Finally a new MSA should be carried out after having implemented the changes.

The next step for a big company, which conducts a large amount of MSAs, would be to acquire a means of prioritising MSAs. To setup a scientifically valid and proven methodology in order to decide which MSA should be optimised next. This methodology is to be applied through a tool and gives a priority listing, considering cost effectiveness. This methodology would be based on a large amount of input data, specific for the company at hand. [25]

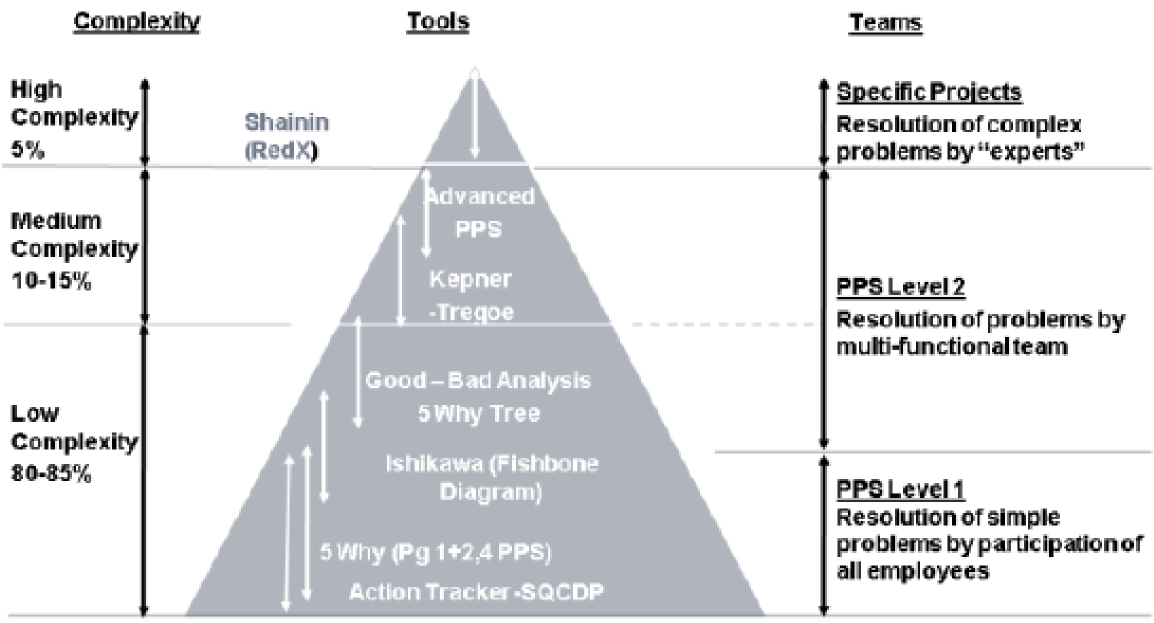


Figure 2.24: A breakdown of the practical problem solving (PPS) technique, as applied at Airbus [6]

Gauge Reproducibility and Repeatability

Then there is also the opportunity to look at an ANOVA analysis, or an Average and Range method.

There are a great many of different methods that can be applied for the GR&R studies, a selection of these is given in the following list. [37] [44]

1. Analysis of variance (ANOVA) method
2. Average and range method ($\bar{X}$ and R)
3. Average and standard deviation method
4. Automotive Industry Action Group (AIAG) method
5. Within part variation (WIV) method
6. Short range method for:
   (a) Destructive testing
   (b) Non-destructive testing
7. Long range method for:
   (a) Destructive testing
   (b) Non-destructive testing

From this list, the first two (Analysis of variance (ANOVA) method & Average and range method ($\bar{X}$ and R)) are the most widespread in use. These two are also depicted in figure 2.23 as well as the difference between them. The ANOVA method makes 1 more division as compared to the average and range method. As such it provides more specified causes for the variation. Furthermore, the analysis can be performed in any circumstance and the variations are estimated more accurately.

2.4. Stakeholder Analysis

Next to the invaluable information which was obtained through regular research, diving into papers and extracting the needed knowledge to get more of a grips on the topic and its surrounding issues, a small *Stakeholder analysis (SHA)* was conducted. This section is broken down in two subsections, it starts with subsection 2.4.1 in which an outline is given for the SHA. Thereafter, a synopsis of the results of the questionnaire is provided in subsection 2.4.2. Furthermore, three appendices are related to this section. First, in appendix C the English & German versions of the questionnaire are appended. Second, the answers as provided by the participants are given in appendix D and finally, the participants of the questionnaire are appended in appendix E.

2.4.1. Outline of the stakeholder analysis

First some thought was given into deciding who'd be a good candidate to participate in the SHA and thereafter in how to prioritise them. This group of in- and external stakeholders consists mostly of Airbus affiliated people, for the purpose which it's intended here. A stakeholder map which plots the influence / power of the stakeholders versus their interest can be seen in figure 2.25. [45]

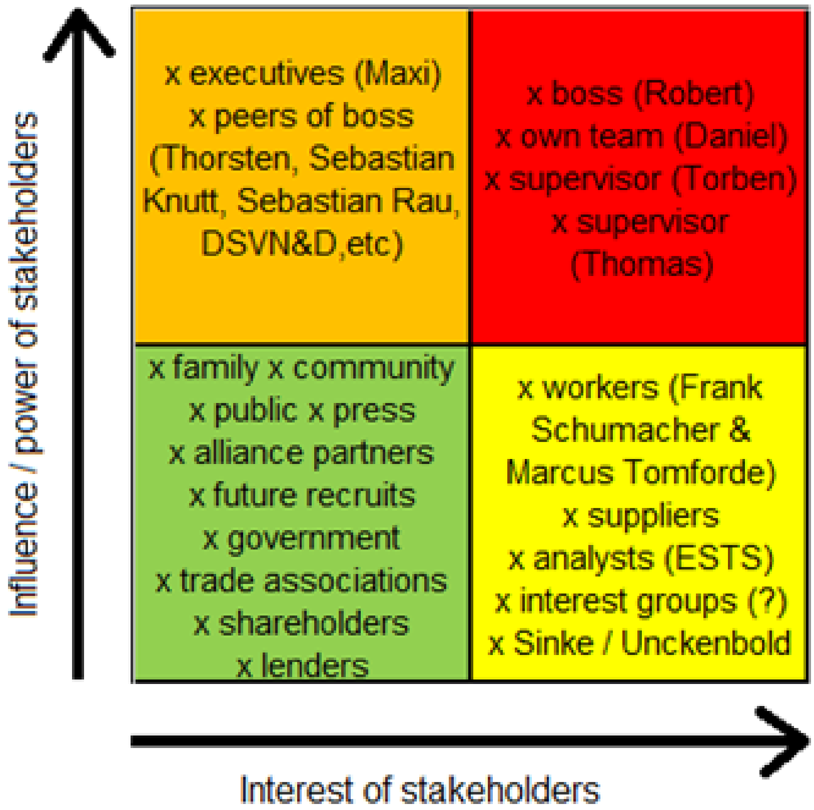


Figure 2.25: Stakeholder map for MSA prioritisation [9]

Here the colours for the quadrants represent the importance. Stakeholders in the red quadrant are to be considered the key players, their ideas are to be valued the most. Next come the orange ones, their needs should be met. The yellow ones aren't all that important, showing consideration that their thoughts are valued is a good start. The greens are the least important and will not likely cast a deciding vote in any further actions.

With the stakeholders, who are to take part in this analysis, selected and prioritised, it's key to get more familiarised with their needs and desires for the project. This is where the questionnaire comes into play and which determines its content. The questionnaire is the main part of this SHA, which, to allow for greater comprehension by the ones questioned, was available both in English as well as German.

2.4.2. The results of the questionnaire

Once the interviews, guided by the questionnaire, for the SHA were conducted, they were analysed to extract main conclusions out of them. The summary that was thereafter distilled is now presented in thus subsection.

- The execution of MSAs are pivotal for the healthy existence for large companies which produce products in big quantities. Without MSAs, a company would not be able to validate their measurement results and as such not be able to discover flaws in their production processes through this simple verification method. Without certain quality qualifications, a company would not be able to guarantee long term survival.
- There is no prioritising strategy present at Airbus for MSAs. There is just of list MSAs which still need to be performed and they are being completed starting from those which are expected to be easy which do not take a lot of time and interfere the least with production. This to allow for completing as many MSAs as possible in the shortest time.
- There is ample room for improvement with respect to MSA prioritisation
- It could be a good idea to split up GR&Rs further into their separate repeatability and reproducibility aspects.

  For example, imagine quality inspector A gets measurement values which are very similar to each other and the same holds for quality inspector B. However, when comparing A with B, they differ significantly. In this exemplary case, only B is near the real value of the product.

  This would give a good repeatability, bad reproducibility and bad GR&R. Improving reproducibility could be real easy with more clear instructions for the quality inspectors and with that the GR&R could be improved very easily. Prioritising MSAs which have bad reproducibility is a good idea
- There is no real consensus with respect to the current vision concerning MSA prioritisation; answers depend greatly on the background of the interviewee. Do note the obvious positive correlation between production rate, CNQ, rate of defects & NC. For higher production rates, the others will generally increase too, provided no other alterations have been made
  - Specialists consider their part the most important (be in favour of GR&R, C_{pk}, risk)
  - Managers aim more towards CNQ. Arguing that by going after the CNQ issues, the other issues will present themselves and get handled too
- Ideally, the prioritisation methodology should not get influenced by market dynamics; the sequencing can however alter due to it, from e.g. increased production rates somewhere and therefore increased CNQ
- Availability of C_p/C_{pk} data should not have an effect on the prioritisation of MSAs. This data should get obtained and in the meanwhile high CNQ will most likely already indicate for bad SPC data
- It is expected that there are relations present in the data which could help for MSA prioritisation.
  - Between GR&R & C_p/C_{pk}
  - Higher production raises CNQ/NC
  - Do not overlook the human factor. Increased production rates will initially also increase the pressure on workers, increase stress, increase human error.
  - Bad C_{pk} predicts high NC & thus high CNQ
- MSAs should be handled from *the Stade quality department (QDS)*, as it is.
- It is expected that investments for improved MSAs will pay off. However, simply employing more people to conduct more MSAs is not a given solution; these people will first need training before they can perform at the right level of skill. When MSA results are below par, the need rises for *Practical Problem Solving/Failure Modes and Effects Analysis (PPS/FMEA)*, especially when CNQ is high.

The answers as given to the questionnaire are further appended in appendix D. The questionnaire was held anonymously, to allow for free speech. The key, towards linking people to their answers, is provided in table E.1 in appendix E. This table also provides a bit of background on the participants, to have a heightened understanding of their knowledge and skill with respect to MSAs.

The execution of the SHA increased the awareness of what was known by Airbus itself and in which direction they were currently going.

From all the answers as provided by the participants, a general outcome is distilled. This then leads to the weights as given to several parameters for the prioritisation tool in chapter 5.

2.5. Relation between GR&R and C_{pk}

The last section in this chapter is about the relationship between GR&R and C_{pk}. [10] This relation is visualised in figures 2.26 and 2.27 for two cases.

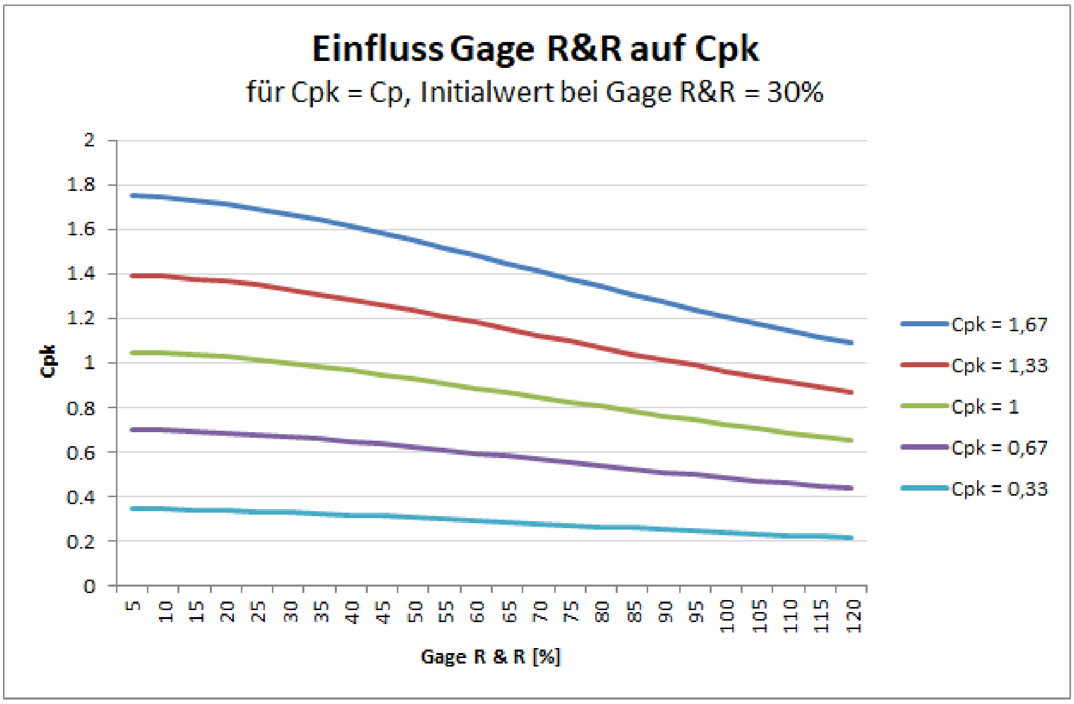


Figure 2.26: Influence of GR&R on C_{pk}, with $C_{pk} = C_p$ [10]

To get at these figures, use was made of Airbus' empirical data for the process which measures the laminate thickness of the stringers of the Vertical TailPlane (VTP) of the A320. First, the total standard deviation (σ_t) was determined for the process, as per equation (2.6):

$$\begin{aligned} \sigma_{t1,2} &= \sqrt{{\sigma_{p1,2}}^2 + {\sigma_{MS}}^2}, with \\ \sigma_{p1} &= \sqrt{\left(\frac{1}{6}\right)^2 - \left(\frac{1}{20}\right)^2}, \\ \sigma_{p2} &= \sqrt{\left(\frac{1}{12}\right)^2 - \left(\frac{1}{20}\right)^2}, \\ \sigma_{MS} &= \frac{1}{\frac{100}{GR\&R}6} \end{aligned} \tag{2.6}$$

With σ_p and σ_{MS} as the standard deviations for the process and measurement system, respectively. Note that GR&R is expressed as a percentage in this equation. Furthermore, note the subscripts of 1 and 2 for the process; they indicate a slight difference in the equations for the two figures.

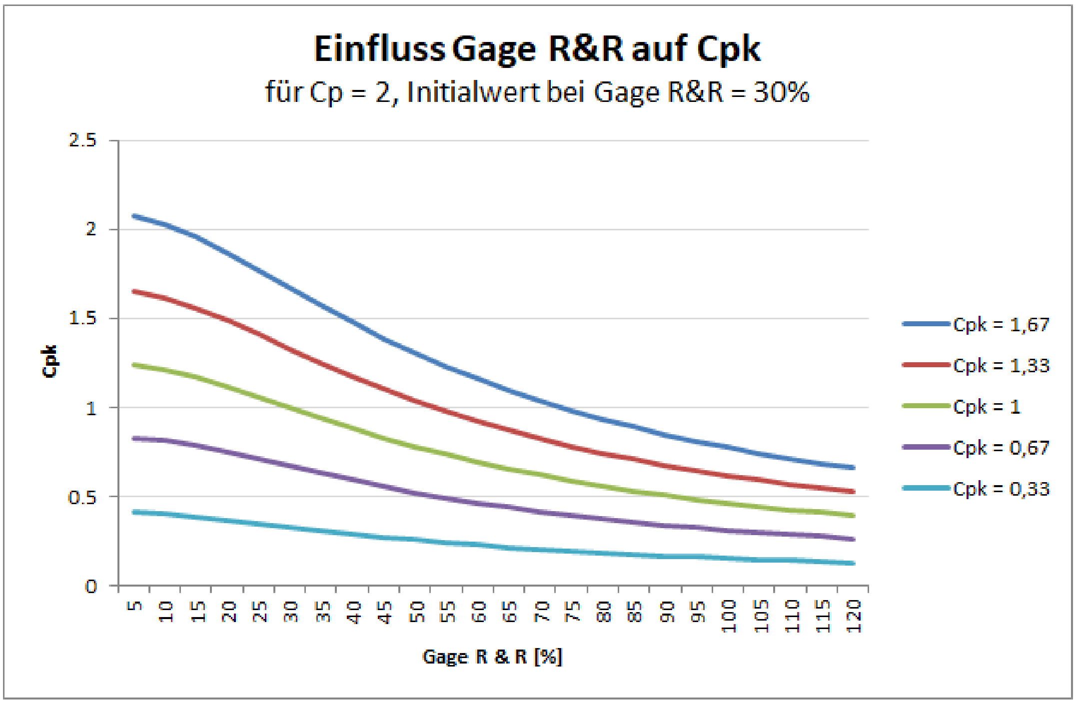


Figure 2.27: Influence of GR&R on C_{pk}, when C_p = 2 [10]

Herewith, C_{pk} could be related to GR&R through equation (2.7):

$$C_{pk1} = \frac{\frac{C}{2}}{3\sigma_t}, C_{pk2} = \frac{\frac{C}{4}}{3\sigma_t} \tag{2.7}$$

The constant C corresponds with the five values (and colours of the lines) as shown in the figures. These values have been chosen as these are the cut-off values for Airbus within their SPC data.

3 Research Definition

To work towards the project goal in an efficient and effective way, it is good to tackle the entire project in a systematic and methodological manner. Therefore the research questions, aims, objectives and framework that go along with it are presented in this chapter. It starts in section 3.1, where the research question is established. Then in section 3.2 the needed steps are listed and thereafter the methodology is presented in section 3.3. The next section deals with the experimental setup and is documented in section 3.4. This chapter ends with section 3.5 in which the expectations are summarised.

3.1. Research objective and question

To reach the project goal, the main research objective should be met, which is:

Come up with a methodology for Measurement System Analysis (MSA) prioritisation, by means of data analysis in the field of Process Capability (C_{pk}), Gauge Repeatability & Reproducibility (GR&R), Cost of Non Quality (CNQ) and Non Conformities (NC) for Airbus production processes in Stade.

To facilitate this, the following research question is established:

'Is it possible to develop a prioritisation tool as described in the research objective?'

By solving this question, relations between the relevant data - C_p / C_{pk}, GR&R, risk and CNQ - for MSA prioritisation are discovered and with these a sensible means for said prioritisation can be constructed.

To be able to solve this question, two other main questions and several sub-questions are treated first. By solving these (sub-)questions, the problem at hand can be tackled:

1. What is Airbus' current strategy with respect to executing MSAs?
   (a) What exactly is an MSA?
   (b) For which processes are MSAs executed?
   (c) How is prioritisation currently being handled?
2. How do all interested stakeholders feel about (the need for) a MSA prioritisation tool? Which opinions do the distinctive parties have on the core concepts as well as the assumed relationships between them, in regards of the Airbus Stade organisation?
   (a) Who are the main stakeholders, considering the envisioned MSA prioritisation tool, for Airbus in Stade?
   (b) What is relevant for such a tool, according to these stakeholders?
   (c) What are the main differences and similarities in these opinions, both in terms of problems, as well as envisioned solutions?

3. How do the relevant data relate with each other?
    (a) What data is considered to be relevant for the tool?
    (b) What is the nature of the data?

By means of the acquired knowledge through the research questions, the research objective can be obtained: To come up with a methodology for Measurement System Analysis (MSA) prioritisation, by means of data analysis in the field of C_p, C_{pk}, MSA and CNQ data for Airbus production processes in Stade. Around this methodology a tool will be developed to execute said prioritisation. Along the way towards this objective, several sub goals are developed and should be executed. To make all of this more clear, it can be put in a research framework and get linked with task blocks.

3.2. Planning of the thesis

In this section, the systematic and methodological approach for dealing with the thesis is elaborated upon. Note that the execution and completion of the thesis can be regarded as an iterative process. As such, (some of) the steps listed will be repeated as a result from a growing understanding of the problem. A Work Breakdown Structure (WBS) has been created to visualise the needs and can be seen in figure 3.1:

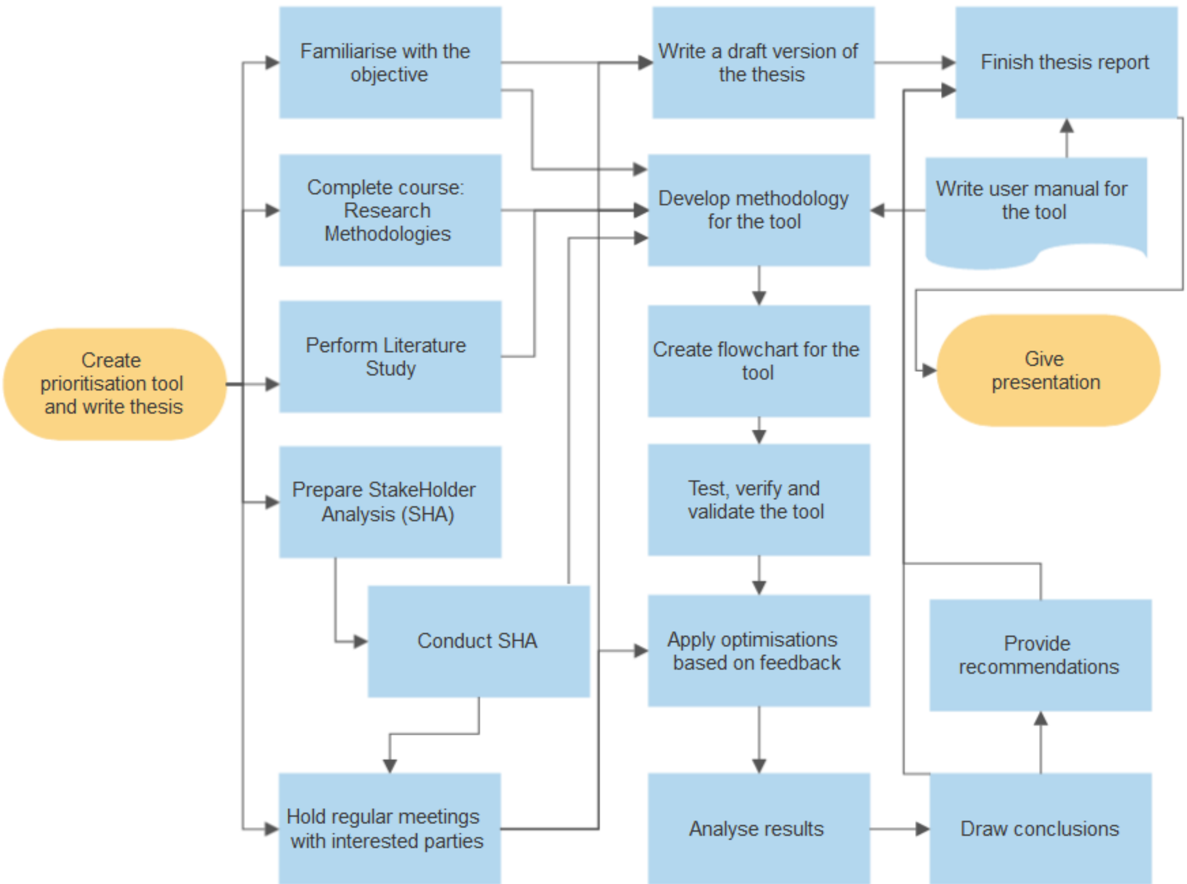


Figure 3.1: Work breakdown structure for the completion of the MSA prioritisation tool

Note that although there aren't loops displayed everywhere in the figure, the project in itself is of a highly iterative nature. When new information surfaces, tweaks within task are bound to be required. These loops are kept out to not completely clog the figure, as it would sacrifice clarity. The interested parties, as mentioned in the figure, are Airbus' departments of Engineering, Manufacturing Engineering, Production, Programming and Quality, with the last one being the project owner.

3.3. Theoretical content / Methodology

The relationships between the relevant data will lead to a theory. These relationships will then thereafter be tested through simulations with empirical data with the tool to verify and validate it.

When a hypothesis is extracted out of this, it would be: *"It is possible to develop a prioritisation tool and it will likely see Cost of Non Quality as the driving factor."* The main reason for this, is that Airbus is a commercial company and as such has a largely financial goal.

For the project, a hybrid combination between a *Grounded Theory Approach (GTA)* and a *case study* is selected as the best option towards reaching the objective. The GTA is defined by the book of Verschuren: *A research that is carried out according to the grounded theory approach may be characterised as a strategy that can be used to gain theoretical insights with only the minimum of prior knowledge, and by continuously comparing phenomena that are involved.* [30] Considering that with this research project relationships between empirical data are to be found and from that a methodology is to be set-up, it fits perfectly within the realm of a grounded theory approach. The case study opts at going for depth rather than breadth. This is one of the more common selected methods for qualitative research for practice oriented research projects, which fits as an actual problem will be researched. The steps to be taken are well connected with the ones already shown in section 3.2.

3.4. Experimental set-up

The empirical data which is being worked with is obtained in several ways. It always starts of as pure raw data but is often further manipulated before one can deduce anything from it. For example take the MSA data that is generated for the thickness of the skin at the rudder of the A320. This data is generated by means of manually measuring the thickness of the skin at predefined locations with an ultrasound device (Panametrix 35 DL) and repeating this measuring procedure three times with three *Quality Inspectors (QIs)* each. These QIs are personnel who are trained and qualified to work with the right control / measurement devices on these production processes. A more in depth description of the MSA process can be found in the internship report that was created shortly before this document; it also concerns Airbus Stade. [42] *Realise that when measurements are being taken, which are not going to be processed further for an MSA, but solely used for Quality Control (QC) of that which is measured, the measurements are only performed once by one QI.*

By running this empirical data through Minitab [41], the GR&R can be obtained, which is the data that is used towards the methodology. The QIs conduct these measurements in the production halls, which often means their postures while working are not the most ergonomically favourable ones and as such do not benefit the GR&R values.

None of this leads to any insurmountable issues though; the data keeps getting extracted from its sources and remains of sufficient quality. As the research as well as the data gathering is done on site of the Airbus factory in Stade, the collaboration with industry is on a first-hand basis. The practical implications that go along with this, are that all data on the relevant variables is gathered directly from the source and whenever any know-how concerning any of the processes or data-processing or both is requested, it is available on short notice. Which is very convenient for selected research methodologies. The same holds true about the data as obtained through the stakeholder analysis; for further queries, the ones involved can rather easily be reached (through email). Furthermore, as it is a research which is conducted on behalf of Airbus, it is more than likely that all of the employees will show great cooperation whenever questions arise. This notion can be considered verified, as the colleagues were also very much available for queries during the internship that proceeded this MSc thesis. With careful planning and open communication, effects due to unavailability issues should not be too hard to mitigate.

Turning over to the development of the tool, it should be in compliance with the current programming languages Airbus uses for its tools. The main languages which are used by Airbus are PySpark (the Spark Python Application Programming Interface), Structured Query Language (SQL) and JavaScript (JS). From these three, the first should be seen as the main programming language, the second for handling the data and the third to visualise interactive dynamic webpages. Which is set-up to be a joint endeavour with the programming team present at Stade, who are well aware of all the considerations that come along with it. Thus far, the MSc researcher has little to no experience with the three languages mentioned above; he will have to grow, in this sense, during the project. As such, the main limitation lays in the availability of these programmers, both in respect of them being busy with other projects, as well as (summer) vacations. Another limitation is present in the fact that it is undesirable for the code to be running very slow and/or using a lot of computational power, therefore the coding should be fairly elegant and efficient.

Next to this, the visualisation that comes forth from the tool, should also be in accordance with other visualisations, for example the capability dashboards as created through Palantir [46], to allow for easy use of the tool.

Linking the experimental setup with the research questions; the first two research questions are not incorporated herein, these are concerned with the establishment of knowledge. The third however is very much in line with the experimental setup; considering the relations will be tested by the tool.

3.5. Expected results, outcome and relevance

The data that will be worked with is mostly measurement data and derivatives therefrom. This will be data from:

1. Statistical Process Control (SPC),
2. Measurement System Analysis (MSA; GR&R),
3. Cost of Non Quality (CNQ) for production processes at Airbus in Stade.

To add more clarity, the following breakdown is executed:

1. Independent variables: These are the variables which are manipulated and cause changes in the dependent variables:
   (a) The way how measurements are executed,
   (b) The location where measurements are executed,
   (c) The speed at which measurements are executed.
2. Dependent variables: These are affected by the independent variables, as are listed above:
   (a) C_p,
   (b) C_{pk},
   (c) GR&R,
   (d) CNQ.
3. Parameters: These are considered to be constants at set times. However, over time, they can change (e.g. a new training increasing the skill of the quality inspectors) to different values:
   (a) The (skill of the) quality inspectors mobilised who perform the relevant measurements,
   (b) The measurement devices employed by these QIs towards the gathering of the data,
   (c) The production rate of the process which is being considered.

The results that are desired to be investigated are the relationships between the amassed data and how to use them towards decisions with respect to prioritisation of process optimisations. These results would ideally show clear causal relationships.

Obtaining such results would lead to indisputable choices in the decisions for which MSA to optimise next. As such the outcome would be the desired tool which will give substantial guidance with respect to reasoning for MSA prioritisation.

Finally evaluating the relevance of the entire project; this can be split in two parts, first the relevance for Airbus as a company looking for profit and second for the body of science (of Airbus). By developing a working methodology to prioritise MSA optimisations and equipping a tool with the logarithm associated with it, a considerable amount of money can be saved. Especially due to the recurring nature of the savings involved. Looking at the project from a less directly money driven angle, information will be obtained that can be further evaluated and lead to more generalised tools with even more variables included which can be employed in more situations.

4
Methodology

This chapter deals with what actually happened, both the thinking processes as well physical actions, in order to come to the prioritisation tool. The first section deals with the selection of data that will be used for the tool. Thereafter, simplified models with less data were constructed to get initial estimates and results; these are reported in section 4.2. The chapter ends with section 4.3, in which the *Matrix Quality Review (MQR)* is presented. This gives a bit of an outline on the tasks that have to be completed to arrive at the desired tool as well as provide some ideas for future improvements to increase the applicability of the tool even more.

4.1. Data selection

A lot of the data that is to be used was already specified by requirements from Airbus. Nonetheless, it proved to require some selecting and manipulating to get useful data out of the raw data that was present in the Airbus databases.

This led to the following need of data:

- Non Conformity (NC)
- Cost of Non Quality (CNQ)
- Measurement System Analysis (MSA): Gage Repeatability & Reproducibility (GR&R)
- Statistical Process Control (SPC): Process Capability (C_p, C_{pk})
- Risk: *Severity, Occurence and Detectability (SOD)* ratings

For all of these data inputs, specific ideas and rationales are in place with respect to their use. For instance, realise that all processes deal with different amounts of product, due to differing production rates for different aircraft (families). [1] Elaborating slightly on them provides the following:

The *NCs* are facing a challenge. The troubles that are attributed to the processes are often clustered which makes it very hard to pinpoint which problem belongs to which process. This was dealt with by just retrieving the total costs per process out of the available data and work with these; it is not the most accurate, but within the current availability of data, it is the only solution.

The *CNQ* data was expected to be the most straightforward, this was however not the case. Apparently the data differed depending on the source of the data and the origin of this problem could not be found; added difficulty here was the extreme caution as applied by Airbus, as this data was the most sensitive in their eyes.

[1] Airbus' commercial aircraft deliveries for 2017 https://www.airbus.com/newsroom/press-releases/en/2018/01/airbus-commercial-aircraft-delivers-record-performance.html

With respect to *MSA*, the available GR&R data is used. For the time being, there is just a check to see whether the process has undergone an MSA and whether it has passed. The passing criteria require a GR&R value to be below 30.

For *SPC*, there is a distinction made between the use of C_p & C_{pk} data, as at the point of conception it wasn't completely clear which would prove to be most useful for the tool and would also be most easily available. Furthermore, note that this data is formed over different time intervals; the processes concerning the A320 family are based on one months worth of production, the A330 on six, the A350 on three and the A380 on twelve. This therefore leads to the SPC data being comprised over 47, 33, 20 and 15 aircraft respectively and realising the processes associated with them are performed at least twice per aircraft, they are all well within the requirements for SPC with respect to amount of samples (minimum of 30) as previously discussed in subsection 2.2.1.

Finally, the *Risk* data comes into play. Initially, risk specific data was not being considered, but feed-back let towards the involved of this data. The risk data is incorporated by reviewing all the industrial processes at play in Airbus' plant in Stade. For all of these processes, the *Inspection Characteristics (ICs)* & therewith related *Control Devices (CDs)* were reviewed for SOD. This data was often refined and manipulated in greater extend, as the determination of risk is a rather subjective topic.

4.2. The simplified models

To ease the understanding of the data and their interactions with respect to MSA prioritisation, several smaller, easier models have been constructed. These allow for some intermediate verification and validation of what is expected in the end. This starts with a 2D model, which can be found in subsection 4.2.1, is continued with a 3D model in subsection 4.2.2 and ends with a 4D model in subsection 4.2.3. The first model deals with NC and CNQ data, the 3D model is an extention of the 2D model by adding MSA data and in a similar fashion, the 4D model is obtained by including SPC data to the mix.

4.2.1. The 2D model

This subsection starts with the creation of table 4.1 which displays a simplified MSA prioritisation and is thus coined the *MSA Prioritisation Matrix (MPM)*. This table holds all the data which are used for the first two simplified models for nine processes and is therefore also applicable to subsection 4.2.2. Furthermore, it contains columns for MSA data related to the jigs & tools which are not yet obtained by Airbus. For this subsection, the 2D model, only the NC & CNQ input is required. This 2D model is treated in two cases; in the most simple / intuitive form and in an improved manner. In the subsection thereafter, it is then expanded to contain the MSA data with respect to part production too.

The values as used in this table have been obtained from Airbus' data-sheets. The handling of this data, on a greater scale, will be clarified in chapter 5, which deals with the prioritisation tool.

Table 4.1: MSA Prioritisation Matrix (MPM) with NC, CNQ and MSA data for the 2D and 3D model

MSA Prioritisation Matrix (MPM)	3D Priority Model									
	2D Priority Model				MSA data				Priority	Action
	Number of NCs	CNQ [$ 10^3]	Priority	Action	Part ACC*	Part GG%°	Jigs & Tools ACC	Jigs & Tools GG%		
Process 1	80	110	1	A	8	60	NA†	NA	1	A
Process 2	160	220	1	A	8	60	NA	NA	1	A
Process 3	90	105	1	A	16	24	NA	NA	2	E
Process 4	55	60	2	C	15	55	NA	NA	3	F
Process 5	20	70	2	C	10	26	NA	NA	4	C
Process 6	70	10	3	B	12	70	NA	NA	5	G
Process 7	60	0	3	B	25	15	NA	NA	6	B
Process 8	10	2	4	D	29	9	NA	NA	7	H
Process 9	2	0	4	D	33	13	NA	NA	8	D

*ACC = Accuracy. It represents the strictness of the tolerance, with a low number indicating a low tolerance and a higher need for accuracy
°GG = Gage Repeatability and Reproducibility (shorter notition)
†NA = Not Available

Note that in this table NA stands for Not Available. Currently, Airbus is already obtaining GR&R data for their processes related to part production, but not yet for those related to the use of the jigs and tools. In the foreseeable future, this piece of data will be included too and is therefore already present in this table. Furthermore, figures 4.1, 4.2 and 4.3 are produced to visualise the prioritisation for the 2D and 3D models respectively.

The intuitive 2D model

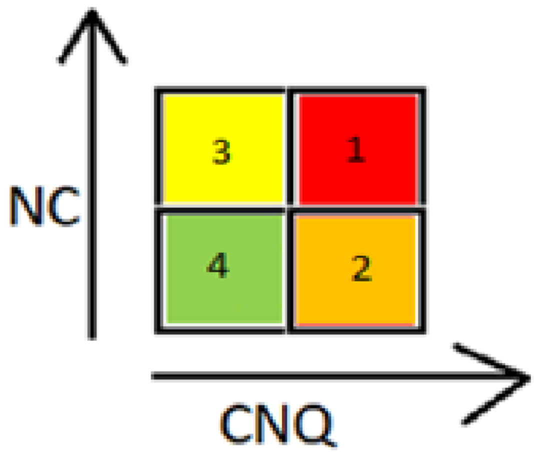


Figure 4.1: Simplified priority for MSA execution, based on just NC & CNQ data

In figure 4.1, only data with respect to NCs & CNQ is used. Priority comes with the lowest number and is influenced, for the biggest part, by the CNQ data.

The top right corner quadrant represents processes which endure a high amount of NCs with high CNQ. A process which falls in this quadrant (red) is obviously a good candidate to have a high priority for undergoing a (new) MSA.

The next in line is the one in the second quadrant (orange), here, although the CNQ are high, there's only a low amount of NCs. This combination is illogical. For some reason, product is not classified as NC (something being out of range of the tolerances), nonetheless, there appears to be a large amount of product that needs to be reworked, or even scrapped. With a new MSA and possibly subsequent new tolerance settings, this could get discovered rather easily and in that sense save quite some time and money, as well as boost quality which is very desirable for staying in the market (be able to sell aircraft with more ease).

The third quadrant (yellow) is the reversed situation of the previous. There are a lot of NCs, these do however not cause a lot of CNQ. Once again, changing the tolerances might be an easy solution, but in this case they should be softened. A different solution could be to check whether there might be other measuring devices applicable for these processes, which are less sensitive and as such result in less false warnings. As this situation does not cause any damage to the brand/company, only costs time/money, as the quality remains good, it is of lesser importance/priority, yet still worthwhile to investigate. All possibilities which could lead to savings in time/money are potentially good projects.

The last case comes with the fourth quadrant (green). Both NC and CNQ are (relatively) low. The processes which are situated in this quadrant have the least priority, provided there is no other information available which spikes their priority. For instance, if one of these processes was to be chosen as a test case with the goal to find a better control device, because the process is particularly well suited for swapping out control devices, e.g. due to easy accessibility/controlability.

Deducing mitigation actions from the information as listed in table 4.1, leads to the following list:

- A: Improve the measurement system (both NC and CNQ are high). Alternatively, improve the process
- B: Improve the process, both by looking at the MS as well as increasing the tolerances (NC isn't high, yet CNQ remains high)

- C: Change (= soften) the tolerance (NC is high, although CNQ isn't high)
- D: Reduce the amount of measurements (NC as well as CNQ are low)

Note that this list is related to the 2D model and as such the A through D is linked to 1 through 4, as per fourth & fifth column in table 4.1.

The improved 2D model

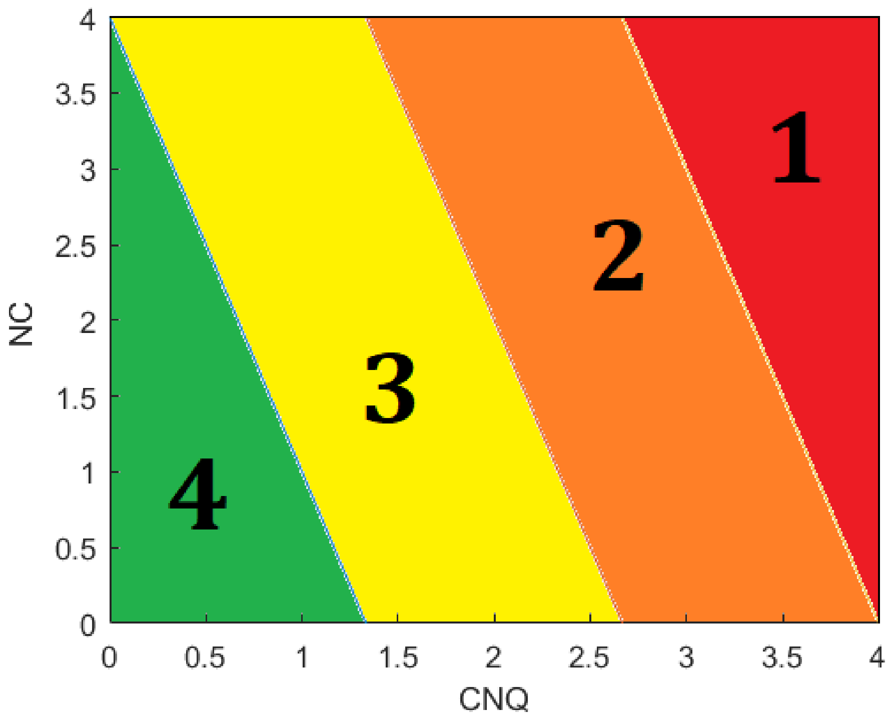


Figure 4.2: Simplified priority for MSA execution, based on just NC & CNQ data

In figure 4.2, the same data is used (NC & CNQ), yet now linked through a formula. More accurately, the location a process obtains within this figure, therewith its priority, can be expressed mathematically with equation 4.1:

$$Q = A * CNQ + B * NC \tag{4.1}$$

In this equation, A and B represent constants giving weight to the CNQ and NCs respectively. Q is the constant which expresses the gravity of the situation as caused by the CNQ and NC.

The figure displays four distinct areas; *Area 1* is bounded on the left by equation 4.1, in which the constants are 3, 0.75 and 0.25 for Q, A and B respectively. It represents processes with relatively speaking the highest combination of CNQ and NC. As such it is coloured in red and receives first priority; it is a good candidate for undergoing the next MSA. Within area 1, the more to the top right the process is, the higher the priority. If one were to consider the CNQ and NCs as either high or low, they would generally both be high in this area. *Area 2* follows thereafter. On the right it is bounded by the same line as area 1 had on its left and on the left by replacing the value for Q by a 2. The It comes next in line with respect to priority and is as such coloured in orange. The *third area* is shaded in yellow and is bounded on the left by having a value of 1 for Q. The *last region* is the green one and has the lowest priority. It is bounded on the left by the physical borders of 0 NC and 0 CNQ and on the right by the border the yellow one had as left border.

Note that this improved version of the 2D model doesn't just deal with high or low input from the two respective variables, but treats their whole spectra.

4.2.2. The 3D model

In a similar fashion, by elaborating on the intuitive 2D model, the more complicated 3D model (named 3D, as it deals with the 3 most important input data) can be constructed. This is done by adding a third data set: GR&R. This then results in table 4.2. Note that in this table the eight possible extreme cases are handled for imaginary processes 11 through 18; each entry for each specific data type is set as either high or low. The mitigation actions as for processes 1 through 9 can still be found in table 4.1.

Table 4.2: Simplified 3D model: priority based on NC, CNQ & GR&R data

Process #	NC	CNQ	GR&R	Priority	Action
11	high	high	high	1	A, F
(12	high	high	low	2	E)
13	low	high	high	3	G
14	low	high	low	4	C
15	high	low	high	5	G
(16	low	low	high	6	A)
17	high	low	low	7	B
18	low	low	low	8	D, H

With the data from this table, a picture was generated to represent the simplified prioritisation outcomes for executions with reduced amounts of data. The three axes each hold their own data type and the figure can be seen in figure 4.3. Note that the lowest priority (8), is not visible in this figure; it is in the inside of the figure, touching the origin (0, 0, 0).

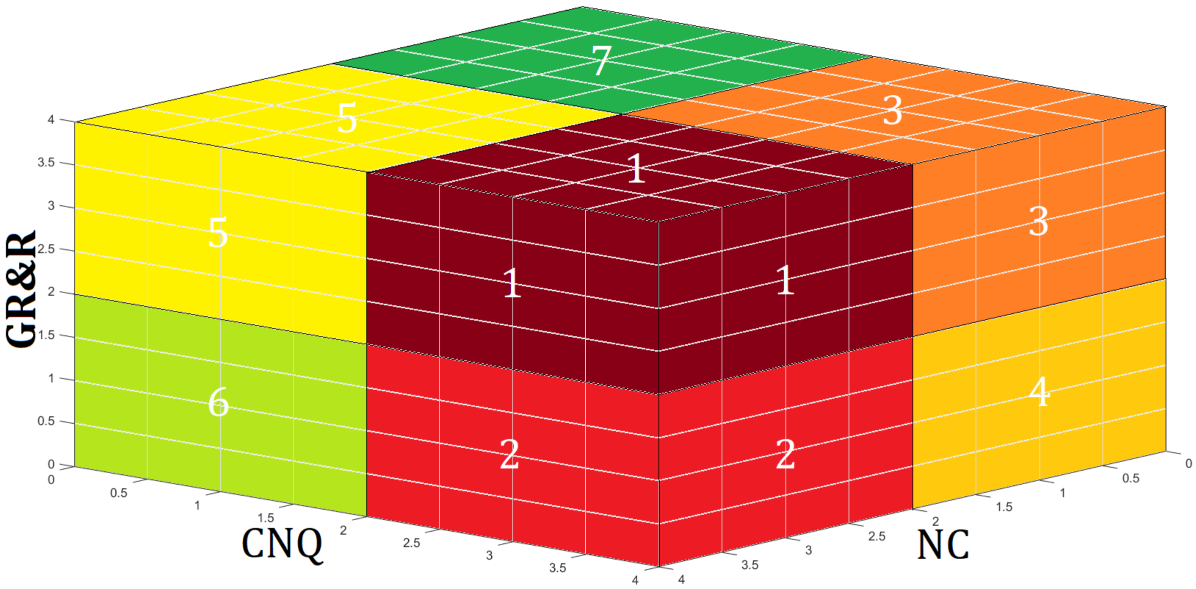


Figure 4.3: Simplified priority as per 3D model for MSA execution, based on just NC, CNQ & GR&R data

The actions that would be recommended to result from this table, listed as A till J, are the following:

- A: Improve the MS (Incapable MSA combined with either high CNQ and amount of NCs or low CNQ and NCs)
- B: Change the tolerance (low CNQ yet high amount of NCs for a capable MSA)
- C: Improve the process (CNQ is high but with a low amount of NCs, GR&R is just sufficient)
- D: Reduce the amount of measurements (good MSA and CNQ is low, as are NCs)
- E: Improve the process (GR&R passed, high CNQ and NCs)

- F: Improve the MS & process (GR&R failed, high CNQ & NCs)
- G: Improve the MS & change tolerance (Failed GR&R with either high CNQ and low NCs, or low CNQ and high NCs)
- H: Reduce amount of measurements & Change Tolerance (Very good GR&R, low CNQ & NCs)

Note that processes 11 and 16 have the same action as do 13 and 15, respectively A and G. However, for process 16 the priority is much lower due to less CNQ and NCs and for process 15 the tolerance needs to be adjusted to be more lenient as opposed to catch more NCs with process 13. Furthermore, note that a combination of high NC and CNQ with a low GR&R as well as the opposite, low NC and CNQ with high GR&R is odd; as is represented by processes 12 and 16 respectively. These are indicating between brackets in table 4.2 in red.

4.2.3. The 4D model

Coming from the 3D model, the 4D model is an extended version of it by adding SPC data, which is also obtained from the Airbus database. This addition of data leads to table 4.3. By adding more and more data, a more accurate prediction can be given with respect to which MSA should be prioritised while striving for cost reductions and quality increases. Similar to table 4.1, in which there is a column reserved for tool specific GR&R data, there is a column for tool SPC data which is not yet available from Airbus, but is already incorporated as it's expected to get added sooner rather than later.

Table 4.3: MSA Prioritisation Matrix (MPM) with NC, CNQ, GR&R and SPC data for the 4D model

MSA Prioritisation Matrix (MPM)	4D Priority Model												
	Number of NCs	CNQ [$ 10^3]	GR&R data				SPC data				Priority	Action
			Part		Tool (= Jig)		Part		Tool (= Jig)			
			ACC	GG%	ACC	GG%	Cp	Cpk	Cp	Cpk		
Process 1	80	110	8	60	NA	NA	0,95	0,85	NA	NA	1	A
Process 2	160	220	8	60	NA	NA	0,95	0,85	NA	NA	1	A
Process 3	90	105	16	24	NA	NA	0,75	0,50	NA	NA	2	E
Process 4	55	60	15	55	NA	NA	0,80	0,60	NA	NA	3	F
Process 5	20	70	10	26	NA	NA	0,70	0,30	NA	NA	4	C
Process 6	70	10	12	70	NA	NA	0,90	0,80	NA	NA	5	G
Process 7	60	0	25	15	NA	NA	1,00	0,90	NA	NA	6	B
Process 8	10	2	29	9	NA	NA	2,50	1,80	NA	NA	7	H
Process 9	2	0	33	13	NA	NA	1,80	1,70	NA	NA	8	D
Process 10	xx	xx	xx	xx	NA	NA	xx	xx	NA	NA	xx	xx

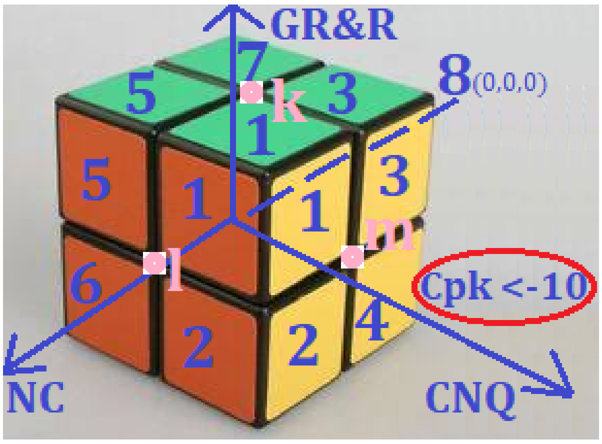
To ease the perception of a real 4D model, which is hard to visualise and grasp, it is constructed in a discrete manner by taking a few logical ranges for C_{pk}. These intervals are listed in table 4.4. *Note that a table with more intervals is used in subsection 5.1.3 which allows for more fine-tuning in the program.*

Reviewing the figure of the visualisation for the 3D model (figure 4.3), the 4D visualisation is essentially five more times the same figure, yet within a different SPC environment, as per the intervals as specified in table 4.4. For the outermost C_{pk} ranges, C_{pk} <-10 and C_{pk} ≥2, the following two pictures have been generated; figures 4.4a & 4.4e respectively. The three axes still hold the same data; NC, CNQ and GR&R. As a result, the prioritisation within the figures themselves does not alter; the differences come forth from comparing the figures with each other.

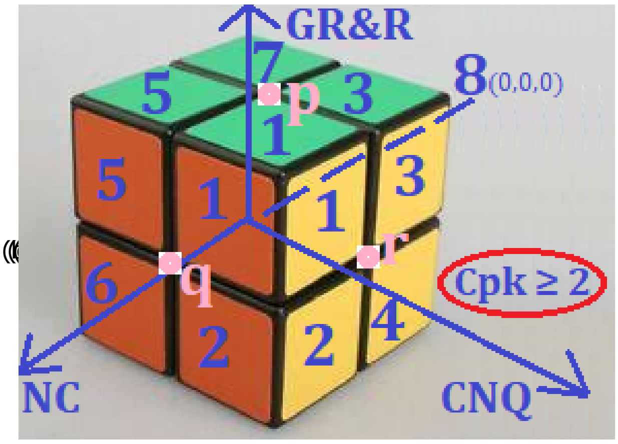
Note that in these two figures six points are selected; points k (10,10,20), l (10,20,10) and m (20,10,10) in figure 4.4a and points p (2,2,4), q (2,4,2) and r (4,2,2) in figure 4.4e. Qualitatively, they represent the same locations, within their own figures, they can be compared easily. Quantitatively however, this is quite different, to compare them, one should realise that the first picture is in general five times worse, due to the much worse C_{pk} environment.

Table 4.4: C_{pk} ranges as used for the 4D model

Cpk ranges [-]	
Cpk <-10	a
-10 ≤ Cpk < -1	b
-1 ≤ Cpk < 1	c
1.66 ≤ Cpk < 2	d
Cpk ≥ 2	e



(a) Simplified priority for MSA execution for bad C_{pk}



(e) Simplified priority for MSA execution for good C_{pk}

Figure 4.4: Simplified priority for MSA execution, based on just NC, CNQ, GR&R & SPC data: (a) fourth dimension represented by C_{pk} <-10 (b) fourth dimension represented by C_{pk} ≥ 2

The mitigation actions that would be recommended to result from table 4.3, listed as A till H, are the following:

- A: Improve the MS (Incapable MSA, C_p/C_{pk} are not capable, high CNQ and amount of NCs)
- B: Change the tolerance (C_p/C_{pk} aren't capable, at low CNQ yet high amount of NCs for a capable MSA)
- C: Improve the process (C_p/C_{pk} aren't capable, CNQ is high but with a low amount of NCs albeit sufficient GR&R results)
- D: Reduce the amount of measurements (C_p/C_{pk} as well as GR&R are capable, CNQ is low, as are NCs)
- E: Improve the process (GR&R passed, SPC incapable, high CNQ and NCs)
- F: Improve the MS & process (GR&R failed, SPC incapable, high CNQ & NCs)
- G: Improve the MS & change tolerances (GR&R failed, SPC incapable, low CNQ, high NCs)
- H: Reduce amount of measurements & change tolerance (GR&R passed, SPC very good, low CNQ & NCs)

Some of the thoughts behind it:

- There will not be high results (= bad) for NC, provided the C_{pk} is good
- There will not be good C_{pk} values, provided GR&R is bad

- There will not be good GR&R outcomes, when the MS is unsuitable
- There will not be high values for CNQ (=bad), when the C_{pk}, tolerance & GR&R are good

An issue that surfaced while working with the data as present at Airbus, is that a lot of the data is in fact a grouping of more data aspects. For example, CNQs and NCs are often added up for the processes - to get these separated is a need to get proper numbers per process and as such prioritise per process.

4.3. Measurement System Analysis Quality Review

This section is dedicated to the *Measurement System Analysis Quality Review (MQR)*. To get a better overview, a table is constructed and added as table 4.5. This table provides a table of content as associated with the prioritisation tool and the status of all its parts.

The following can be deduced from this table:

- Concerning the data that is being used in the tool.
  - CNQ: The use of CNQ is not yet fully functional within the tool. It is very hard to divide the raw data per program (e.g. A320, A330), process (e.g. pred-rilling holes into the VTP, installing bolts in the flaps) and even further divisions. Effort has been put into coming up with solutions, but they have not yet been found; needs more thought & work.
  - NC: A manner to optimally integrate the NC data within the tool has not yet been established. It is very hard to divide the raw data per program (e.g. A350, A380), process (e.g. spray painting the outer wing-box, riveting the skin) and further divisions. Hasn't been initiated yet; just some ideas.
  - GRR: A weighted division for Severity, Occurance and Detectability (S, O & D) per inspection characteristic & measurement device has been constructed. Still requires extra cells in the MSA tab in the Harmonised Inspection Planning (HIP) tool.
  - C_{pk}: Data has been obtained from the capability dashboards. These have been linked with one another and are fully functional.
  - Risk: Should be split per IC, also add what is important per case (e.g. a thickness measurement is of higher importance when it is stress related, as for positioning (assembly) & customer satisfaction). More information on this can be found in table 4.6.
- A first desire/output from the tool is the ability to determine goals that should result from input data. Relate to tables 4.1 and 4.3, as an optimisation, this process could get automated.
- The second and third steps are to determine the mitigation actions from these goals and who are in charge of executing them:
  - A, C, E and F: These actions often get executed in parallel with suppliers such as Alten and P3
  - B: Depending on the complexity (of the causes), it may require deep investigation and is therefore hard to execute
  - D: Should be contemplated carefully before executing this action. Avoid that it has to be reversed in the (near) future
  - G: Action often gets executed in parallel with suppliers such as Alten and P3, could be rather complex
  - H: Requires extensive considerations; could be rather complex
- Development of the tool: Started on developing for the details of C_{pk} and MSA in Microsoft Excel.
- Describing & documenting the process: Present in loads of separate documents; assembled into one file.

Table 4.5: Measurement System Analysis (MSA) Quality Review (MQR)

Measurement System Analysis (MSA) Quality Review (MQR)				Status Completed Yes / V	No / O
Prioritisation MSA					O
	CNQ				O
	NC				O
	GRR			V	
	Cpk			V	
	Risk			/	/
Tracking Matrix					O
	Automatically processing and forwarding actions (per siglum)				O
		1st step: Determine goals resulting from data input		V	
		A: Improve MS	Action for Q(uality / DSO1)	V	
		B: Change Tolerance	Action for Engineering	V	
		C: Improve Process	Action for Manufacturing Engineering	V	
		D: Reduce # Measurements	Action for Q(uality / DSO1)	V	
		E: Improve Process	Action for Manufacturing Engineering	V	
		F: Improve MS & Process	Action for Q(uality / DSO1) & ME	V	
		G: Improve MS & CT	Action for Q(uality / DSO1) & E	V	
		H: Reduce # of MPs & CT	Action for Q(uality / DSO1) & E	V	
		2nd step: Actions		V	
		A: Execute MSA		V	
		B: Research recommended changes		V	
		C: Execute PPS / Ursachen Analyse (Root cause analysis)		V	
		D: Cut out measurement points at sensible places		V	
		E: Excute C		V	
		F: Excute A & C		V	
		G: Excute A & B		V	
		H: Excute D & B		V	
		3rd step: Responsibility		V	
		A: QDSO1		V	
		B: E		V	
		C: ME		V	
		D: QDSO1		V	
		E: ME		V	
		F: QDSO1 & ME		V	
		G: QDSO1 & E		V	
		H: QDSO1 & E		V	
Development of the tool				V	
Describe and document the process				V	

Associated with the risks as mentioned in table 4.5, a risk-tree is constructed and shown in table 4.6. In this table, the *Inspection Characteristics (ICs)* and *Key Characteristics (KCs)* are extracted through the HIP-tool. The raw data as available there has already undergone a clean up session to take out obsolete data. Would be good if it would undergo another check up (verification/validation).

Table 4.6: Binary risk-tree; indicating whether the ICs are considered of importance for the five categories

RISKTREE	Customer	Stress	Aero-dynamics	Environment	Assembly
Spacing measurement	↓	↓	↓	↓	↑
Damage / Contamination	↑	↓	↑	↑	↓
Deformation measurement	↑	↑	↓	↓	↑
Thickness measurement	↓	↑	↓	↓	↓
Diameter / Ø	↓	↑	↓	↓	↑
Tool measurement	↓	↓	↓	↓	↑
Flight control	↑	↓	↑	↓	↓
Geometry	↓	↓	↑	↑	↑
Inner quality	↓	↑	↓	↓	↓
Laminate thickness measurement	↓	↑	↓	↓	↓
Ground connections / connection	↓	↑	↓	↓	↑
Surface finish	↑	↓	↑	↑	↓
Surface protection	↑	↓	↑	↑	↓
Position	↓	↓	↓	↓	↑
Roughness	↑	↑	↑	↑	↓
Gap measurement	↓	↓	↓	↓	↑
Flush measurement	↓	↓	↓	↓	↓
Ultrasound tests	↓	↑	↓	↓	↓
Ripple	↑	↑	↑	↑	↓
Resistivity	↓	↓	↓	↓	↓
Angle	↑	↑	↑	↑	↑

Within this table, use has been made of arrows pointing up or down. These indicate the importance level for the ICs and KCs with respect to five columns for customer, stress, aerodynamics, environment and assembly. An upwards arrow represents high importance and an arrow pointing down signifies low importance.

Note that the entry for geometry can actually be seen as an umbrella term which includes thickness, position, angle, distance, etc. Also note that environment could be included within the tab for customer, considering customers nowadays wish to brand themselves as being environmentally aware.

5

Prioritisation Tool

The previous chapters have all been in service of this chapter; the description of the tool that was constructed for the prioritisation of MSAs. The tool is in essence one big master sheet in a Microsoft Excel workbook, which accesses and manipulates several other sheets in the same workbook. The sheets are conveniently named in a descriptive manner, which suits the sections and subsections as present in this chapter. In section 5.1, the three sheets which are related to C_{pk} are handled in separate subsections. Then in section 5.2, two sheets concerned with the CNQ side of the tool are dealt with. Thereafter, in section 5.3, the next three subsections focus on risk and GR&R. Next, there are two subsections in section 5.4 to deal with the master sheet which gives the results for the prioritisation. Finally, section 5.5 describes how the tool should be used.

To keep an overview while creating the tool, a flowchart was made. This flowchart can be seen in figure A.1 in appendix A. The flowchart has one main decision check, which focuses around the availability of the data for the tool. During the course of developing and testing the tool, it became apparent that there would always be issues with data not being available. To circumvent the tool getting stuck in an endless loop, it would proceed to the next block if it had already been through the data-check once and the issues didn't get resolved.

Although the tool was planned to be created in a different environment, it was constructed in Microsoft Excel, there are however ideas to further optimise it and get it translated into a different format. These ideas are further elaborated upon in chapters 6 and 7. Considering there are quite a number of (nested) Microsoft Excel functions present in the tool, which are cross-referenced through several sheets, a more in depth walk-through for these functions is appended in appendix B.

5.1. C_{pk} affiliated

In this first section, the three sheets that deal with C_{pk} are treated. It starts with subsection 5.1.1, which is nothing more than a large data sheet. The calculations that are based on this sheet are located in subsection 5.1.2. This then leads to subsection 5.1.3 which obtains information that gets passed on to the master sheet in subsection 5.4.1.

5.1.1. First sheet: Cpk

The first sheet in the Microsoft Excel workbook is a copy and paste of a large amount of data. This data can be extracted from the capability dashboards, which can be found through Skywise [46] by those people who have sufficient access to the Airbus cloud.

The specific document in Skywise is called: "$2\_Calculate\_CPK\_Increment\_V2$" and accesses a large matrix of 189559 rows by 13 columns (n x m); each row signifies a measurement. In figure 5.1 a snapshot of the Excel sheet is included.

The first row gives the outline of the table and holds the following entries for the columns: NB_Month, ID_Point, ID_SPC, REP, $Date\_Start$, $Date\_End$, $Date\_Calc$, CP, CPK, NBIV, NBIVNA, NBIVOOT and MEAN. The other 189558 rows are just data entries.

The first column signifies over how many months the data has been collected. In this case, that translates into options for one, three, six and twelve months. The lower the amount of months,

	A	B	C	D	E	F	G	H	I	J	K	L	M
2	N	ID_Po	ID_SF	REP	Date_Sta	Date_En	Date_Cal	CP	CPK	NE	NBIV	NBIVOOT	MEAN
3	1	767759	72289	Rand	01/03/2017	31/03/2017	01/03/2017	2.1479316	-0.3400892	21	0	13	2.5866667
4	1	767781	72289	Rand	01/03/2017	31/03/2017	01/03/2017	2.4638186	-0.1010797	21	0	4	1.6866667
5	1	767788	72289	Rand	01/03/2017	31/03/2017	01/03/2017	5.5847188	6.20E-15	21	0	2	2.78
6	1	767781	72289	Rand	01/06/2017	30/06/2017	01/06/2017	3.8896035	0.0704001	17	0	2	1.7058824
7	1	767759	72289	Rand	01/06/2018	30/06/2018	01/06/2018	5.1095231	0.1459864	7	0	1	2.6614286
8	1	767759	72289	Rand	01/12/2016	31/12/2016	01/12/2016	1.3945731	0.1716398	13	2	0	2.6992308
9	1	767781	72289	Rand	01/12/2016	31/12/2016	01/12/2016	1.4207601	0.225304	13	2	0	1.7515385
10	1	767759	72289	Rand	01/06/2017	30/06/2017	01/06/2017	1.3284582	0.2363874	17	0	0	2.7211765
11	1	767759	72289	Rand	01/11/2017	30/11/2017	01/11/2017	1.1400355	0.3063845	8	0	0	2.7575
12	1	767759	72289	Rand	01/09/2017	30/09/2017	01/09/2017	5.3333333	0.3555556	9	1	0	2.6766667
13	1	767780	72289	Rand	01/03/2017	31/03/2017	01/03/2017	2.2945759	0.3698218	21	0	0	1.752381
14	1	767780	72289	Rand	01/12/2016	31/12/2016	01/12/2016	1.2847525	0.3770635	13	2	0	1.7953846
15	1	767781	72289	Rand	01/06/2018	30/06/2018	01/06/2018	2.3857658	0.4089884	7	0	0	1.7557143
16	1	767972	72289	Rand	01/12/2016	31/12/2016	01/12/2016	0.8605021	0.4385251	13	2	0	2.4538462
17	1	767781	72289	Rand	01/11/2017	30/11/2017	01/11/2017	2.4589027	0.5012379	8	0	0	1.76625
18	1	767759	72289	Rand	01/12/2017	31/12/2017	01/12/2017	2.5712008	0.5083965	11	34	0	2.7290909
19	1	767781	72289	Rand	01/01/2018	31/01/2018	01/01/2018	4.1522517	0.5312192	19	0	0	1.7415789
20	1	767863	72289	Rand	01/06/2017	30/06/2017	01/06/2017	5.2565907	0.5333894	17	0	0	2.8205882
21	1	767863	72289	Rand	01/12/2016	31/12/2016	01/12/2016	3.4739697	0.5478183	13	2	0	2.8430769
22	1	767778	72289	Rand	01/03/2017	31/03/2017	01/03/2017	3.0805709	0.5647713	21	0	0	2.2233333
23	1	767779	72289	Rand	01/09/2017	30/09/2017	01/09/2017	1.7378188	0.5822436	9	1	0	1.8088889
24	1	767780	72289	Rand	01/06/2017	30/06/2017	01/06/2017	3.1456788	0.5921278	17	0	0	1.7611765
25	1	767901	72289	Rand	01/12/2016	31/12/2016	01/12/2016	4.181667	0.62725	13	2	0	2.84
26	1	767971	72289	Rand	01/06/2017	30/06/2017	01/06/2017	1.8973736	0.6361782	17	0	0	2.9141176
27	1	767824	72289	Rand	01/12/2016	31/12/2016	01/12/2016	2.9140228	0.6892785	13	2	0	2.8746154
28	1	767778	72289	Rand	01/06/2018	30/06/2018	01/06/2018	3.664595	0.7067433	7	0	0	2.2271429
29	1	767966	72289	Hautfeld	01/12/2016	31/12/2016	01/12/2016	2.6504064	0.7186679	13	2	0	2.8884615
30	1	767973	72289	Rand	01/03/2017	31/03/2017	01/03/2017	2.0774966	0.7221774	21	0	0	2.4890476
31	1	767777	72289	Rand	01/03/2017	31/03/2017	01/03/2017	2.1499252	0.7268795	21	0	0	2.7852381
32	1	767779	72289	Rand	01/12/2016	31/12/2016	01/12/2016	1.3985773	0.7315635	13	2	0	1.87
33	1	767777	72289	Rand	01/12/2017	31/12/2017	01/12/2017	2.2017456	0.7405871	11	34	0	2.7845455
34	1	767779	72289	Rand	01/06/2017	30/06/2017	01/06/2017	2.4621025	0.7664826	17	0	0	1.8011765
35	1	767777	72289	Rand	01/12/2016	31/12/2016	01/12/2016	1.7470876	0.7828296	13	2	0	2.8292308
36	1	767781	72289	Rand	01/09/2017	30/09/2017	01/09/2017	4.110961	0.7870558	9	1	0	1.7622222

Cpk | CpkCalculations | CpkUse | CNQR | CNQF | Risk | SOD | GR&R | Processes | Sort Prio | Tabelle1

Figure 5.1: A snapshot of the Excel sheet as associated with Cpk

the higher production rate, as this means that less time is required to already generate a statistically significant amount of data. Here these are the numbers for the A320, A350, A330 and A380 production programs respectively.

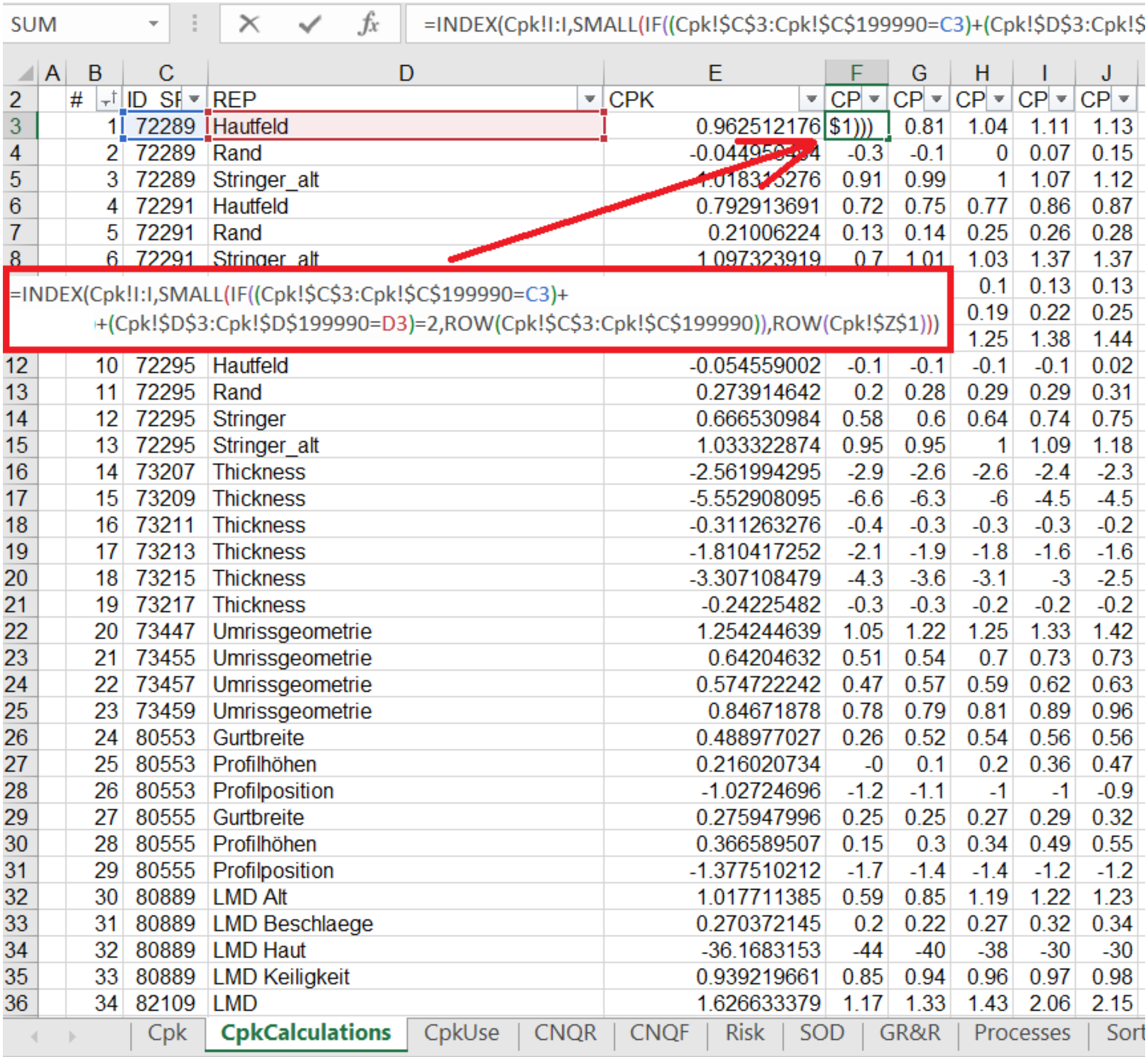
5.1.2. Second sheet: CpkCalculations

The second sheet holds a smaller matrix: (639 x 9), with on the first row the following content, respectively: $\#$, ID_SPC, REP, CPK1, CPK2, CPK3, CPK4, CPK5 and CPK. Figure 5.2 provides a snapshot of the relevant Excel sheet.

The first three columns represent the number, the specific Airbus ID and a short description for what is being evaluated. Next there are five columns which essentially do the same, they select the worst five C_{pk} values per measured parameter. This is done by referring back to the first sheet and sorting through it. The last column is the one which will be used later in the prio tool. This column averages the five worst C_{pk} values per measured parameter. Due to only working with the worst five, the data set gets reduced from just under 200,000 entries to a mere 640 (factor 300) without really effecting the significance, as the most valuable entries are the worst entries, as those are the ones one has to deal with. Furthermore, it reduces the amount of calculations the tool has to execute quite a bit and as such speeds up its use. *Note: due to the fact that this sorting, as applied in the five CPK columns, works through array formulae, "ctrl + shift + enter" has to be used to execute the formulae to get a correct result. This is a handling mechanic from Microsoft Excel.*

Going through this sheet, there are a few cells which do not provide usable output. There could be several reasons for this; to name a few:

- There are not five C_{pk} values for a parameter, so there can't be an average over the five. In this case, the process is omitted from the prio list. Reasoning behind it is that if there aren't even that few inputs available, one should not base any conclusions on it - unable to form meaningful conclusions upon it. Exceptions do occur though, for instance if the CNQ associated with the process



SUM | =INDEX(Cpk!I:I,SMALL(IF((Cpk!$C$3:Cpk!$C$199990=C3)+(Cpk!$D$3:Cpk!$

	A	B	C	D	E	F	G	H	I	J
2		#	ID_SF	REP	CPK	CP	CP	CP	CP	CP
3		1	72289	Hautfeld	0.962512176	$1)))	0.81	1.04	1.11	1.13
4		2	72289	Rand	-0.04495[illegible]4	-0.3	-0.1	0	0.07	0.15
5		3	72289	Stringer_alt	1.018313276	0.91	0.99	1	1.07	1.12
6		4	72291	Hautfeld	0.792913691	0.72	0.75	0.77	0.86	0.87
7		5	72291	Rand	0.21006224	0.13	0.14	0.25	0.26	0.28
8		6	72291	Stringer_alt	1.097323919	0.7	1.01	1.03	1.37	1.37
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.1	0.13	0.13
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.19	0.22	0.25
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.25	1.38	1.44
12		10	72295	Hautfeld	-0.054559002	-0.1	-0.1	-0.1	-0.1	0.02
13		11	72295	Rand	0.273914642	0.2	0.28	0.29	0.29	0.31
14		12	72295	Stringer	0.666530984	0.58	0.6	0.64	0.74	0.75
15		13	72295	Stringer_alt	1.033322874	0.95	0.95	1	1.09	1.18
16		14	73207	Thickness	-2.561994295	-2.9	-2.6	-2.6	-2.4	-2.3
17		15	73209	Thickness	-5.552908095	-6.6	-6.3	-6	-4.5	-4.5
18		16	73211	Thickness	-0.311263276	-0.4	-0.3	-0.3	-0.3	-0.2
19		17	73213	Thickness	-1.810417252	-2.1	-1.9	-1.8	-1.6	-1.6
20		18	73215	Thickness	-3.307108479	-4.3	-3.6	-3.1	-3	-2.5
21		19	73217	Thickness	-0.24225482	-0.3	-0.3	-0.2	-0.2	-0.2
22		20	73447	Umrissgeometrie	1.254244639	1.05	1.22	1.25	1.33	1.42
23		21	73455	Umrissgeometrie	0.64204632	0.51	0.54	0.7	0.73	0.73
24		22	73457	Umrissgeometrie	0.574722242	0.47	0.57	0.59	0.62	0.63
25		23	73459	Umrissgeometrie	0.84671878	0.78	0.79	0.81	0.89	0.96
26		24	80553	Gurtbreite	0.488977027	0.26	0.52	0.54	0.56	0.56
27		25	80553	Profilhöhen	0.216020734	-0	0.1	0.2	0.36	0.47
28		26	80553	Profilposition	-1.02724696	-1.2	-1.1	-1	-1	-0.9
29		27	80555	Gurtbreite	0.275947996	0.25	0.25	0.27	0.29	0.32
30		28	80555	Profilhöhen	0.366589507	0.15	0.3	0.34	0.49	0.55
31		29	80555	Profilposition	-1.377510212	-1.7	-1.4	-1.4	-1.2	-1.2
32		30	80889	LMD Alt	1.017711385	0.59	0.85	1.19	1.22	1.23
33		31	80889	LMD Beschlaege	0.270372145	0.2	0.22	0.27	0.32	0.34
34		32	80889	LMD Haut	-36.1683153	-44	-40	-38	-30	-30
35		33	80889	LMD Keiligkeit	0.939219661	0.85	0.94	0.96	0.97	0.98
36		34	82109	LMD	1.626633379	1.17	1.33	1.43	2.06	2.15

=INDEX(Cpk!I:I,SMALL(IF((Cpk!$C$3:Cpk!$C$199990=C3)+
+(Cpk!$D$3:Cpk!$D$199990=D3)=2,ROW(Cpk!$C$3:Cpk!$C$199990)),ROW(Cpk!$Z$1)))

Cpk | CpkCalculations | CpkUse | CNQR | CNQF | Risk | SOD | GR&R | Processes | Sort

Figure 5.2: A section of the Excel sheet as associated with CpkCalculations

are very big, it should get investigated nevertheless. Such exceptions are dealt with/caught later on in the tool, for added robustness. However, keep the 20-80 rule in the back of your mind; the amount of extra coding/input/work to attain it might not weigh up to the gains (20% of the effort for 80% of the gains, another 80% effort for the remaining 20% gains)

- There is no SPC data available for this process parameter. This in itself can be caused by several reasons, yet is not further looked into. Most occurring cause is a miss-match in retrieving data from the data-lake. This is for instance the case with close to 100 entries for surface quality

There are several formulae present in this sheet. For clarity's sake, one of the bigger formulae is given here as equation 5.1. It is also highlighted in figure 5.2.

$$\begin{aligned}\{= INDEX(Cpk!I:I, SMALL(IF((Cpk!\$C\$3:Cpk!\$C\$199990 = C3) + (Cpk!\$D\$3:...\\ ...Cpk!\$D\$199990 = D3) = 2, ROW(Cpk!\$C\$3:Cpk!\$C\$199990)), ROW(Cpk!\$Z\$1)))\}\end{aligned} \tag{5.1}$$

It is constructed by combining the last four standard Microsoft Excel functions as given in appendix B.1. The working of it, is described as follows:

First, the formula refers back to the first sheet (Cpk); here it checks IF it can find ROWs for which columns C and D (3^{rd} till 199990^{th} row) match both columns C and D of the second sheet (CpkCalculations).

IF that is the case, it investigates column I of the first sheet and returns the x^{th} SMALLest value it finds in there, which corresponds to the ROW of the previously determined matching C & D column entries, while x fluctuates from the smallest to the 5^{th} smallest (giving five outputs - this is accomplished by copying the formula five times and changing the Z1 parameter from Z1 up till Z5 - which is done in columns F through J of this 2^{nd} sheet).

Having obtained these five worst C_{pk} values per process, they are averaged to get one C_{pk} value per process in column E. These averaged values are later on used in the third sheet, as is further explained in subsection 5.1.3, where weights are assigned to them. These will finally be used to determine their priority for undergoing a new MSA in subsection 5.4.1.

Note: The arrays which are used here, are just single columns (I, C & D), therefore there is only a row given when determining a location within the array; the column indicator is omitted, as it holds no merit here.

5.1.3. Third sheet: CpkUse

The third sheet consists out of one large matrix (426 x 6) and two small tables for in between calculations and comparisons. A part of this large matrix is included as figure 5.3.

The matrix has the following entries on it's first row: $\#$, ID_SPC, REP, ID_SPC + REP, CPK, Rated C_{pk}. The first three are copy pasted from the sheet *CpkCalculations*, after eliminating any doubles, by which the amount of data shrinks significantly and as such the calculations go much faster. The fourth column merges the second and third column, to then use this column to compare in the ninth sheet: *Processes*. The fifth column is a copy of the CPK column of the *CpkCalculations* sheet and the final column compares the fifth column with the table to assign a weight for C_{pk} per process parameter. Note that the formulae, as used in cells E3 and G10, are highlighted in figure 5.3.

Continuing with the tables, they assign weights to the C_{pk} values, which will then later be used in the full prio tool in subsection 5.4.1. The tables are constructed in a very structured manner. The first column is left almost empty, the second column signifies the C_{pk} range with the third specifying the cut off value and then finally the fourth assigning the weight per range. Note that these cut off values are always a lower limit.

The first table is the initial one and can be seen in table 5.1. In this first table, the main focus was on simplicity. Note that the entire range for C_{pk} is included by setting the outer ranges as <-30 and ≥30 respectively. Although such large absolute numbers are hardly ever present, it is good to check for them; to quickly locate them as they would likely indicate mistakes in the data.

Table 5.1: Initial weights assigned for the full range of C_{pk}

Cpk ranges [-]	Cut-off value	Assigned value
Cpk <-30	-30	100000
-30 < Cpk < -10	-10	10000
-10 ≤ Cpk < -3	-3	1000
-10 ≤ Cpk < -2	-2	100
-2 ≤ Cpk < -1	-1	10
-1 ≤ Cpk < 1	1	keep #
1 ≤ Cpk < 1.33	1.33	keep #
1.33 ≤ Cpk < 1.66	1.66	keep #
1.66 ≤ Cpk < 2	2	keep #
2 ≤ Cpk < 3	3	10
3 ≤ Cpk < 10	10	100
10 ≤ Cpk < 30	30	10000
Cpk ≥ 30		100000

The second is an adaptation of the first one, it was constructed after running the full tool a few times and deciding that some tweaks here and there could be beneficial, it is visualised in table 5.2. Note that only the second one is used and, if so desired, can be modified by either changing the limits of a range or the weights assigned to them. Furthermore note that the colours, as used in the second and third column, match those as used in cell G10 in figure 5.3.

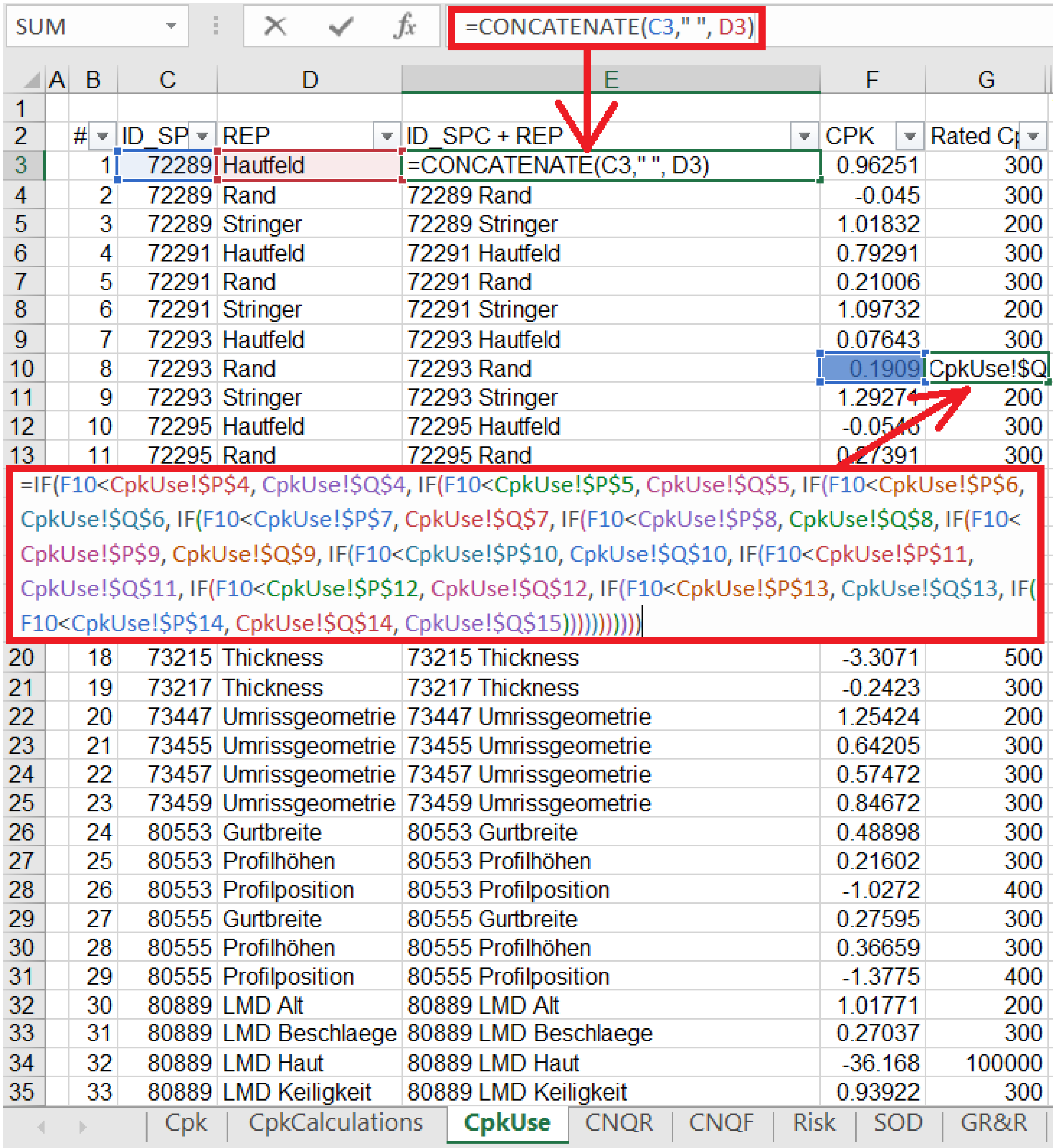


Figure 5.3: A part of the Excel sheet as associated with CpkUse

Table 5.2: Modified weights assigned for the entire range of C_{pk}

Cpk ranges [-]	Cut-off value	Assigned value
Cpk <-30	-30	100000
-30 ≤ Cpk < -10	-10	10000
-10 ≤ Cpk < -2	-2	500
-2 ≤ Cpk < -1	-1	400
-1 ≤ Cpk < 1	1	300
1 ≤ Cpk < 1.33	1.33	200
1.33 ≤ Cpk < 1.66	1.66	50
1.66 ≤ Cpk < 2	2	40
2 ≤ Cpk < 3	3	250
3 ≤ Cpk < 10	10	1000
10 ≤ Cpk < 30	30	2000
Cpk ≥ 30		5000

The thought behind the values which are assigned to the C_{pk} ranges, is that in the full tool, a high number gets a higher prio than a low number. Therefore, the bad C_{pk} values get a very high number and the very good C_{pk} values get a relatively high number; respectively because they represent incapable MSAs and MSAs which could be optimised.

5.2. CNQ affiliated

In this second section, the two sheets that deal with CNQ are treated. First CNQR in subsection 5.2.1 and thereafter immediately followed by CNQF in subsection 5.2.2, the difference between the two originates from their respective intermediate sources. The first is provided by Ralf (an Airbus employee working as conformance management engineer in the quality department) and the second by Friederike (an external Airbus employee (P_3, subcontractor).

With the exception of the data being provided by two separate people and thus having undergone some different manipulations, the content should be the same. There are however some discrepancies between the two and even after rigorous discussions, a real reason was not found. Therefore, both of them are included and when there is a double entry, the worst entry gets selected to be passed further to the master sheet for the prio calculation. *Note: To simplify the use of this data, all costs are added up to one variable per process: Total cost.*

5.2.1. Fourth sheet: CNQR

The data in this sheet comes in as a big raw matrix file with dimensions of 12453 by 61. It is obtained through the Q-Navigator of Q-Service-Stade[1] and can only be accessed with the proper rights as it is confidential information which can not be shared in this document. To allow for the intended educational purposes, a modified version - *exact numbers are altered* - will be used here.

In line with the previous sheet, a table is constructed to assign weights for CNQ ranges; this table is included as table 5.3.

Table 5.3: Initial weights assigned for wide range of CNQ

CNQ ranges [€]	Cut-off value	Assigned value
CNQ <5	5	keep #
5 ≤ CNQ < 10	10	10
10 ≤ CNQ < 50	50	50
50 ≤ CNQ < 100	100	100
100 ≤ CNQ < 500	500	500
500 ≤ CNQ < 1000	1000	1000
1000 ≤ CNQ < 5000	5000	5000
5000 ≤ CNQ < 10000	10000	10000
10000 ≤ CNQ < 50000	50000	50000
CNQ ≥ 50000		100000

5.2.2. Fifth sheet: CNQF

As the content of the two should be the same, the table for the weights is the same too. The data matrices differ in dimensions though, as this one comprises 12690 rows by 41 columns.

Some of the differences are accounted for by a different means of creating this matrix. This data is a collection of data which is obtained through SAP [47] and the output after running an ACCESS database. It services as a break down structure with respect to where costs originate from in the process.

For the goal of this prioritisation tool, further investigations which could detect the cause for discrepancies between the two data-sheets are considered to be out of scope. The main interest of Airbus was in the creation of the tool. At a later point, modifications could be introduced when a final stance on the CNQ data is obtained.

[1] Internal link for Airbus' Quality department in stade http://collaborate.airbus.corp/sites/Q-Service_Stade/sitepages/Welcome.aspxl

5.3. Risk and GR&R affiliated

Risks are the third factor within the prioritisation of MSAs and this third section is dedicated to them. Attention is given to the risks that are involved with all these processes and how they come into play for the MSA prioritisation. The risks will span over two sheets in the workbook, they start with *Risk* which is further documented in subsection 5.3.1 and continues with *Severity, Occurrence and Detectability (SOD)* in subsection 5.3.2. These risks are linked to the *Inspection Characteristics (ICs)* and *Control Devices (CDs)* that play a role for MSAs at Airbus.

5.3.1. Sixth sheet: Risk

This sheet consists of two tables, both are constructed based on expert input. First table 5.4, which is a combination of two tables as present in the tool, as they both deal with ICs.

The first ten columns (including the blue total), assign initial weights to signify the impact for the relevant fields in case errors pop up. These fields were selected to be: customer, engineering stress, aerodynamics, environment and assembly. First, a binary division is made to determine whether a certain IC is affected by one of the categories and thereafter a total risk number is generated by multiplying the separate categories with their respective weights for each IC. *Note that in this case, angle measurements come at the highest risk.*

The last four columns of the table are however linked with the Severity, Occurrence and Detectability (SOD) and relate to subsection 5.3.2.

Table 5.4: Hybrid table: First part shows the significance of risk with respect to customer, engineering stress, aerodynamics, environment, assembly and a total for each IC. Second part gives the weighted SOD rating for these ICs.

RISKTREE			Weights:	5	10	5	3	3		Weights SOD (1-10)			
#	# in HIP	IC - Inspection Characteristic	Data type	Customer	Engineering Stress (σ,τ)	Aero-dynamics	Environ-ment	Assembly	Total	Severity	Occur-rence	Detect-ability	Total SOD (double weight for severity)
1	60	Spacing measurement	measurement	0	0	0	0	1	3	4	5	2	15
2	76	Damage / Contamination	attribute	1	0	1	1	0	13	3	8	2	16
3	57	Deformation measurement	laser	1	1	0	0	1	18	6	2	2	16
4	56	Thickness measurement	measurement	0	1	0	0	0	10	9	5	5	28
5	5	Diameter / Ø	measurement	0	1	0	0	1	13	5	2	6	18
6	96	Tool measurement	measurement	1	0	0	0	1	8	2	8	2	14
7	109	Flight control	attribute	1	0	1	0	0	10	9	8	2	28
8	6	Geometry	measurement	0	0	1	1	1	11	6	4	2	18
9	1	Inner quality	attribute	0	1	0	0	0	10	9	2	7	27
10	7	Laminate thickness measurement	measurement	0	1	0	0	0	10	9	6	5	29
11	77	Ground connections / connection	measurement	0	1	0	0	1	13	5	5	5	20
12	75	Surface finish	attribute	1	0	1	1	0	13	4	8	5	21
13	41	Surface protection	attribute	1	0	1	1	0	13	6	8	4	24
14	8	Position	measurement	0	0	0	0	1	3	4	5	2	15
15	9	Roughness	measurement (	1	1	1	1	0	23	3	7	3	16
16	55	Gap measurement	measurement	0	0	0	0	1	3	5	3	2	15
17	58	Flush measurement	measurement	0	0	0	0	0	0	5	5	2	17
18	49	Ultrasound tests	measurement	0	1	0	0	0	10	9	2	2	22
19	93	Ripple	attribute	1	1	1	1	0	23	6	7	2	21
20	78	Resistivity	measurement	0	0	0	0	0	0	6	5	5	22
21	11	Angle	measurement	1	1	1	1	1	26	4	6	3	17

The first part of the table gets manipulated in the second table, namely table 5.5, which subsequently provides input for the master sheet in which the complete prioritisation gets handled. A few things should get noted about this table:

- The three ICs with the highest and lowest importance are coloured red and green, respectively. Both with respect to the significance of the risk and for the SOD.
- A multiplier is applied on the column of severity to make it twice as important. The logic behind it is that in this manner, the easier linear thinking of the weights from 1 till 10 can still be used and simultaneously it does acknowledge that severity has the potential to be critical. High values for occurrence and detectability, albeit bad, are of lesser importance
- There is only one total value below 20 for attribute data types with respect to SOD. This suggests that attribute ICs are in general more prone to SOD.

Table 5.5: Adjusting the scores from the first part of the first table to be workable input for the big prioritisation sheet

Risk ranges [-]	Cut-off value	Assigned value
Risk <3	3	keep #
3 ≤ Risk < 6	6	10
6 ≤ Risk < 9	9	50
9 ≤ Risk < 12	12	100
12 ≤ Risk < 15	15	500
15 ≤ Risk < 18	18	1000
18 ≤ Risk < 21	21	5000
21 ≤ Risk < 24	24	10000
24 ≤ Risk < 27	27	50000
Risk ≥ 27		100000

Note: the highest assigned number is 50,000, for the current distribution of weights, although the table insinuates 100,000. This resulted from a modification of weights and is left as such, so it can cater for other possible alterations.

5.3.2. Seventh sheet: SOD

This sheet contains two weighted tables, one with ICs, the other with *Control Devices (CDs)*. The first table is however not displayed here, as it is conjoined to form table 5.4 in subsection 5.3.1.

The data in this sheet isn't completely raw. The ICs and CDs which are not related to MSAs have been excluded from the sheet, as are those which do not show up in the old *Harmonised Inspection Planning (HIP)* environment. Likewise, a few which weren't part of HIP have been added. Once again, the weights as assigned to the parameters, have been determined through discussing with experts. The same holds for the decisions about which CDs and ICs to exclude and include. These experts, the inspection planners (IPs), deal with issues related to ICs and CDs on a daily basis and have a good understanding on the severity of them on a per category basis.

The control devices are only undergoing an evaluation for detectability, as opposed to the ICs which also endured an evaluation for severity and occurrence, as these do not depend on the equipment, yet on the process. This table, concerning the CDs, is given as table 5.6. There are many more CDs than ICs and as such this table is quite a bit more extensive.

With time being an everlasting adversary, it was decided to not further specify for more fitting weights for the CDs. As such, the default value of five is still present here in table 5.6. The effect of the CDs was concluded to be rather marginal in comparison with the other inputs and has therefore not received any priority. In a latter modification, this could of course be incorporated. The two CDs highlighted in yellow (Chisel & Wiping cloth respectively) have been excluded from the investigation, as they're no longer being used as control devices.

5.3.3. Eighth sheet: GR&R

In this eighth sheet, there is a large matrix (203 x 19) directly imported from HIP; it is the MSA list. It provides data on which processes have undergone an MSA and more related information. It is thereafter modified for certain inputs. Furthermore, there is a table which assigns weights for the *Gauge Repeatability & Reproducibility (GR&Rs)*, in the same fashion as has been seen in the previous sections. For the tool itself, most of the data in the large MSA matrix has no real use. However, due to no formulae acting on this data, it does not slow the tool down tremendously and it does allow for

Table 5.6: Control devices weighted for detectability

#	CD - Control Device / Prüfmittel	Detectabilty (initial)	Detectabilty (modified)	#	CD	D (I)	D (M)	#	CD	D (I)	D (M)
38	Loop Resistance Tester	5	5	121	Torque indicator	5	5	18	Feeler gauge	5	5
79	Absolute pressure gauge	5	5	28	Positioning device	5	5	26	Dial indicator	5	5
98	Mobile measuring device TSI (Model AeroTrak 8220)	5	5	17	Three-point internal micrometer	5	5	105	Probe with 3mm ball	5 5	5 5
119	Anritsu VNA Master MS2026A	5	5	6	Measuring stick	5	5	14	Micrometer	5	5
109	Surface roughness gauge	5	5	123	Knock hammer	5	5	9	Torque wrench	5	5
55	Coating thickness gauge	5	5	27	3D-edge-finder	5	5	56	Parametrics	5	5
112	Laser projection	5	5	43	Hydraulic test stand	5	5	113	Particle sizer	5	5
45	Length measuring device	5	5	114	Clamp	5	5	101	Ply Book	5	5
48	Electrical angle measuring device	5	5	106	Coordinate measuring machine	5 5	5 5	107 99	Hand-Scanner Radius gauge	5 5	5 5
44	Force measuring device	5	5	89	Measuring comb	5	5	92	GAP-Gun	5	5
16	Two-point internal micrometer	5	5	115	Tensiometer	5	5	29	Renishaw	5	5
68	Laser-Interferometer	5	5	8	Thermometer	5	5	80	Plug gauge	5	5
103	Optical continuity tester	5	5	66	Depth marker	5	5	32	Manometer	5	5
116	Volume resistivity meter	5	5	94	Laserscanner	5	5	64	Quicktester	5	5
31	Clamping length doctrine	5	5	71	Lasertracker	5	5	111	Steel ruler	5	5
41	Temperature sensors	5	5	20	Angle meter	5	5	XXX	Chisel	5	5
117	Loop resistance tester	5	5	XXX	Wiping cloth	5	5	126	Touch tester	5	5
124	Alignment telescope	5	5	53	Ohmmeter	5	5	81	Gauge	5	5
44	Force measuring device	5	5	84	Ultrasonic	5	5	74	Calliper	5	5

easier comprehension, as one can combine the data more easily and see what connects where and how. It also allows for easier management of actions that should be taken in the future, as information on who performed what and when is also included there.

The rows have been edited in such a fashion that they are singles, no merged cells, as that gives trouble with filtering. Next to that, in case there are double entries, they get separated to allow for isolation. In these instances, the original stays numbered as it was and the extra rows get an added a, b, c, etc to their #. MSA 0021 is a good example; it is valid for the A330 as well as the A330 NEO, but both should get their own row, to allow for proper use.

A piece of this Excel sheet, without the tables, can be seen in figure 5.4; here the formulae for cells U7 and X7 have been highlighted.

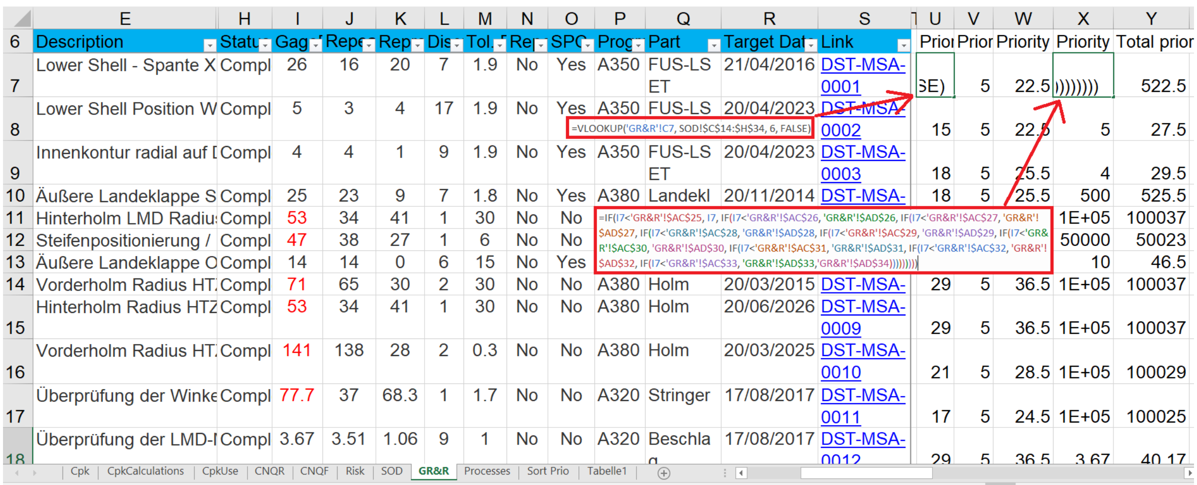


Figure 5.4: A piece of the Excel sheet as associated with GR&R

A table for weights, as has popped up several times in this chapter already, is present here too and can be seen in table 5.7. Note that the colours as associated with the formula from cell X7 correspond to the colours as are present in the table.

Furthermore, be aware that this sheet does not yet incorporate GR&R results, yet just connects the processes which undergo MSAs with weighted values for ICs and CDs, as previously determined in subsection 5.3.2. Here the CDs receive a 50% increase, to allow for a heightened importance.

Table 5.7: Weights for GR&R

GR&R ranges [%]	Cut-off value	Assigned value
GR&R < 10	10	keep #
10 ≤ GR&R < 15	15	10
15 ≤ GR&R < 20	20	50
20 ≤ GR&R < 25	25	100
25 ≤ GR&R < 30	30	500
30 ≤ GR&R < 35	35	1000
35 ≤ GR&R < 40	40	5000
40 ≤ GR&R < 45	45	10000
45 ≤ GR&R < 50	50	50000
GR&R ≥ 50		100000

5.4. Full prio

This section represents the core of the tool, this is were the sheets get connected with each other and the most laborious calculations get executed. First, in subsection 5.4.1, most of the calculations are performed and then in subsection 5.4.2, the processes get sorted for prioritisation.

5.4.1. Ninth sheet: Processes

Again a big matrix (668 x 44) with data. The first 20 columns come from HIP, the last 24 are manually added to allow for the needed calculations, 15 of these are however hidden, as they only provide intermediate calculations and do not need to be seen to get a quick overview. As a picture says more than a thousand words, once again a piece of this Excel sheet can be seen in figure 5.5.

	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AG	AH	AI	AJ	AK	AL	AO	AP	AQ
1	VERKETTET	Cpk	Cpk	CNQ_	W: C	CNQ_F	W: CN	Pric	Pric	Pr	Prio C	Risk	Risk	Ris	Weig	W: C	W: Pr	W: F	Full P	Top 10
2	57735 Innere Qualität			0	0	950	1000	27	18	5	34.5	10	11	11	300	1000	1000	100	2400	115100
3	57736 Innere Qualität			0	0	950	1000	27	18	5	34.5	10	11	11	300	1000	1000	100	2400	105600
4	57906 Innere Qualität			0	0	483.03	500	27	18	5	34.5	10	11	11	300	500	1000	100	1900	105110
5	57907 Innere Qualität			0	0	483.03	500	27	18	5	34.5	10	11	11	300	500	1000	100	1900	101110
6	57908 Innere Qualität			992	1000	1092	5000	27	18	5	34.5	10	11	11	300	5000	1000	100	6400	100610
7	57909 Innere Qualität			992	1000	1092	5000	27	18	5	34.5	10	11	11	300	5000	1000	100	6400	65300
8	57910 Innere Qualität			0	0	100	500	27	18	5	34.5	10	11	11	300	500	1000	100	1900	65300
9	57911 Innere Qualität			0	0	100	500	27	18	5	34.5	10	11	11	300	500	1000	100	1900	60400
10	57918 Holmbreite			0	0	100	500	18	18	5	25.5	11	11	11	300	500	500	100	1400	60400
11	58004			0	0	670	1000	###	22	5	29.5	#N/A	10	10	300	1000	500	100	1900	60400
12	72289 Hautfelc	0.963	300	68.73	100	210.95	500	18	29	5	36.5	11	10	11	300	500	5000	100	5900	
13	72289 Stringer	1.018	200	68.73	100	210.95	500	17	29	5	36.5	0	10	10	200	500	5000	100	5800	
14	72289 Rand	-0.045	300	68.73	100	210.95	500	15	29	5	36.5	3	10	10	300	500	5000	100	5900	
15	72291 Stringer	1.097	200	507	1000	607	1000	17	29	5	36.5	0	10	10	200	1000	5000	100	6300	
16	72291 Hautfelc	0.793	300	507	1000	607	1000	18	29	5	36.5	11	10	11	300	1000	5000	100	6400	
17	72291 Rand	0.21	300	507	1000	607	1000	15	29	5	36.5	3	10	10	300	1000	5000	100	6400	
18	72293 Stringer	1.293	200	0	0	3981	5000	17	29	5	36.5	0	10	10	200	5000	5000	100	10300	
19	72293 Hautfelc	0.076	300	0	0	3981	5000	18	29	5	36.5	11	10	11	300	5000	5000	100	10400	

Cpk | CpkCalculations | CpkUse | CNQR | CNQF | Risk | SOD | GR&R | Processes | Sort Prio | Tabelle1

Figure 5.5: A segment of the Excel sheet as associated with Processes

The use of these columns is elaborated upon in the next list; with a split between hidden and visible columns:

- Visible columns: These are the most important columns, keeping just them visible creates a less cluttered overview. The last two columns allow for streamlining further management decisions; they give the total prio index per process.
  - Column C: A copy of Column AP (for sorting purposes).
  - Column U: ID_SPC is concatenated with the REP.
  - Column V: The third sheet (CpkUse) is assessed; it searches through the matrix to find the match of ID_SPC & REP with C_{pk} and then returns this C_{pk} value.

  - Column W & AJ: Similar to V, but returns the prio index for Cpk instead. AJ is a copy of W for easier observing through the tool.
  - Column AK: Compares the CNQ prio from the Airbus employee with the subcontractor; takes the highest.
  - Column AL: Assign a prio index for GR&R
  - Column AO: Assign a prio index for Risk.
  - Column AP: Sums the values from AK, AL and AO to give the full prioritisation.
  - Column AQ: Displays the top 10 results (prio rating) from AP.
  - Column AR: Displays the top 10 results (which process) from AP.

- Hidden columns:
  - Columns A, B and D through T: HIP data is imported.
  - Columns X, Y, Z and AA work in conjunction on CNQ for column AK.
    - Column X: Assesses the fourth sheet (CNQR); it searches through the matrix to find the match of Product with HTZ2 (German manufacturers part number) and then returns the value for CNQ as per the Airbus employee.
    - Column Y: Proceeds with what X did; now relates the CNQR with the assigned prio index for CNQR.
    - Column Z: Assesses the fifth sheet (CNQF); it searches through the matrix to find the match of Product with HTZ2 and then returns the value for CNQ as per the Airbus subcontractor. Comparable with column X.
    - Column AA: Proceeds with what Z did; now relates the CNQF with the assigned prio index for CNQF. Comparable with Y.
  - Columns AB, AC, AD and AE provide an intermediate prio index for GR&R through the ICs and CDs. These numbers get modified again in column AL.
    - Column AB: Looks up the seventh sheet (SOD); it searches through the matrix to find the match of REP with the IC and then returns the prio index for SOD.
    - Column AC: Similar to AB, yet now compares with the 'level5' label instead of REP. This distinction is made because they're supposed to provide the same data, yet do not. Column AE then selects the worst of the two to stay conservative.
    - Column AD: Similar to AB & AC, yet now searches through the matrix to find the match of 'MACHINE' with the CD. Note however that the CDs are not listed in this sheet and it therefore does not function and has therefore not been given more attention towards weighing them. Including this is a recommendation for future updates.
    - Column AE: Selects the highest SOD score from AB and AC and adds AD to it, to give a total prio index for GR&R
  - Columns AG, AH, and AI provide an intermediate prio index for Risk through importance with respect to Customer, Engineering Stress, Aerodynamics, Environment and Assembly. Very similar to AB, AC and AE. In column AO this gets transformed to it's final index.
    - Column AG: Looks up the sixth sheet (Risk); it searches through the matrix to find the match of REP with the IC and then returns the prio index for Risk.
    - Column AH: Similar to AG, yet now compares with the 'level5' label instead of REP. This distinction is made because they're supposed to provide the same data, yet do not. Column AI then selects the worst of the two to stay conservative.
    - Column AI: Selects the highest Risk score from AG and AH, to give a total prio index for GR&R

5.4.2. Tenth sheet: Sort Prio

The final and tenth sheet of this tool is sort prio. It is purely there for improved client handling. The sheet is a copy paste of the ninth sheet and here one can sort for highest priority in column AP. In the other columns, the corresponding ID_SPC & REP can be found. This could not be done in the ninth sheet itself, as the interlinked formulae pose a problem.

Once again, a picture is included for visual aid; a section of the sheet can be seen in figure 5.6.

	D	E	F	G	H	U	V	W	AK	AL	AO	AP
1	WORKSHO	MACHINE	PRODUCT	INSPECTIO	REP	VERKETTE	Cpk	Cpk Rate	W: CNQ	W: Prio G	W: Risk	Full Prio
2	TTT ET SA Ä	FF Untersch	D575-74203	09D5757420	LMD Skin	86162 LMD	-35.7712	100000	10000	5000	100	115100
3	TTT ET SA S	SCHALE M.	D553-71394-	09D5537139	LMD Haut	80889 LMD	-36.1683	100000	500	5000	100	105600
4	TTT ET SA N	NT 2	D553-70226-	09D5537022	Randabstand	85889 Randa	-38.8278	100000	5000	100	10	105110
5	TTT ET SA N	NT 2	D553-70026-	09D5537002	Randabstand	85886 Randa	-41.7413	100000	1000	100	10	101110
6	TTT M A350	VSV070 CJ	V553-71040	ACTI-31-00-	Barrel Nut P	86131 Barrel	-713.895	100000	500	100	10	100610
7	TTT ET TA S	TA Diff-Schal	F553-71713	09F5537171	Spalt	85691 Spalt	-0.86815	300	50000	5000	10000	65300
8	TTT ET TA S	TA Diff-Schal	F553-71713	09F5537171	Spalt	85692 Spalt	-0.25473	300	50000	5000	10000	65300
9	TTT ET TA S	TA Diff-Schal	F553-71713	09F5537171	Restwandsta	85691 Restw	0.360333	300	50000	100	10000	60400
10	TTT ET TA S	TA Diff-Schal	F553-71713	09F5537171	Restwandsta	85692 Restw	-0.17268	300	50000	100	10000	60400
11	TTT M A350	LOWER SHE	V534-76743	09V5347674	Shim	86100 Shim			50000	100	10000	60400
12	TTT ET SA N	Oberschale r	D575-74410-	DSTD575744	LMD Stringer	85813 LMD	-6.45758	500	50000	5000	100	55600
13	TTT M A350	UPPER SHE	V534-76742	STR-1618-00	Distance fran	85767 Distan	0.22797	300	50000	5000	100	55400
14	TTT M A350	UPPER SHE	V534-76742	ATR-1618-00	Frame end ci	85768 Frame	-0.39285	300	50000	5000	100	55400
15	TTT M A350	UPPER SHE	V534-76742	ATR-1618-00	Frame end ra	85769 Frame	-0.0141	300	50000	5000	100	55400
16	TTT M A350	UPPER SHE	V534-76742	AKC-1618-00	Distance LH	85786 Distan	0.245713	300	50000	5000	100	55400
17	TTT ET SA N	Oberschale li	D575-74410-	DSTD575744	LMD Stringer	85812 LMD	-0.06086	300	50000	5000	100	55400
18	TTT ET SA N	Oberschale li	D575-74410-	DSTD575744	LMD Skin	85812 LMD	-0.26658	300	50000	5000	100	55400
19	TTT ET SA N	Oberschale r	D575-74410-	DSTD575744	LMD Skin	85813 LMD	-0.26968	300	50000	5000	100	55400
20	TTT M A350	LOWER SHE	V534-76743	AKC-022_11	Frame x-direc	85821 Frame	0.332826	300	50000	5000	100	55400

Cpk | CpkCalculations | CpkUse | CNQR | CNQF | Risk | SOD | GR&R | Processes | Sort Prio | Tabelle1

Figure 5.6: A portion of the Excel sheet as associated with Sort Prio

5.5. Operating the tool

This section could be described as a short manual for the tool. It improves comprehension on how input should be given, how output should be interpreted and anything else that might help with the use of this tool for its MSA prioritisation purpose. It is a step by step guide for which actions need to be taken per sheet.

The operator starts with the first sheet, here he or she copies the data it extracts from Skywise. It would be sensible to do this once per month, or again after five new MSAs have been executed, whichever occurs sooner. Using this as an interval gives a fair trade-off between using the freshest data and not over straining the workload. In case practise shows that the interval should be altered, then that is an option.

Next comes the second sheet, here the operator manually weeds out all the multiple entries, by only listing unique combinations of ID_SPC & REP. This is a laborious task, however, it only needs to be executed once. Thereafter the tool will evaluate the data and list the five worst C_{pk} per set and give an average for them. These steps should be repeated with the same interval as those for sheet one.

In the third sheet, the operator needs to copy the results from the second sheet (average C_{pk} per unique set). Once this is done, the sheet will assign corresponding weights to them. As expected, these steps should also be repeated with the same interval as those for sheets one and two.

The fourth and fifth sheet require similar actions; pasting extracted data into them. For the fourth, the data is provided by Ralf, for the fifth by Friederike. Although these sheets contain CNQ instead of C_{pk} data, the interval of repeating the actions remains the same.

The sixth, seventh and eighth sheet can be seen as semi-constants; the ICs and CDs are extracted once from HIP and the determination of their influence on the MSA prioritisation is not subject to change. In the event of new ICs / CDs arising, e.g. from new processes being executed, then these should of course be added. Of course, the weights can be altered, if there is cause to think other values would represent the (new) situation better.

The ninth sheet is slightly tricky; the first 19 columns are copy pastes. However, between the second and third column, a new column is inserted which holds *Full Prio*. It is placed at this location for ease of viewing/interpreting the tool. The columns thereafter contain formulae and will execute upon placing the data.

The tenth sheet is a copy paste of the most essential parts of the ninth sheet. In the tenth sheet, the operator sorts for highest priority and can pass this information through to his or her supervisor.

6
Discussion

Although great care has been executed on trying to remain as objective as possible, there will always be some subjective visions present. As such, a discussion can be held with respect to the methodology, the results and how to interpret them for this project.

As the entire endeavour is a dynamic process within a dynamic company, (last minute) changes of plans are part of daily business. These have led to unneeded delays. For instance, the manner in which the tool should be built. The initial idea was to construct the tool in Microsoft Excel, as that is also the platform which the Harmonised Inspection Planning tool (HIP) uses and would therefore allow for a relatively simple connection between the two; they would comply with each other. Later on, an idea popped up from my chef to place it in the SkyWise environment, as that is the main location for storing Airbus data. Storing data on SkyWise is relatively cheap, however, the tool would also constantly download data from SkyWise - due to in between calculations - and that would not be cheap. So the idea shifted back to staying with a Microsoft Excel tool.

There is a relationship between Cost of Non Quality (CNQ) and Gage Repeatability and Reproducibility (GR&R). Worse GR&R results, which means higher values for GR&R, give rise to more issues with the product and thus more costs. However, some fiddling around with the data is required, as they are not 1 on 1 comparable. In general, CNQ are higher for processes in which more products are produced and more expensive materials and methods are used. As such, a change in production rates will reflect in a similar change in CNQ and therefore value can be put in the ability to predict how production rates will alter throughout the near future. The same holds for the relation between CNQ and Process Capability (C_p & C_{pk}). Again a very logical statement, as otherwise both Measurement System Analyses (MSA) and Statistical Process Control (SPC) would not be part of any industrial production process.

The data that is being worked with can be related with current (monthly) production rates and as such the data can be refined for taking out this variable. However, as production rates are meant to not fluctuate too much - which they also don't - there is no real need for this. Whether a process in itself gives a high percentage of failures, represented by Non Conformities (NCs) /amount of product or CNQ/amount of product, is less relevant for a company than the absolute numbers for NCs and CNQ. Therefore, production rates can remain embedded in the CNQ/NCs.

In a similar fashion, the CNQ data sheets as provided by Airbus come with a great diversity in inputs; e.g. there are columns for material cost, costs associated with the order size (e.g. a truck can deliver 1000L of spray-paint/day, if the need however rises to 1100L/day, there is a need for a second truck, or a larger truck, to still comply with demand - this step-size change is generally associated with a step-size cost change too), costs originating from the use of outsourcing, costs for (operating) the machines, personnel costs and for overall/total costs. Although there is some logic in treating them individually, again with respect of increased ability to adapt optimally for changing production rates, this would come in at a secondary phase. Just working with actual data instead of acting on predictions for the future that follow from that data is more secure. Therefore it is fine to just stick with the total CNQ per process instead of working with components.

The use of NC data turned out to be impossible at this point. The NC data is currently being obtained/processed in such a manner that they are coupled/linked together in such a fashion that they can not be treated separately and assigned to specific processes. This results in the inability to use them in the prioritisation tool for MSA selection. However, by assuming there is a rather linear relationship between CNQ and NCs there is not necessarily a great need for NC data per process. Airbus did mention from rather early on that they realised NCs could pose a challenge, but they had not yet given it proper thought due to limited resources. If Airbus decides to change the manner in which they obtain/store NC data, then the intertwining of that data should not come at great difficulty as a result from the other work which has been done already.

Looking at the tool, there are quite a number of zeros present for input data, especially for the CNQ fields. In a number of cases this will simply mean that no CNQ were associated with that process during that period of time, however, there will also be cases that the real CNQ as present for said processes, could not properly be linked to them. This creates a skewed representation of reality and as such leads to inaccurate prioritisation. However, this is unlikely to be happening at processes with high CNQ involved, as they are scrutinised ever so much more. Nevertheless, this leaves room for improvement and will be referred back to in subsection 7.2.1.

Currently, there is also still a link missing between the Control Devices (CDs) and the processes, although it was expected that these could be matched with each other without too much trouble. This lack however, has been mitigated for a great deal by using the Inspection Characteristics (ICs), as they are often intertwined with each other.

Due to these gaps in data, the tool is not the most accurate. This however also has a flip side, with the tool being very robust. Next to this, with more effort being put in obtaining the wanted data and thereafter manipulating them, the tool can undergo a number of straight forward optimisation steps.

Referring back to subsection 2.2.3: In what measure will the absence of data lead to prioritisation decisions? Is grey data worse than red data? For the time being, in case grey data shows up, it will be treated with less importance than red data, as it gives no straight indication of trouble within the process, it only indicates trouble with the obtaining of data. In case such a process also happens to have for instance high CNQ associated with it, it will already get a high prioritisation because of that.

This lack in availability and accessibility of data is in the same manner the greatest hurdle with respect to the method as used here. The methodology was based on working with data and finding relations between them, which got hampered whenever data was not there. In hindsight, the accumulation of data should have happened sooner as well as quicker. Therewith unveiling the apparent issues would giving more room for dealing with these contingencies.

Overall though, the tool does do what it was supposed to do. It takes in all the data it can get and turns this into a prioritisation for MSA. Using the tool takes away the randomness as currently present in the selection of which MSA to carry out and is bound to lead to a quicker drop in CNQ.

7
Conclusions & Recommendations

This chapter contains both the conclusions as well as the recommendations that can be deduced from the efforts that have gone into the creation of this thesis. First, in section 7.1 the conclusions will be treated and these will then be followed by the recommendations in section 7.2.

7.1. Conclusions

Seeing the results, several conclusions can be drawn from them. These conclusions can be split up into conclusions related to the tool as well as conclusions related to the research questions; as such they'll be treated in two separate subsections, subsection 7.1.1 and 7.1.2 for the research questions and tool conclusions, respectively.

7.1.1. Conclusions concerning the research questions

For all three research questions the conclusions are mostly drawn from the StakeHolders Analysis, as per subsection 2.4.2.

1. What is Airbus' current strategy with respect to executing MSAs?
    - Airbus has already developed an efficient way of dealing with which processes to subject to an MSA. This is being done for the Key Processes (KPs): processes which hold Key Characteristics (KCs) or CriTical Items (CTIs). There are however no guidelines with respect to prioritisation. Only when a process is known to encounter difficulties, it is prioritised. In all other cases, the Quality Inspectors (QIs) tackle them rather randomly distributed over time, whenever it fits the easiest, trying to reach their goal of performing X amount of MSAs in Y amount of time.
2. How do all interested stakeholders feel about (the need for) a MSA prioritisation tool? Which opinions do the distinctive parties have on the core concepts as well as the assumed relationships between them, in regards of the Airbus Stade organisation?
    - The main stakeholders are found to be the chefs of the departments for Manufacturing, Manufacturing Engineering, Production, Programming and Quality, with the last one as project owner. To no surprise they all consider functionality to be of the utmost importance for the tool; that it deals with the data in an effective way. Furthermore, ease of use and ability to improve on, as they envision for the tool to be used and potentially expanded with other data.
3. How do the relevant data relate with each other?
    - The data which was considered relevant was indeed the data which was previously expected; C_{pk}, GR&R, CNQ and NC. Risk (SOD) was added later on. Furthermore, this data turned out to be governed by dependent variables. The overal research question did not find a complete answer, just for C_p with GR&R a real relation was found, the others have a more 'this is just logical' relation.

7.1.2. Conclusions with respect to the tool

The most obvious one being that the main driver for this prioritisation tool will be costs, as was also already expected. Companies operating within the real world have to take their own measures to stay in business; would they fail to do so, they would go bankrupt or experience less optimal profit. As such, they wish to deliver high quality products at a as low as possible cost. Another conclusion would be that although the labour which was put in this project was plentiful and the tool can be used as is, there is still a lot of room for optimisations. The most apparent of these will be mentioned in section 7.2. All in all though, it can be concluded that the tool is a welcome asset for Airbus, as it does provide what was sought after.

7.2. Recommendations

The recommendations can be split in two parts, the first part addresses optimisations that can already be worked on, these are listed in subsection 7.2.1 and the second part reviews logical alterations that can be made due to changes for Airbus as a whole and is presented in subsection 7.2.2.

7.2.1. Optimisations for the tool and methodology

It comes with heartfelt recommendations to keep a close look at the tool while it is put to use. Tweaks to improve its functionality and ease of use will pop up as it's still in its infancy. It should also get expanded to incorporate more data / variables to allow for more precise recommendations with respect to Measurement System Analyses (MSA) prioritisation. At this point in time, it is also rather labour intensive to run the tool, automating it more to draw resources from the data lakes and process these subsequently, will greatly increase its value for the company. Parallel to this, it should also receive a more in depth and user friendly user manual, so it can be rolled out to other Airbus stations world wide, as the prioritisation of MSAs can be improved all over the company. Furthermore, it could be worthwhile to restructure the program to operate with fewer operating languages, as it is now dealing with several and this creates for unwanted lag while processing. Another noteworthy improvement lays in altering the way how Airbus is currently handling and storing the data it gathers over its processes. The majority of this data is extremely raw as well as incomplete and needs a lot of processing before it can even be used by the tool. By increasing the compliance between the data, which is needed for the tool, and the manner in which it is currently being extracted from all the processes, quicker and more correct outcomes can be ensured.

CDs are not incorporated in the 'master' datasheet for the tool, therefore they're not part of the prioritisation. Including them is a recommendation.

A major downside of the tool is the, as already mentioned, speed at which it operates; it is very slow. This is mainly due to the great amount of data is running through and relating with each other. Nevertheless, there will surely be options to optimise this.

There are instances were data is lacking. This can be known as well as unknown, with the unknowns being worse. The knows would for instance be the occasions where grey data shows up, as mentioned in subsection 2.2.3. An example of an unknown would be unexpected entries of zeroes for data, e.g. for CNQ, as previously pointed out in chapter 6. Both of these lead to the obvious recommendation that these issues should be tackled as much as possible.

7.2.2. Future recommendations due to changes in Airbus' production and its associated processes

With the thesis spanning over a considerable period of time, certain data which is being worked with, is in a sense already outdated. This gives opportunities for further improvements. Here specifically, this is to be linked with two production programs of Airbus; the A220 and the A380.

To start on a positive note from Airbus' perspective; they've taken a majority stake in Bombardier and therewith created the A220 program, which is not represented in the data which is being worked with. [1] [2] The reach of the tool can thus be extended by including the A220 family.

[1] Airbus takes majority stake in Bombardier https://www.airbus.com/newsroom/press-releases/en/2018/07/airbus--majority-stake-in-c-series-partnership-with-bombardier-a.html

[2] Creation of the A220 program https://www.airbus.com/aircraft/passenger-aircraft/a220-family.html

As a result of a dent in the A380 backlog, with Emirates dropping an additional 39 aircraft, there are only 51 A380 left to be delivered and Airbus has therefore decided to discontinue the A380 program as per 2021. [3] [4] As such, once the deliveries have been finalised, the tool can undergo a relatively easy optimisation step by simply extracting all A380 related data out of it, as this will increase it's working speed without loss of useful output.

Another planned change within Airbus' production methodology is the execution of MSAs on jigs and tools separately. This will increase the understanding of the influence the jigs and tools have on the production process and could lead to better fits between jigs and tools with their respective processes. This could then also get further adapted in the prioritisation tool, as was already mentioned in subsection 4.2.1.

[3] Airbus releases news on discontinuation of the A380 program https://www.airbus.com/newsroom/press-releases/en/2019/02/airbus-and-emirates-reach-agreement-on-a380-fleet--sign-new-widebody-orders.html

[4] Airbus' orders and deliveries as per Oct '19 https://www.airbus.com/aircraft/market/orders-deliveries.html

A

Flowchart for the prioritisation tool

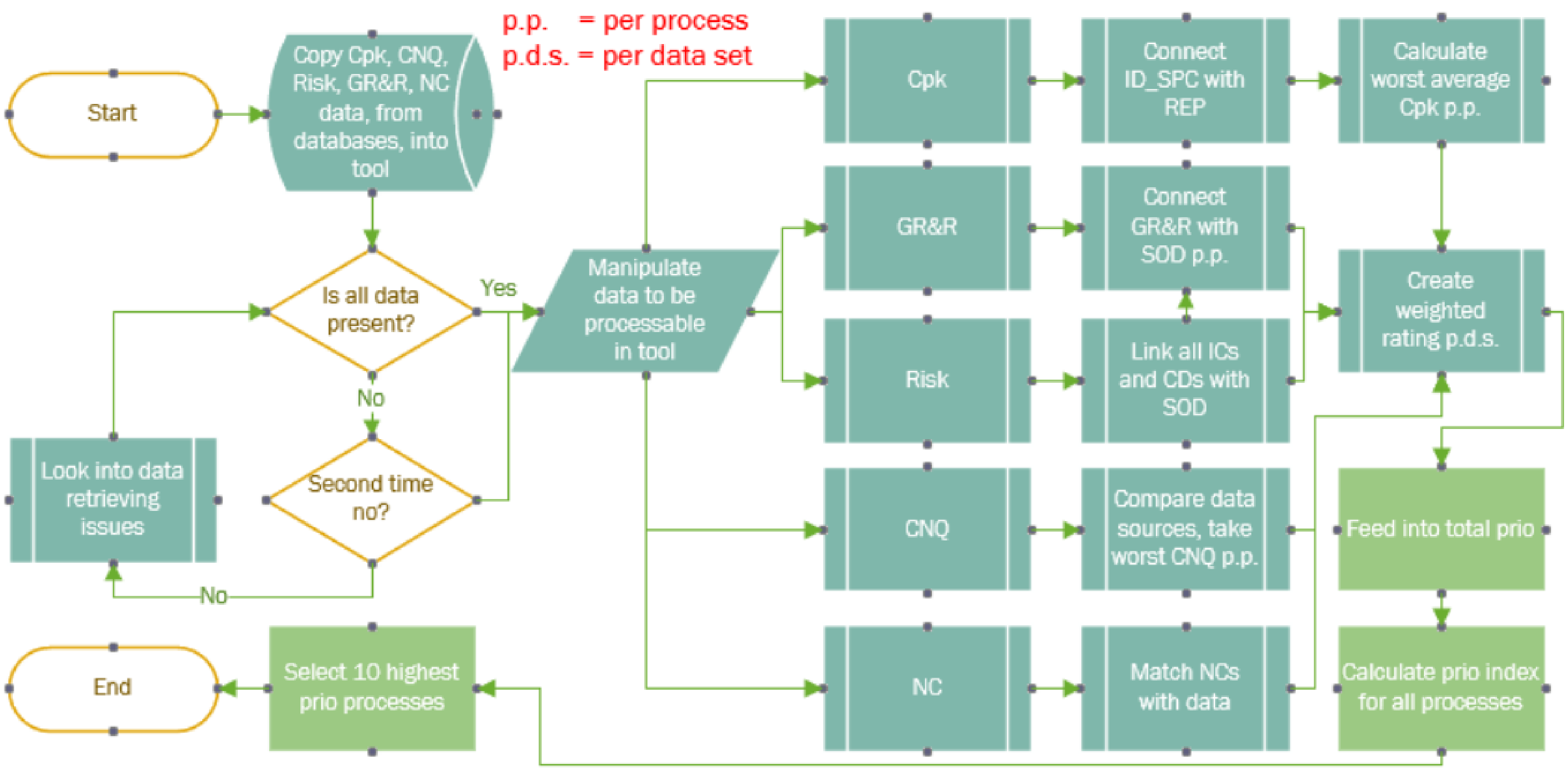


Figure A.1: Flowchart for the MSA prioritisation tool, as further explained in chapter 5

B

Excel Functions

This appendix is to be used in conjunction with chapter 5, which treats the Excel book which is setup to execute the prioritisation of MSAs. Extra explanation, with respect to the standard functions which Excel supports, is documented here.

To enhance the ease of use, the appendix is structured in the following manner. Each sheet, as present in the tool, is given a section, provided standard Excel functions are used in there which have not been used and explained before already. This starts with the functions as used in the second sheet in section B.1, thereafter those for the third sheet in section B.2, followed by section B.3 which holds the eighth sheet. Finally the ninth sheet which combines all the sheets and is here represented by section B.4.

Note that there are thus no separate sections for six sheets: sheet one, four, five, six, seven and ten.

B.1. Second sheet: CpkCalculations

As the first sheet contains only a lot of data and no manipulations are performed within it, this chapter starts of with the second sheet: CpkCalculations. This sheet contains five standard Excel functions and these will receive a short introduction here:

1. Sum: There are several options; one can add individually inputted numbers, cell references, or cell ranges. The syntax is the following *(note that whatever is written between [brackets] means that it is optional and can be omitted)*:
   - =SUM (number1, [number2], ...)
2. Index: There are two forms in which this function can be used; array and reference. In this case, the first is in order. An array is given (possibly from another sheet), from which a value is retrieved as indicated by its row and column (if it spans multiple rows and or columns) location within the array. The syntax is the following:
   - =INDEX (array, #row, [#column])
3. Small: Once again, an array is given, from which the x^{th} smallest value is returned. Here x is the second entry in the syntax for the small function. It operates with the following syntax:
   - =SMALL (array, x)
4. If: A statement is provided which can be either truthful or false. In case the statement is correct, a certain predefined output is given; if it is false, another output is given. The syntax for the function is as follows:
   - =IF (test, [output for true], [output for false])

5. Row: This function will return the row # of a cell or range.

   It'll return the row # of a cell or range.

   - =ROW ([reference])

B.2. Third sheet: CpkUse

There is only one new function in the third sheet, however, the IF function which was seen in the previous section, returns in a big nested fashion in this sheet.

1. Concatenate: It joins two or more text strings together into one string. The syntax is the following:

   - =CONCATENATE (text1, [text2], ...)

By nesting if statements with each other, they can create a rather intricate web of operations. For the use of it in the third sheet, it can be understood more easily by looking at it in the following way: There is a table which provides the boundary conditions with respect to Cp values and by running through that table, output values are assigned to the Cps which are given as input and can thereafter be used as input in the complete prioritisation tool which is dealt with in subsection 5.4.2, treating the tenth and final sheet.

B.3. Eighth sheet: GRR

There are no new standard Excel functions used in the fourth up and until the seventh sheet. In the eighth sheet, there is again a new function:

1. VLookUp: With this function, one can look up and retrieve data which is located in a specific column (column, hence V for vertical) of an array. It can be used in two fashions, the first (which is the default option) looks for an approximate match, in which wildcards (*) can be used too for partial matches and the second for an exact match. The values which are being sought after must be present in the first column of the array with the lookup columns to the right of it. The syntax is the following:

   - =VLOOKUP (value, array, column, [lookup range])

   The optional input for [lookup range] is either 'TRUE' or 'FALSE', where 'TRUE' is used by default. For 'TRUE', an approximate match will suffice, whereas for 'FALSE', only an exact match will result in output.

B.4. Ninth sheet: Processes

The ninth sheet contains three new functions and these are examined in this section.

1. ISNA: This function is used to discover any #N/A errors. It returns true when the error is found in a specific cell and false when it isn't. It comes with the following syntax:

   - =ISNA (value)

2. MAX: This function searches through an array and returns the maximum value it finds. It operates with the following syntax:

   - =MAX (array, x)

3. Large: The large function is rather similar to the max function, yet allows for more freedom as it searches for the x-largest value within the array. The syntax to use this function:

   - =LARGE (array, x)

C

English & German Questionnaires

In this appendix, both the English as well as the German questionnaire are provided. First the English questionnaire in section C.1 and then immediately followed by section C.2 with the German questionnaire.

C.1. English Questionnaire

Questionnaire for Stakeholder Analysis at Airbus Stade, 2018 – Theme: MSA Prioritising.

Dear recipient of this questionnaire,

This questionnaire, amongst others, is being conducted to aid in the creation of a prioritisation methodology for the execution of Measurement System Analyses (MSAs) for processes at Airbus in Stade (might get more widespread if deemed useful). By means of this methodology, a tool is to be developed which will actually assist in the aforementioned decision-making process.

You are invited to take part in this questionnaire, due to the nature of your job description at Airbus and/or knowledge in the field of MSA. Your knowledge and expertise are valued and will be considered while coming up with the methodology.

Note:

- The questionnaire is provided in English and German. Completing it in English is preferred, but in German is fine too.
- The questionnaire is taken by several people, each with their own individual interest, influence and expertise with respect to the subject. Participation of each and every one is highly appreciated as well as necessary in order to obtain useful results from the analysis.
- All information will be anonymised when being dealt with and remain confidential.
- Answers are neither good nor bad and will have no effect on you as a person nor as an employee.
- After the questionnaire has been held with all participants (14), you will all receive the outcome of the analysis and be given the opportunity to object to something or to change your mind / view. Allowing for open discussion / feedback, as the goal remains to optimise a part of the strategy Airbus employs.
- Find four (4) documents attached to this questionnaire:
    - Info MSA – An MSA user guide, specifically for the execution of a Gage Repeatability & Reproducibility (GR&R) study by the QDSO department
    - Procedure: *'Implement Measurement Systems A2019.6 Issue C'* – English document
    - Manual: *'Messsystemanalyse Gage R&R'* – German document
    - Manual: *'Measurement System Analysis Gage R&R'* – English document
        - These last two give a more elaborate explanation on MSAs, both in German and English, they are far from required to study, but give a good reference in case you want to check something out concerning MSAs.
- For questions which require a rating from 1 up until 5, use the following qualitative ranks:
  1: completely useless, 2: useless, 3: neutral, 4: useful, 5: very useful
  1: very bad, 2: bad, 3: neutral, 4: good, 5: very good
  1: very unimportant, 2: unimportant, 3: neutral, 4: important, 5: very important
- Try to answer all questions to the best of your abilities (with or without researching).

General/background Questions:

- From which department are you, what is your function within Airbus and how is it affiliated with MSAs?
- How would you rate your own knowledge / skill level with respect to MSAs specifically? Are you aware of the MSA documents and their content, as attached to this questionnaire? Or comparable (non-Airbus specific) information?
- Are you, or have you been involved with the execution of MSAs? How many?

Subject Questions:

1. How useful do you deem MSAs to be (could think of assuring SPC data, quality improvements, etc)?
2. Who determines which process is next in line to undergo a (new) MSA? Where does he or she base his or her decisions on in that respect? What is the current MSA prioritisation strategy at Airbus (if there is any, that you know of)?
3. With reference to the previous question; is the current procedure of prioritisation at Airbus, with respect to MSAs, optimisable? Do you have any suggestions how to optimise the process, be it with or without (considerable) investments?
4. Which parameters do you deem to be the most important, in light of MSA prioritisation? Consider, among others, Gage Repeatability & Reproducibility (GR&R), Process Capability (Cp & Cpk), Cost of No Quality (CNQ), Production rate, Rate of defects, Non Conformity (NC), etc. Do you have other important additions? Why (not)?
5. How would you rate the aforementioned / added parameters and why?
6. Consider that some flexibility is needed on the (long term) aircraft market, as certain aircraft types see their production rates going up while others go down. Does this change your answer on the previous question?
7. Are there any logistical arguments involved that give reason to give preference to one or the other process to be next in line to undergo an MSA? If so, could (and should) they be taken out of the equation?
8. Is the type of measurement instrument used in the MSA, e.g. an ultrasonic thickness gage like the Panametrix 35 DL to measure laminate thickness or a bore gauge to measure the size of a hole, a (supportive) reason to give priority to a process to undergo an MSA? Why (not)? Think of reasons such as time needed to conduct an MSA with that specific device, or training needed for operators to be eligible to work with the device.
9. If there is no Process Capabilty / Statistical Process Control (PC/SPC) data present for the process, should it be seen as less important to be high up on the priority list to undergo an MSA?
10. Do you suspect that there is a certain relationship between parameters, which could be of importance, in the decision-making process? How would this relationship manifest itself?
11. Which department should have the most influence, with respect to providing input for the methodology for MSA prioritisation and the subsequent tool development, based on knowledge of MSAs or dealing with the execution of them.
12. Does it sound attractive to you, to increase the pace at which MSAs are conducted? Would it be a good idea to reserve more resources (employ more people), in order to execute more MSAs (in the same timespan)? Would these investments pay of?
13. Do you have any knowledge on how MSA prioritisation is handled elsewhere (e.g. at Toyota)? If yes, please provide.
14. Is there anything left unasked / said? Please mention whatever else might come to your mind to be of value towards the research / methodology development for the tool. This could be with respect to literature to consult, other people to talk to, Airbus specific content, or just about anything you deem valuable.

Thank you for your participation!

C.2. German Questionnaire

Fragebogen zur Stakeholder-Analyse bei Airbus Stade, 2018 - Thema: MSA Priorisierung.

Lieber Empfänger dieses Fragebogens,

Dieser Fragebogen dient unter anderem zur Erstellung einer Priorisierungsmethodik für die Durchführung von Messsystemanalysen (MSA) für Prozesse bei Airbus in Stade. Mit dieser Methodik soll ein Werkzeug entwickelt werden, das den oben genannten Entscheidungsprozess tatsächlich unterstützt.

Aufgrund der Art Ihrer Stellenbeschreibung bei Airbus und/oder Ihre Kentnisse bzgl. MSA sind Sie aufgefordert, an diesem Fragebogen teilzunehmen. Ihr Wissen und Ihre Expertise werden geschätzt und bei der Ausarbeitung der Methodik berücksichtigt.

Hinweis:

- Der Fragebogen wird auf Englisch und Deutsch zur Verfügung gestellt. Es ist in Englisch zu bevorzugen, aber auf Deutsch ist auch in Ordnung.
- Der Fragebogen wird an 14 Personen versandt, die jeweils ihr individuelles Interesse, ihren Einfluss und ihr Fachwissen in Bezug auf das Thema haben. Die Teilnahme jedes einzelnen wird hoch geschätzt und notwendig, um nützliche Ergebnisse aus der Analyse zu erhalten.
- Alle Informationen werden bei der Bearbeitung anonymisiert und bleiben vertraulich.
- Antworten sind weder gut noch schlecht und haben keine Auswirkungen auf Sie als Person oder als Mitarbeiter.
- Nachdem der Fragebogen mit allen Teilnehmern (14) gehalten wurde, erhalten Sie alle das Ergebnis der Analyse und erhalten die Möglichkeit, etwas zu beanstanden oder Ihre Meinung zu ändern. Erlauben offener Diskussion / Feedback, da das Ziel bleibt, einen Teil der Strategie, die Airbus beschäftigt, zu optimieren.
- Finden Sie drei Dokumente zu diesem Fragebogen:
    - Info MSA – Ein MSA-Benutzerhandbuch speziell für die Durchführung einer Gage-Wiederholbarkeit und Reproduzierbarkeit (GR & R) Studie durch die QDSO-Abteilung
    - Handbuch: *‚Messsystemanalyse Gage R & R‘* – deutsches Dokument
    - Handbuch: *‚Messsystemanalyse Gage R & R'* – englisches Dokument
        - Die letzten beiden geben eine ausführlichere Erklärung der MSAs, sowohl in deutscher als auch in englischer Sprache. Sie sind bei weitem nicht erforderlich, um zu studieren, aber geben Sie eine gute Referenz, wenn Sie etwas über MSAs herausfinden möchten.
- Verwenden Sie für Fragen, die eine Bewertung von 1 bis 5 erfordern, die folgenden qualitativen Ränge:

1: völlig nutzlos,	2: nutzlos,	3: neutral,	4: nützlich,	5: sehr nützlich
1: sehr schlecht,	2: schlecht,	3: neutral,	4: gut,	5: sehr gut
1: sehr unwichtig,	2: unwichtig,	3: neutral,	4: wichtig,	5: sehr wichtig

- Versuchen Sie alle Fragen so gut wie möglich zu beantworten (mit oder ohne Nachforschung).

Allgemeine / Hintergrundfragen:

- Aus welcher Abteilung sind Sie, was ist Ihre Funktion bei Airbus und wie ist sie mit MSAs verbunden?
- Wie schätzen Sie Ihr eigenes Wissen / Können in Bezug auf MSAs konkret ein? Sind Ihnen die MSA-Dokumente und deren Inhalt bekannt, die diesem Fragebogen beigefügt sind? Oder vergleichbare (nicht Airbus-spezifische) Informationen?
- Sind Sie oder waren Sie an der Ausführung von MSAs beteiligt?

Thema Fragen:

1. Wie nützlich halten Sie MSAs (kann Kosteneinsparungen, Qualitätsverbesserungen usw. in Betracht ziehen)?
2. Wer bestimmt, welcher Prozess als nächstes ein (neues) MSA durchlaufen wird? Wo begründet er seine Entscheidungen in dieser Hinsicht? Was ist die aktuelle MSA-Priorisierungsstrategie bei Airbus?
3. Mit Bezug auf die vorherige Frage; Ist das derzeitige Verfahren der Priorisierung bei Airbus in Bezug auf MSAs optimierbar? Haben Sie Vorschläge, wie Sie den Prozess optimieren können, sei es mit oder ohne (erhebliche) Investitionen?
4. Welche Parameter halten Sie angesichts der MSA-Priorisierung für am wichtigsten? Berücksichtigen Sie unter anderem Gage-Wiederholbarkeit und Reproduzierbarkeit (GR & R), Prozessfähigkeit (Cp & Cpk), Kosten für keine Qualität (CNQ), Produktionsrate, Fehlerrate, Non Conformity (NC) usw. Haben Sie weitere wichtige Ergänzungen? Warum (nicht)?
5. Wie bewerten Sie die oben genannten / hinzugefügten Parameter und warum?
6. Bedenken Sie, dass auf dem (langfristigen) Flugzeugmarkt eine gewisse Flexibilität erforderlich ist, da bei bestimmten Flugzeugtypen die Produktionsraten steigen, während andere abstürzen. Ändert dies Ihre Antwort auf die vorherige Frage?
7. Gibt es irgendwelche logistischen Argumente, die Anlass geben, dem einen oder anderen Prozess den Vorzug zu geben, um als nächstes Mitglied einer MSA zu werden? Wenn ja, könnten (und sollten) sie aus der Gleichung herausgenommen werden?
8. Ist der Typ des in der MSA verwendeten Messinstruments, z.B. ein Ultraschall-Dickenmessgerät wie das Panametrix 35 DL zur Messung der Laminatdicke oder ein Bohrlochmessgerät zur Messung der Größe eines Lochs, ein (unterstützender) Grund, einem Verfahren zur Durchführung einer MSA Priorität einzuräumen? Warum (nicht)? Denken Sie an Gründe wie die Zeit, die für die Durchführung eines MSA mit diesem spezifischen Gerät benötigt wird, oder an Schulungen, die erforderlich sind, damit Bediener mit dem Gerät arbeiten können.
9. Wenn für den Prozess keine Prozessfähigkeit / Statistische Prozesskontrolle (PC / SPC) Daten vorhanden sind, sollte es als weniger wichtig angesehen werden, auf der Prioritätenliste ganz oben auf der MSA zu stehen?
10. Haben Sie den Verdacht, dass zwischen den Parametern ein bestimmter Zusammenhang besteht, der für den Entscheidungsprozess von Bedeutung sein könnte? Wie würde sich diese Beziehung manifestieren?
11. Welche Abteilung sollte in Bezug auf die Bereitstellung von Input für die Methodik für die MSA-Priorisierung und die anschließende Entwicklung von Tools den größten Einfluss haben, basierend auf dem Wissen über MSAs oder dem Umgang mit deren Umsetzung.
12. Klingt es für Sie attraktiv, das Tempo, in dem MSAs durchgeführt werden, zu erhöhen? Wäre es eine gute Idee, mehr Ressourcen zu reservieren (mehr Leute einzustellen), um mehr MSAs (im gleichen Zeitraum) auszuführen? Würden diese Investitionen zahlen?
13. Haben Sie Kenntnisse darüber, wie die MSA-Priorisierung anderswo gehandhabt wird? Wenn ja, bitte angeben.
14. Gibt es etwas, das ungefragt / gesagt wurde? Bitte erwähnen Sie, was auch immer Ihnen in den Sinn kommt, um für die Entwicklung von Forschung / Methodik für das Tool wertvoll zu sein.

Danke für Ihre Teilnahme!

D

Questionnaire Results

Questionnaire taken by #1: 28.06.2018. 12:45-13:45

Subject Qs:

1. Very useful and important. One should know how well the MSs perform, as they provide assurance over the correctness of the obtained data in the measurements. Should know which ones to improve.
   An example of improving a measurement system, was by switching from 'taster' to 'Bugelmessschrauber', the taster was not the correct/most useful device for the process it was controlling. Got a much better GR&R after switching the tool.
2. Robert Petz. There is no real strategy as of right now, to determine which MS will get the next MSA. Current tactic has been to first complete MSAs there where the execution of the MSA will not cause for too much hassle. E.g. there where it won't cause the need for stopping production for several days, or where there is less risk, as the execution is relatively easy. Do difficult ones later one (or even check whether they really need one; if you can't just use the outcomes from very similar processes, e.g. measuring the same thing in an A320 or an A380 process). Measurements with laser or contour are 'big', take a lot of time; get done last. Even for the processes which already have undergone an MSA, but fell through, repeat them before starting with the more difficult MSAs.
   There is some talk about sequencing in MSA manual 7029 A. Check it out.
3. Yes, it can of course be optimised. Right now it is just a decision by Robert (Maxi). Redoing the ones that failed, possibly with a different measurement instrument.
   Making investments is in principle not an issue at all. Will be granted, provided there has been tests which turned out that the investments make sense (e.g. check mail with Sven Schiron – from Jotbe.com; Airbus is checking out a different measurement device, if it works better for the task at hand, it might be 'bought' (or hired), to improve the MSA outcome – even though the device is rather costly – in the end it will be worthwhile, considering a great number of processes can be tested (in an improved way) with it
4. GR&R => <30% - CNQ not so much important at all. Looking at quality, not so much at finance.
   Christian Kratsch discovered a relationship between Cp/Cpk & GR&R.
5. As said in 4; CNQ is low priority, want to be looking at quality aspects. Biggest one is GR&R, having a good (low) value there, means the measurements as obtained can be trusted quite a bit. The more they can be trusted, the more sure it is that the product which is delivered meets its specifications and stays within the tolerance limits.
6. When the process is being controlled close at its tolerance limits, a worse MSA outcome (higher GR&R value) could potentially even lead to better (lower) CNQ values. As it means the quality inspector has more influence on the outcome of the product passing the control, or getting rejected.
   Having taken quality as main goal for the prioritisation, CNQ can be used as an additional reason.
7. Yes, the processes which can undergo an MSA rather easily, get their MSAs done first. As such the ones where lasers instruments are used, or contours measured are delayed in the sequence. This is also checked with the production rate and how tight the delivery schedule is. The more tight the delivery schedule is, the less of a disturbance is desired; therefore diminishing the likelihood of executing the MSA soon. The production of aircraft cannot be halted. Furthermore; at automatic machines which are being utilised 24/7, not 'running' equals money being lost => unwanted.
8. Same answer really as in 7. Whatever may create difficulties, which could be the location which should be measured, or the device to be used, or the training needed for the personal to be properly schooled to execute the MSA in the correct way, is a reason for postponing the execution of that specific MSA.

9. No, the execution of MSAs remains equally important. Therefore one should not delay an MSA on grounds of not having PC/SPC values.
10. Yes. There is a relationship already known between GR&R and Cp/Cpk. Furthermore, with a bad Cpk, you can expect high NC and thus high CNQ/product.
11. QDSO (So QDSO1, QDSO2 and QDSO itself).
12. No. At the moment many MSAs have been executed already, what is more important is to see where to invest to improve the MSA outcomes. E.g. to buy a new device with which the measurements are executed more accurately and precise, or more training for the quality inspectors, for the same reason.
13. No.
14. No.

Questionnaire taken by #2: 02.07.2018. 12:40-13:30

Subject Qs:

1. 5. The MS needs to be validated for the process it is being applied to. Gives benefits wrt quality & finance
2. A message/assignment comes in at the inspection planning department; there is a new MSA needed due to there being a new MS in place, or a new process setup, etc. The manager/Head of of QDSO1 decides where the next MSA gets executed. Look in HIP to see what/which/where MSAs have been executed + result. There is no real strategy.
3. There are many options eligible for improvements. But how to do this, not too sure.. different instrument, (more) training of the quality inspectors. Some structure / a recipe how to do this would be nice. Stuff would then always get handled in the same manner. Could be good to get MSAs as daily business for people, then they'd be forced to be more involved with it.
4. Suspect MSAs/GR&R to have an influence on Cpk. With a better MSA result, be able to get more centred Cp and thus better Cpk. For instance because of applying the measurement device more properly.
   With respect to production rate; see to it that the production process isn't affected too much and the production time doesn't get blown out of proportions. For instance if a new MS is required to improve the GR&R, it will be a problem to get this new MS when this would severely impact the production in a negative way for a process that already has difficult to keep up with its production rate. Do not want to raise real issues. Added time from executing the MSA; also the costs of new MS are in the equation.
   Keep in mind if something is being measured directly, or indirectly. One should know what the process parameter is.
5. –
6. There should be no real influence, as long as the production rate can be maintained.
7. Yes, e.g. now in the summer period, it should be checked whether the necessary facilities to conduct a certain MSA are even present. Be it the measurement device, the quality inspectors or even the product. When possible, try and plan for minimised impact by conducting MSAs during summer breaks at certain processes.
8. See previous Q.
9. No. Irrespective of there being SPC data available, a MS can still have priority to undergo an MSA; think of CNQ/NC parameters.
10. Is possible, but have no knowledge of this. Do think that Cpk improves for improved MSA, due to the process being more centred.
11. QDSO1
12. Would not employ more people to increase the pace.
    It is useful (& a requirement – to secure quality of product) to have MSAs everywhere. Now the next step is to also make sure they all have outcomes for GR&R <30%
13. No; no further knowledge about other companies and their view on MSA prioritisation. Do assume that there should be some logic at big companies who also have a lot of processes that need MSAs.
14. –

Questionnaire taken by #3: 02.07.2018. 13:45-14:00

Subject Qs:

1. Super important; should be the prime priority to get MSAs on processes.
2. There is no strategy for this at Airbus.
3. Yes it is most definitely optimisable. Best road towards optimisation could be through costs.
   The production processes which have a lot of product outside of the tolerances should get a MSA first. The ones who do produce (mostly) within the tolerances are already good to continue as they are; they just aren't officially verified/validated.
4. CNQ/NC. With optimisation projects getting applied there where CNQ/NC are high, it makes sense to do the same with MSAs. Thereafter, look at Cpk.
5. –
6. –
7. –
8. –
9. No.
10. –
11. MSAs are a pure quality theme, as such it should be investigated from QDS onwards (QDSO, QDSA). It is a standard building block in their work package.
12. When an MSA gets executed, it is not impossible that it turns out that the process is performing (even) worse than expected. Knowing the production is (far) below par somewhere might not be an advantage.
13. –
14. Have a talk with #20. S/he has a lot of knowledge on MSAs, has been involved at many MSAs for Q.

Questionnaire taken by #4: 03.07.2018. 10:55-11:50

Subject Qs:

1. Neutral (3/5 from rating) vision on use. The main issue with MSAs is that one is comparing measurements with measurements. The real value of the product is not used (as it is unknown). Having said that, one does of course attempt to work with the real value, which is approximated by the best of abilities through calibration.
   Comparing measurement values as obtained from the quality inspector who uses a Panametrix as a handheld tool, or the Pulsed Array Ultrasonic Testing (PAUT) device.
2. The Inspection Planner who is involved with the theme. Getting input where new MSs are implemented or a new process. These will then undergo an MSA. No real (other) prioritisation strategy present.
3. Yes, it leaves room for improvement. There should be more attention given to SPC data. When there are big leaps in the measurement values (visualised with Cpk), one should realise that this could be caused due to the fact that an unfit measurement device, for the task at hand, is being used. Changing the measurement device could be a way to solve it.
4. CNQ. Quality is the main driver for MSAs. Looking at GR&R is also very useful, especially after a repair or something has happened.
5. CNQ: 4 & NC: 4
   Repeatability: 4
   Reproducibility: 4
   Process capability (Cp & Cpk): 4
   Production rate:3
   Rate of defects: 3
   Quality is what is needed to keep the aircraft in the sky. Or even just the construction and (?? Mindfart.. microsleep for a few seconds… forgot what I was saying here (even though 'copying' from the sheet filled in by #4)).
6. –
7. Evaluate who has time to conduct an MSA. Select an MSA to be executed that fits within the specific theme knowledge for that inspection planner. Doing it this way, the IP will continuously build up specific experience for this type, resulting in positive effects from the learning curve. This can further be utilised and transposed to very similar processes to reduce the workload.
   Be smart and take good notice of all other factors that influence the outcomes. Then make sure to keep these factors equal during the execution. Think of an A350 process which gets it MSA conducted in an A380 hall. However, its inspection planning does normally occur is the A350 hall, which might have different values for the influencing factors (light, moisture, accessibility of product/tools/jigs).
8. Yes. Assume that the most problems and CNQ are associated with the processes which are hard to apply an MSA on. As such, run MSAs for these first, as the most money is likely to be saved through these.
9. No; shouldn't make a difference.
10. Possibly, yes. One might want to split up the GR&R into the Repeatability and the Reproducibility.

Following example:

Quality Inspector A gets measurement values which are very similar to each other, the same holds for QI B. However, comparing A with B, they have very different results with respect to one another. Only QI B is near the real value of the product.

==>

Good Repeatability: The SAME results are obtained for the SAME characteristic, successively measured by/with the SAME person/instrument.
Bad reproducibility: The SAME results are NOT obtained for the SAME characteristic, successively measured by/with a DIFFERENT person/instrument.

==>

A bad GR&R result is obtained. This could however be altered solely by making it more easy for the Qis to understand what and HOW they’re actually supposed to execute the measurements. Therefore, it could be a very good idea to prioritise MSAs for those processes which appeared to have a bad value for the reproducibility – after the execution process for measurements has been altered in such a way that it is now (much) easier for the Qis to perform their task correctly

11. A Multifunctional Team should be setup. The respective checkpoint per aircraft (part) production should have its chef as a representative and their local desires should be compared by one another through the chef of QDSO1, to get to a complete priority.
12. No. It is likely more useful to have a proper look whether the measurements and its outcomes are currently being executed in the correct manner. Updating QSOIs could help more, to e.g. improve reproducibility (the operators will then be more precise in). Looking at the measurement device, it might be a very worthwhile investment to change instrument, when it turns out that the instrument which is currently being used does not fit for the execution of measurements for that specific process.
13. No.
14. No.

Questionnaire taken by #5: 04.07.2018. 11:00-11:45

Subject Qs:

1. Very important. It most often even is a hard requirement for processes. Especially for those who concern Key Characteristics (KC).
   Obviously, the possibility remains that an outcome from the MSA isn't positive. Sometimes a process just can't be measured accurate and precise enough to stay within the tolerances and have a GR&R of less than 30%. The risks involved with such a process should nevertheless still be carried.
   Possibly one should not a complete GR&R. For instance when a fully automated process is being controlled, there is no need to analyse the reproducibility, as every inspection planner will measure in the same way. In case this is being done, this should come with proper theoretical knowledge and arguments. Also engineering gut feel. Do not just merely follow regulations in the most strict manner, but think about what is being done.
2. Requests for MSAs pop up from project management. Not immediate priority.
   Utilise document: *'FUI.IN.03.06.'* -> about Implementing Measurement Systems.
   A request for an MSA can also have its origin in the production, that it seems useful from that departments Point Of View (POV).
   Research whether the processes which are being evaluated are critical, respectively KCs, as for those the MSAs are a strict requirement. This happens to be well defined at the A350 programme, but less so for the single aisle (A320 & A330) programmes.
3. Yes, can be optimised. For instance, evaluate how critical a process is; what kind of an influence does a deviation from the tolerances in this process have on other processes and departments? Think of Production / Engineering / Quality. With respect to the tolerances, might also want to check up on the Design department and see whether the tolerances should remain as they are now.
4. Together with #5.
   Realise that all these parameters should not be looked at separately, but note that they're all connected with one another – influence one another. For each process there could be (slightly) different preferences, as such an individual evaluation generally gives outcomes. It is good to simply start from GR&R, as this is already nicely represented in a percentage. Cpk on the other hand is based on absolute numbers. Furthermore, to even be able to continue with any further steps on a process; one needs to understand how the MS operates. This starts off with the GR&R.
5. See 4.
6. Return of Investment (RoI) is always a big thing with respect to commercial purposes. Money is a key driver. As such, the market prospects concerning production rates do indeed have an influence. For increasing production rates, there is an increasing priority.
7. Thinking of 'Quick Win', relatively easy improvements with relatively low risk are appealing. Do however keep Quality as the main requirement.
8. Yes and no. One could opt to prioritise the processes which use a relatively easy instrument for its MSA. However, the hard ones often have the most leeway to actually win back on the investments.
   Also make sure to have a quick look at the QSOIs and differences concerning the data that is returned back the MS. This often just means to monitor Cpk data properly and when unexpected changes happen, quickly react on it (e.g. change the current measurement device for a new one).
9. No. Actually, it makes more sense to look at this from the inverse way. Start off with an MSA and obtain PC/SPC data thereafter. Especially for critical processes (requirement).
10. Yep. Need trustworthy measurement values, which can only be obtained after verifying the MS. Once this has been done, the values come along with it.

For processes with high production rates, an increased Cpk has added value. As the amount of NCs associated with the process go down. Correspondingly lower costs.

11. Quality (QDS). They can however consult other departments and experts on matters, such as Manufacturing Development Engineers.
    Especially considering optimisations at older processes, as the new ones often occur due to being assigned.
12. Do not forget there is also a *‘human factor’* involved. Be watchful to not cause any problems between / with other people that are also part of the MSA execution process.
    Furthermore, increasing the rate of running MSAs might not help with ‘the problem’ – it might just highlight the problem even more, in case it turns out there are even more processes with less than adequate MS outcomes.
    This could provide increased problems with respect to budget. ISO9100 regulates where MSAs are a necessity; at the critical parts.
13. -
14. New Focal Point: Mareike Eckhard (DSVA) – might want to reach out to her too.
    Also the Methodology Engineer & M.E. Delegate. These do not have to be located at QDSO, but could also be at DSV.
    Another point of interest is to realise where the gains / profits are to be noticed. When the profits do not show up anywhere in the QDSO department, they’re less likely to use their own budget for it.

Questionnaire taken by #6: 04.07.2018. 14:40-15:30

Subject Qs:

1. Very useful. Allows to check whether the measurement instrument is fit for the job it is fulfilling. Which in turn is needed to assure that quality products are being produced.
2. When a new requirement pops up.
   Check with Robert & Daniel.
3. –
4. GR&R. Do make sure to realise that the right conditions are applied in all cases. Think of the measurement surface (1), climate conditions (2), calibration (3), whether the measurement device is still valid (4) and more (5-X).
   There is no QSOI (regulation / instruction) present for the execution of mass measurements.
5. –. Advise: Talk with the people that actually have more profound knowledge of the topic: Daniel.
6. Never lose track of the production rates, as they have an obvious direct impact on the costs (of no quality) involved in a process.
   Furthermore, the production rate should remain viable to reach. So the impact, related to conducting the MSA, should remain within limits to ensure the goals of producing a certain amount of parts and aircraft. Otherwise it would cause too much (financial) damage.
7. Yes, for instance vacation of people involved. Try to make sure everyone is constantly employed in a proper fashion. No big impacts related to understaffing at certain points / periods in time. -> Need proper communication with chefs.
8. -. When problems arise, they are given priority.
9. Start off with processes without SPC, as it is unknown how those processes perform.
   At places with negative SPC values -> fast-track MSAs.
   At places with positive SPC values -> delay MSAs.
10. Yes. Also keep the pressure on the workers in mind. Mistakes slip in more often when the pressure is high; this also correlates too production rates, as with increased rates, the pressure will also grow. Might want to (re)consider the tolerances, to ease some of the pressure. (Re)Evaluate whether an MSA is needed.
11. QDSO1 is #1. Further cooperation with check point, QDSO2 and QDSO itself.
12. Depends on the current situation as present at Airbus. Consider that a certain amount of time is needed to actually build up a skill, rather than just execute more of them in a shorter period of time.
13. –
14. Also have a look at TPVs: Frank Muhs, SQM-QM-16-04 & M1030

Questionnaire taken by #7: 05.07.2018. 08:45-09:45

Subject Qs:

Have not really gone through the questions per questionnaire, rather just had a talk / discussion with one another and take information out of there.

Carefully examine FUI.IN.03.06 – Procedure: Implement Measurement Systems. A2019.6 Issue: C. This happens before M7029A is applied.

When utilising a Panametrix, do not forget to give in an initial velocity / frequency as used. Thereafter calibrate.

Also contact:

- Marten Lenz (DSA1)
- Henning Schriever – Bremen
- Jean-Philippe Laurent – Process Owner of FU.IN.03.06 (OEDAZM)
- Jacques Kerault – M&P Process Maturity (TMDAZ – currently retired)

At CFRP, realise that after grinding, they should be covered up with resin at the outside, to prevent any moisture to enter the part. Test on electrical conductivity.

In corners, there is added difficulty to measure exactly that which is to be measured. Not only by skill of the quality inspectors performing the measurements, but also by the device not being able to detect the exact locations from what till what point it is supposed to measure.

He developed a measurement instrument himself. It is a tripod (because something with 3 legs will never be unstable; all 3 legs need to be on the surface to be stable) and is to be placed next to the desired rim / edge of which the height is to be measured. By first measuring the distance from the measurement device till the highest point of the rim, while placing it orthogonal to it and thereafter from the measurement device till a location next to the rim (so ground level), one deducts the first measurement from the latter and knows the exact height of the rim.
Issue with this method… it was actually too accurate. The process on which it was being utilised was unable to produce parts properly within the tolerances and this measurement device made that visible & known.
This resulted in the creation of very many NCs and it was decided to no longer use the device.

Measuring shims is also very hard. Went back to the use of the well-known gap gun.

Do not take the ‘Human Factor’ out of the equation. Emotions from people will also have an effect. E.g. when a close friend / family member of one of the quality inspectors just died, this is very likely to lead towards inaccuracies in his measurements.

Have to comply with ISO9100

Building up a certain amount of routine is also very important. This is to be done on a per location basis.

Questionnaire taken by #8: 09.07.2018. 10:00-10:50

Subject Qs:

Very difficult conversation. Has problems with all questions. Rather than being open-minded and giving useful input, marks most questions as complete bullshit and says people need to ask him the right questions if they wish to gain useful answers.

First determine how you define MSAs => what's the start and end of it?
Start: at the moment the task is given (as MSA leader, do preparations and block timeslots, etc to get all logistics a go)
End: when the GR&R value has been obtained, Minitab has evaluated the outcome values. A next step of continuing with a Practical Problem Solving (PPS) is not part of the MSA process.

1. Very useful (5). For every MSA, a Shainin project is required.
   ISO Plot & Scatter Plot. Discrimination method.
   From the Inspection Planning side, the <u>tolerance method</u> is utilised. Used to guarantee the process is within the tolerance => Quality is ensured.
   From the Shainin side, the <u>variation method</u> is utilised. Procent Process. Allow to distinguish between good and bad. Find optimisation.
2. –
3. There is no strategy, as such it can most definitely be optimised. Did not think about it at all, so can't give ideas.
   Start with risk analysis & FMEA => RPZ
4. Useless question. The decision to execute an MSA should not come from any of these parameters, rather from PPS/Risk analysis. The high risk processes (e.g. could lead to aircraft crashing down) should be prioritised. Having conducted a PPS and optimised the process (and the way of measuring it), it should then get an MSA.
5. Completely useless (1). They're not a reason to prioritise an MSA. See Q4.
6. No (Did not even understand the Q, considered the Q to be about Aircraft crashing down, rather than production rates going down – after explanation still not more input).
7. No.
8. No. Story of FMEA on repeat => Should research more on FMEAs (3D risk map: Severity/Likelihood/Level of control)
9. No. Same same again. Questions are leading in the wrong direction – should worry about PPS/Risk analysis/FMEA.
10. Do not know. Do not care.
11. Wrong question. Do not want to make a weighted decision, give certain departments more weight/importance. Should get use a Multi-Functional Team (MFT) with an impartial moderator to make sure all departments can have their say and are valued properly on content, rather than on how loud they voice their ideas.
    The moderator should simply follow the regulations as are present for MFT meetings.
12. No. There is no sense in just quickly completing MSAs, all that you get out is a number. Then you have a clue how capable your measurement system is in obtaining measurement results with respect to the process. Instead, you should complete MSAs and there where needed follow up with PPS/risk analysis/FMEA to optimise the (measurement) process and conduct a new MSA. Improve quality, rather than just be able to say there have been so many MSAs completed.
    The goals you have should be clearly specified and known to everyone involved. Therefore one should also not utilise an external company to complete MSAs, as they're

only interested in filling their productivity quota, rather than turning up with results from which the quality can be improved. Again: Goals.

13. First answer no. Then he gets reminded that he already said he had knowledge about MSAs in automotive industry. Mentions that the automotive industry is ahead of aerospace industry with respect to MSAs. Does not have concrete examples. Mentions to check up with the German Association of Automotive Industry (VBA Verband der Automobilindustrie)
    Find information under CTK – Testfähigkeit. (CMK: Maschinenfähigkeit)
14. Irma Tisnado Gonzales. Black Belt.

Questionnaire taken by #9: 10.07.2018. xxx

Subject Qs:

1. How useful do you deem MSAs to be (could think of assuring SPC data, quality improvements, etc.)?
   5 – MSA is part of a key analysis tool kit to understand process behaviour and identify actions to improve it.

2. Who determines which process is next in line to undergo a (new) MSA? Where does he or she base his or her decisions on in that respect? What is the current MSA prioritisation strategy at Airbus (if there is any, that you know of)?
   At Broughton there is no core MSA strategy. MSA is used to support, test and validate measurement systems on a project by project basis. Prioritisation is based in project priority and work load,

3. With reference to the previous question; is the current procedure of prioritisation at Airbus, with respect to MSAs, optimisable? Do you have any suggestions how to optimise the process, be it with or without (considerable) investments?
   Type 2 MSA could be used to validate measurement process on a regular scheduled basis but I question the real value of doing so. Fundamentally MSA remains a quality, metrology and engineering tool that is best used on an as required basis.

4. Which parameters do you deem to be the most important, in light of MSA prioritisation? Consider, among others, Gage Repeatability & Reproducibility (GR&R), Process Capability (Cp & Cpk), Cost of No Quality (CNQ), Production rate, Rate of defects, Non Conformity (NC), etc. Do you have other important additions? Why (not)?
   In the MSA context
   GR&R (ANOVA) – 5
   GR&R (Range & Mean) - 3
   GR&R (Attribute) - 5
   Gauge Capability C_g, C_{gk} – 4
   Demonstrable Resolution/Probable Error - 4
   Process Capability C_p, C_{pk} (with charts) – 5
   Cost of Non Quality (CNQ) – 5
   Production rate - 3
   Rate of defects- 4
   Non Conformity (NC) – 3 (Though this is based on context and could be a 4)

5. How would you rate the aforementioned / added parameters and why?

6. Consider that some flexibility is needed on the (long term) aircraft market, as certain aircraft types see their production rates going up while others go down. Does this change your answer on the previous question?
   No – MSA is an analytical tool set applicable to all manufacturing industry, science and engineering. It's applicability is not a function of production rates and even less so aircraft types.

7. Are there any logistical arguments involved that give reason to give preference to one or the other process to be next in line to undergo an MSA? If so, could (and should) they be taken out of the equation?
It has to be driven by process and technical need. It is a key part of new process development and deployment support. I don't see this as a centrally controlled activity.

8. Is the type of measurement instrument used in the MSA, e.g. an ultrasonic thickness gage like the Panametrix 35 DL to measure laminate thickness or a bore gauge to measure the size of a hole, a (supportive) reason to give priority to a process to undergo an MSA? Why (not)? Think of reasons such as time needed to conduct an MSA with that specific device, or training needed for operators to be eligible to work with the device.
Gauge type is not relevant to MSA need. Process requirements should be the deciding factor. Any measurement process needs MSA to validate its capability and suitability for use. Priority is driven by process and technical risk not technology level. A more complex system does require a greater depth of pre Type 2 MSA preparation, but the complexity of the MSA is far less important than the technical and process quality reasons driving the MSA.

9. If there is no Process Capability / Statistical Process Control (PC/SPC) data present for the process, should it be seen as less important to be high up on the priority list to undergo an MSA?
A Type 2 MSA is performed on the measurement portion a production process. PC / SPC data is collected to understand and monitor the process behaviour. If no data has been collect then an MSA should be performed on the measurement system used with in the process to ensure the trustworthiness of the PC/SPC data. In that case it should be a high priority.

10. Do you suspect that there is a certain relationship between parameters, which could be of importance in the decision making process. How would this relationship manifest itself?
There is a considerable relationship between parameters:
Process quality monitoring PC/SPC cannot be trusted unless the measurement system used to generate the data is validated by MSA.

Within MSA itself type1 MSA provided that base line process behaviour. If a gauge or measurement instrument is not capable in an off line type one Type 1 test, the measurement system will not be capable in a a type 2 test. For an acceptable GR&R a good C_g, C_{gk} *is required.*

11. Which department should have the most influence, with respect to providing input for the methodology for MSA prioritisation and the subsequent tool development, based on knowledge of MSAs or dealing with the execution of them.
The lead department should be Metrology working closely with Quality.

MSA test design, execution, data analysis and presentation should be led the metrology, Measurement process: development, improvement, support and deployment should a joint effort between Metrology, Quality and Manufacturing engineering.

12. Does it sound attractive to you, to increase the pace at which MSAs are conducted? Would it be a good idea to reserve more resources (employ more people), in order to execute more MSAs (in the same timespan)? Would these investments pay of?
There is no point of undertaking more MSA's unless the reason for doing so is clearly understood. MSA is an analytical tool and not an end unto itself. Resources should be focused on ensuring process quality can be effectively monitored by ensuring the quality of the measurement data. We don't measure for the sake of measuring we should measure for a clearly defined purpose ultimately to make process control decisions. Undertaking more MSA will be pointless unless the reasons for the tests are clearly defined the results can be acted upon effectively.

13. Do you have any knowledge on how MSA prioritisation is handled elsewhere (e.g. at Toyota)? If yes, please provide.

14. Is there anything left unasked / said? Please mention whatever else might come to your mind to be of value towards the research / methodology development for the tool. This could be with respect to literature to consult, other people to talk to, Airbus specific content, or just about anything you deem valuable.
The MSA Student notes I gave you are the best summary of my thoughts and approach. These are my key points:

The key analytical tools for Measurement Systems Analysis are:

- *Consistency Test, Demonstrable Resolution and Capability*
- *Basic Charts – Bias, Correlation and Linearity*
- *Evaluation of the Measurement Process (EMP)*
- *Variable Scale Gauge Reproducibility and Repeatability (R&R)*
- *Attribute Based Reproducibility and Repeatability (R&R)*
- *Measurement Uncertainty*

To enable the effective practical application of these analytical tools Measurement Systems Analysis should also draw upon elements of:

- *Industrial Engineering*
- *Problem Resolution Tools (Six Sigma)*
- *Measurement Uncertainty*
- *Test Design and Human Factors*

Any MSA activity should be undertaken bearing in mind the following six key tenats of Measurement as defined by the NPL:

The Right Measurements *– Measurements should only be made to satisfy agreed and well specified requirements.*

The Right Tools *– Measurements should only be made using equipment and methods that have been demonstrated to be fit for purpose.*

The Right People *– Measurement staff should be competent, properly qualified and well informed.*

Regular Review *– There should be both internal and independent assessment of the technical performance of all measurement facilities and procedures.*

Demonstrable Consistency *– measurements made in one location should be consistent with those made elsewhere.*

The Right Procedures *– Well defined procedures consistent with national or international standards should be in place for all measurements*

References and Background Information Sources.

EMP 3 Evaluating the Measurement Process – Donald J Wheeler
Measurement Process Qualification – Edgar Deitrich & Alfred Schulze
AIAG Guide Measurement Systems Analysis
NPL guide No80 A National Measurement Good Practice Guide
BS EN ISO 14253-2:2011 Geometrical Product Specifications (GPS) Part 2 Guidance for the estimation of uncertainty in Measurement
ISO TR 12888 Selected Illustrations of gauge repeatability and reproducibility studies
real-statistics.com
spcforexcel.com
qualityamerica.com

Questionnaire taken by #10: 11.07.2018. 14:40-15:50

Subject Qs:

Very open, friendly, helpful conversation and attitude. Really put effort in thinking about what he's saying and incorporates other colleagues (R.K.) to come up with more / better answers / ideas. Good talk.

Should not initially start of from Cpk values when prioritising MSAs. There could be false positives from a MS that isn't accurate enough.

When there's a new MS, an MSA should come along with it.

When there's a change somewhere in the production process, e.g. a tolerance gets smaller.

Does not trust the relationship between GR&R with Cpk –> sceptic. Should check this some more.

Use the complexity of the MS for prioritisation. At the complex ones, more likely to have options for improvements.

When preparing for an MSA, take care of ensuring that a realistic representation of the real process is made during the execution of the MSA (e.g. when a template is used to determine and mark measurement points, make sure to clean of the markings in between measurements (provided the entire measurement system is being analysed, rather than just the measurement device)).
Be aware of this distinction between analysing the entire system as opposed to only focusing on the instrument.
When it is about the system, it could be easily improved by updating the QSOIs (Quality Standard Operating Instruction); this is significantly different when compared with just the instrument which might then need to be replaced by a different instrument, which will need a heap of resources and signatures.

It is impossible to get a result which says the production process is capable while it also says the MSA is not capable.

Do a proper check whether the measurement device is correctly calibrated, with another different instrument. This is also applicable for the initial measurements as made by e.g. automated laser processes.

Tip, before even starting with an update on an MSA: Carefully look at how the previous MSA has been executed. Was the procedure correct? Especially for MSAs that get conducted by external suppliers, as they often do not pay such close attention to the quality of the execution, moreover to the quantity of how many they execute.

1. –
2. There is no strategy / protocol / regulation for which MSA is next.
3. Start from high CNQ. This will most likely be related to low Cpk and high NC. At these processes, the likelihood of saving considerable amounts of costs is the highest. Possibly

the costs are due problems in the production process rather than in the measurement system, but it is good to verify this and therefore the execution of an MSA is warranted. Before a PPS (Practical Problem Solving) or Shainin process is started, a capable MSA should be present.
There is no strategy, as such it can most definitely be optimised. Did not think about it at all, so can't give ideas.
Start with risk analysis & FMEA => RPZ

4. See above, CNQ, as per Q3.
5. –
6. No. It remains CNQ oriented. However, if (future) rates totally change, this should of course be taken into account.
7. Probably it is taken into account in certain cases, but it should be only a minor reason. Main remains CNQ.
8. See above for Q7.
9. No. There are also processes for which there are no real PC/SPC results, such as vision tests for undulations. Nevertheless, these processes can be very important and be related to high CNQ. The Cp/Cpk values do not need to be known to decide it is useful to get a MSA done as soon as possible.
   By starting off with processes where high CNQ is present, one will most likely, indirectly also select those processes where bad Cp/Cpk exists. Validating this idea by PC/SPC data is 'fun' but of no real importance.
10. Everything is in a way related with CNQs.
11. The inspection planning department; QDSO1.
12. Could be beneficial. For all those processes where the CNQ are higher than a certain percentage (nothing determined – yet) of the RC for that process AND a certain absolute value (once again; nothing determined at this point in time), one should try to optimise the process. At optimisation, the first step would be an MSA.
13. No.
14. No.

Questionnaire taken by #11: 13.07.2018. xxx

1. How useful do you deem MSAs to be (could think of assuring SPC data, quality improvements, etc.)? 5
2. Who determines which process is next in line to undergo a (new) MSA? APT network Where does he or she base his or her decisions on in that respect? What is the current MSA prioritisation strategy at Airbus (if there is any, that you know of)? 3
3. With reference to the previous question; is the current procedure of prioritisation at Airbus, with respect to MSAs, optimisable? YES Do you have any suggestions how to optimise the process, be it with or without (considerable) investments? DIGITALISATION of the procedure and computing off data, using Skywise to collect the data …
4. Which parameters do you deem to be the most important, in light of MSA prioritisation? Consider, among others, Gage Repeatability & Reproducibility (GR&R), Process Capability (Cp & Cpk), Cost of No Quality (CNQ), Production rate, Rate of defects, Non Conformity (NC), etc. Do you have other important additions? Why (not)? Tolerancing
5. How would you rate the aforementioned / added parameters and why? Integration of MSA on modelisation and process simulation
6. Consider that some flexibility is needed on the (long term) aircraft market, as certain aircraft types see their production rates going up while others go down. Does this change your answer on the previous question? NO we need to go further
7. Are there any logistical arguments involved that give reason to give preference to one or the other process to be next in line to undergo an MSA? If so, could (and should) they be taken out of the equation? NO reason according to me
8. Is the type of measurement instrument used in the MSA, e.g. an ultrasonic thickness gage like the Panametrix 35 DL to measure laminate thickness or a bore gauge to measure the size of a hole, a (supportive) reason to give priority to a process to undergo an MSA? Its depends only on the capability of the tools to answer the requirements. If there is another device capable it can be used.Why (not)? Think of reasons such as time needed to conduct an MSA with that specific device, or training needed for operators to be eligible to work with the device.
9. If there is no Process Capability / Statistical Process Control (PC/SPC) data present for the process, should it be seen as less important to be high up on the priority list to undergo an MSA? No, there is no link between the data availability and MSA importance
10. Do you suspect that there is a certain relationship between parameters, which could be of importance in the decision making process. How would this relationship manifest itself? Of course it is possible there are interdependencies within the parameters. I have no idea how we can show it.
11. Which department should have the most influence, with respect to providing input for the methodology for MSA prioritisation and the subsequent tool development, based on knowledge of MSAs or dealing with the execution of them. QUALITY/ME/E
12. Does it sound attractive to you, to increase the pace at which MSAs are conducted? NO dogmatic position on this. It depends on the needs.Would it be a good idea to reserve more resources (employ more people), in order to execute more MSAs (in the same timespan)? It depends on the needs Would these investments pay of? YES
13. Do you have any knowledge on how MSA prioritisation is handled elsewhere (e.g. at Toyota)? If yes, please provide. You could asked to Ronan CAUCHY
14. Is there anything left unasked / said? Please mention whatever else might come to your mind to be of value towards the research / methodology development for the tool. This could be with respect to literature to consult, other people to talk to, Airbus specific content, or just about anything you deem valuable. MSA is a key tool to provide sustainability of our production system. It is mandatory to ensure we are manufacturing properly our aircrafts.

Questionnaire taken by #12: 08.08.2018. 10:00-11:00

Did not really go through the questionnaire, instead went freestyle and talked about whatever important came up while talking.

Documents of interest:

- M7029A
- RE1108187_5
- A1089 – Directive
- M1089.X – Methods (Here X ranges from 1 to 4, depending on which part it belongs to; #3 is not completed yet).

Looking into Sterco (document he send along – also saved on pc here):
This document describes the End to End metrology system – The Airbus Measurement System as applied.
Follow ISO 112. Complies with laboratory qualification. Managed to reduce the 700+ requirements to only 132 (still too many though). By breaking them down into 4 methods, it was made manageable.

M1089.2 is most interesting in this thesis – Quality Measuring Systems.
M1089.4 represents the verification & calibration (No validation; this occurs at the product, during audits).

All equipment which is involved in processes needs to have a MSA – this isn't the case now.

There are new process Owners/Leaders @ FU

Comparing countries; in France SAP is being used instead of Minitab. The preferred tool is however Minitab (used in e.g. Germany), for conducting the analysis part of an MSA.

Changing the use from Excel format to a TOOL is very much desired, this TOOL should also be visible to all (factory sites) of Airbus (make it NatCo – National Company wide) – learn from each other, see and share data. Reduce the amount of double work that is otherwise present more than needs be.

A target for MSA / GR&R do not limit it to dimensional need, as is the case now most often. Apply also for pneumatic/electric/etc

Identify the KCs (Key Characteristics), CTIs (Critical Items) and measurement equipment in the CPs (Control Plans) -> Identify them for all the equipment/processes and transport this data into Skywise. From Skywise, the data can be further connected and made visible for everyone interested.
The KCs are monitored by SPC. At the places where there is a lot of variation (within tolerance), a good starting point for the MSA execution is found. This holds especially true when there has not yet been an MSA/GR&R executed just yet.

Note that a type 1 is applied to evaluate the equipment.
Note that a type 2 is applied to evaluate the entire measurement system.
This type 1 is not superfluous, it is still needed at several processes for Airbus; one should not easily assume that all the equipment which is provided/given out by other companies to Airbus

can just be used and believed to be working as suggested. There is no such guarantee, therefore a test is needed.

Run @ Rate => Have a look at it, it is about processes which are being utilised at the current maximum and implied rate. Ramp up has been implemented. Seeing how MSAs are applied here gives proper insight on the weaknesses of a process and how to improve. The people who are as such involved with R@R are very knowledgeable in this field. => Fabien Lavergne <= @ Airbus

Finding documents I need/want:

Hub => Company => Business Management System (BMS) => MyDoc => Put in reference => Result. //Other track: Go via link by Andreas. Again put in the reference (Instead of process name)

On vacation till start of September, after which he'll do some AOS @ Broughton. Has worked @ Bosch.

@ Automotive, FMEA & proper CPs => from there find way of which MSA to 'attack' => Priority.

@ Run@Rate: Cpk > target KPP (Key Process Parameter). Coming from the KPP is always a save idea.

Questionnaire taken by #13: 06.07.2018. email

Did not really go through the questionnaire, instead went freestyle and communicated about whatever important came up while corresponding.

Documents of interest:

- FU.IN.03.06.05 – Qualify and Deploy Measurement System
- M7029
- A2019.6 – Directive

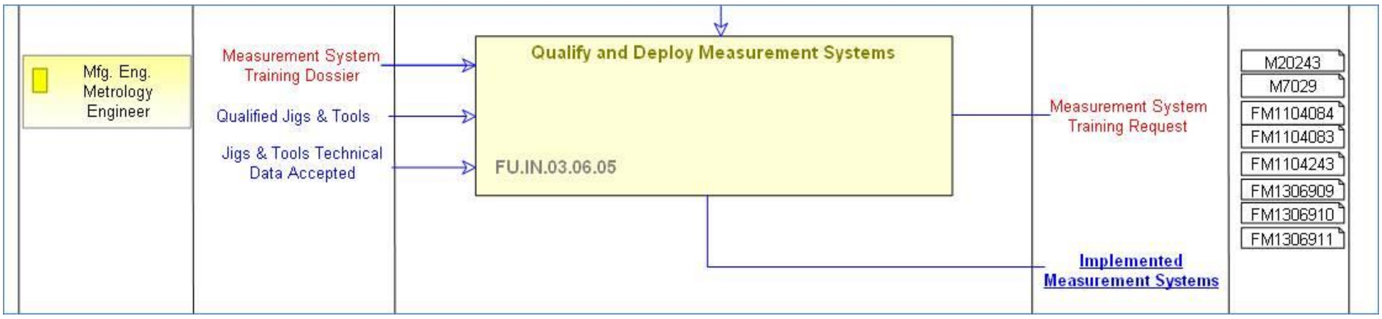
thanks for your explanations. I think we got similar use cases in Bremen so I think such a prio-process can be valuable not only for Stade. I will comment on your questionnaire ASAP.

A short comment to the necessity of MSA:

Under the following link you can find the Airbus business management system HUB page. On the left side you can find processes.

The implementation of measurement systems you can find in "Fulfil" -> "Industrialize" -> "Design & Implement Manufacturing Systems" -> "Implement Measurement Systems". It is FU.IN.03.06, the process linked to A2019.6.

Following the process you can find FU.IN.03.06.05, which is called "Qualify and Deploy Measurement System". This process is also linked to the M7029. See Abbildung 1.



If you go into the process you can find the MSA decision in 5.1.5.1. There you can find the requirements for a MSA. It is mandatory for KC / CTI even if you have qualified an equal system for a similar process and for all other measurement processes if the MS has not been qualified once (see Abbildung 2).

Measurement System Analysis Decision:

Depending on the following criteria a qualification by the Measurement System Analysis (MSA) method shall be made:

- If the measured characteristic is a CTI/KC
- If no equivalent MSA for the combination of MS and Measurement Process can be referenced

In conclusion you need a MSA for all measurement processes plus a single MSA for all measurement processes documenting / ensuring KC /CTI.

In the CC you find our quality responsible for MSA.

Do not underestimate the amount of MSAs that should be conducted, they're there for all CTIs and KCs, as well as for all combinations of MS and MP which are singular in nature (they're not equivalent to another MS/MP combination which does have an MSA already).

Conveys interest and usefulness of such method/tool for MSA prioritisation for other Airbus departments.

Questionnaire taken by #14: 19.07.2018. email

Did not really go through the questionnaire, instead went freestyle and communicated about whatever important came up while corresponding.

Documents of interest:

- EBB GTI Improvement on Fibre Optics
- M7029
- A2019.6 – Directive
- EADS Black Belt (Lean 6 Sigma) Programma //3.4 Measurement Systems Analysis

Big document with the execution of a specific MSA for A380 Fibre Optics which would save ~20,000 € / MSN, as in the GTIs findings came out which often lead to the need of de-installing (parts of) the cabin, as findings came rather late in the process. The worst case even had 500,000 in unnecessary costs.

Apply DRIVER method Define, Review (DR = Understanding), Investigate (IV = Analysis), Verbessern (= Improve), Execute, Reinforce (ER = Action).

No further feedback, due to being careful with workload after having had a stroke 2 years ago. Gave conflicting information with respect to accuracy and precision – when asked for a clarification, no further comments provided.

E

Questionnaire Participants

Table E.1: Stakeholder analysis participants

#	Name	Background Q1	Q2	Q3
1	X	QDSO1, responsible person for MSAs, person to talk to, expert	Quite good. Not quite the expert, do not know everything by heart, but able to execute all what is necessary (work with Minitab)	Been involved with about 100 MSAs, not each and everyone in the same degree, but at least taken notice of the MSA and talked about it with X
2	X	QDSO1, inspection planner for A320/A330	Relatively sparse knowledge. Not so much involved at all. Needs to read up on the topic to be up to speed again and able to say real things. Have had training; more theoretical than practical knowledge/skills on the subject	Been involved with less than 10 MSAs – at the level of MFT
3	X	DSVC, Manufacturing Development Engineer. No real affiliation with MSAs	Mere theoretical knowledge on the subject; far from a specialist	Has not been involved with MSAs in any possible way, this includes MFTs
4	X	QDSO1, inspection planner for A380/A400M	Helped write the MSA manual for QDSO1, theoretical knowledge is pretty good	Only about 2, as such not a lot of practical knowledge/skill with it
5	X	DSVA, Manufacturing Development Engineer. Helped write the MSA manual	A lot of technical / theoretical knowledge. Practical / hands on, not so much	Executed about 5 MSAs
6	X	QDSO1, Inspection Planner A350 WUC	Not so much knowledge about MSAs. Superficial information, for as much as is needed in the daily doings as IP	Helped with less than 5 MSAs
7	X	QDSA, Conformance Management. NDT. FOD Prevention. Operational Surveillance. Certifying	Deep thorough knowledge about MSAs, helped in writing the FUI.IN.03.06 - document with content on how to decide where an MSA should be applied in the production process.	Has not really executed many MSAs. More MFT knowledge.
8	X	QDSO Shainin Projekte	Good	Quite many (20-50)
9	X	Small volume metrologist and MSA subject matter expert at Broughton: Mfg Engineer - JT&TS Metrology - DOVT1	Expert. Also member of staff at Coventry University and lecturer for MSA subject. Very aware of MSA documentation (companies, books, research papers - extensive library), in and outside of Airbus.	Undertakes MSAs of Type 1 and 2 on a regular basis. Should be 50+ type 2 and uncountable many type 1
10	X	QDSO2 - Conformance Management	Not so deep involved, but does have basic knowledge and a lot of information from just being around for a long time already at the Airbus plant	Less than 10

Table E.1: Stakeholder analysis participants

#	Name	Background Q1	Q2	Q3
11	X	DZP - Saint Nazaire. HO Plant Production Support Services (logistic, sub-assemblies production unit, surface protection production unit). Linked with MSA in the past; Process Owner of FUIN0306 - mananged process standardisation of measures on A350 for all Airbus Industry plants	Very good knowledge. Also knows all documents (but atm not really so deep into it anymore, can easily get back on it though).	Been hands on involved with about 5. The processes around it are more his field, the theoretical knowledge etc.
12	X	QMS - Toulouse. Standard Owner for Metrology at Airbus	Very high knowledge and skill level; aware of the documentation (was one of the authors)	Involved with a numerous amount; plenty of experience
13	X	DBVE - Bremen. Manufacturing Development Engineer	Specialist for ordering processes and inspections	Involved with a numerous amount; plenty of experience
14	X	QWCI - Hamburg. Hamburg Quality Conformance Management	MSA Blackbelt: Expert	Yes, e.g. had a big project in 2010 on the A380 fibre optics

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