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Redesign of the presetting process at Fokker Aerostructures Hoogeveen

DESIGN PROJECT IEM

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Contents

Management summary

A design project has been conducted for Fokker Aerostructures Hoogeveen. The design project focused on presetting; a manual process wherein tool assemblies are built for the machining of composite parts. At the moment, much time is wasted in this presetting process because operators are conducting rework and additional activities whereas the end results are also undesired, since many tool assemblies are not meeting the releasing requirements: the presetting tolerances. It was computed that 20% of all the time is lost due to rework and additional activities whereas 44% of the released tool assemblies are not conforming the specifications. As a result, the aim of the design project was to propose a redesign for the presetting process that reduces rework and avoids non-conforming tool assemblies.

After a sophisticated performance system analysis, including interviews, observations and measurements, it was found that that the majority of problems are related to one sub process: the presetting of tool assemblies with collet chuck holders. Measurements showed that most of the time is wasted during the preparation of these tool holders. Furthermore, the majority of the problems indicated by the interviewees are related to collet chuck holders. For this reason, a redesign has been developed exclusively for the presetting process of collet chuck holders. With the aid of the performance system framework and multi-criteria decision analysis, the redesign was established. The proposed redesign includes a package of four countermeasures: a formula to adjust the current diameter tolerances, the replacement of poor collets and clamping nuts and a new education and feedback procedure that can be used to educate and coach employees regarding the presetting process. The design has been validated by implementation in practice. The results indicate that the redesign adequately avoids rework and ensures that the tool assemblies are conforming specifications. It was computed that Fokker Aerostructures can save at least 12.168 euros per year by implementing the redesign, whereas the total proportion of conforming tool assemblies can be increased from 56% to 81.1%. Furthermore, the total amount of rework can be reduced with 71.7%. The first indication is that the redesign can be implemented without negatively affecting the machining process. However, the exact impact should be further investigated in the future.

1 Introduction

Fokker Aerostructures Hoogeveen produces fiber-reinforced plastic parts (composites) for the aerospace industry. In order to survive in the competitive aerospace market, Fokker Aerostructures constantly raises the bar for its composite production process. A critical step in the production process is the finishing of plastic parts by milling and drilling. For this reason, the company is continually working on the capability of this machining process. Although Fokker spends a lot of effort to control various parameters in the machining process, one parameter has received limited attention: the inflow of tool assemblies (cutting tools) into the milling and drilling process. However, there are good reasons to pay attention to this input parameter. It was found that the dimensions of tool assemblies flowing into the machining process are currently not controlled, because tool assemblies are not always meeting the specifications. The tool assemblies, flowing into the machining process, are manually created in a supporting presetting process. In this process, operators are expected to make tool assemblies according to specifications, to guarantee correct tool assemblies for machining. However, it was found that the delivered tool assemblies, flowing into the machining process, are not always meeting these specifications, because presetting operators ignore the specifications during their work. In fact, operators decide by themselves whether the tool assembly is sufficient or not to be send to the machining process. As a consequence, the inflow variation depends on opinions rather than facts, which is undesirable because Fokker wants to increase the capability of the machining process. Moreover, it was found that currently much time is wasted in the presetting process, because operators are conducting rework and additional activities. In particular, operators frequently reassemble or knock on tool assemblies. As a result, the output of the presetting process is limited. The technical management of Fokker Aerostructures therefore wants to redesign the current presetting process, to reduce the rework and eliminate the non-conforming tool assemblies. For this reason, a design investigation has been conducted.

This work presents the findings of a master design project executed for Fokker Aerostructures Hoogeveen. The design study focuses on the presetting process for composite machining. In this design investigation, the current presetting process is documented. Besides, the performance deficiencies in the presetting process are analyzed with the human performance system framework. As a consequence, the current performance is considered from a sociotechnical and behavioral perspective. In addition to the analysis, this dissertation proposes a redesign for the presetting process to reduce the rework and to increase the proportion of tool assemblies conforming the specifications.

This report is structured as follows: a thorough problem analysis in presented in chapter 2. It includes a description of the problem context, an analysis of the problem owner, system and stakeholders, and the definition of the problem and design goal. The research methodology is discussed in chapter 3. In this chapter, the research questions are defined and the methods to answer the research questions are described. Consequently, it includes the introduction of the main research method, the human performance system framework. In chapter 4, the current presetting process is described. The presetting operations and sequence of process steps are illustrated in this chapter. The performance system analysis is addressed in chapter 5. It includes an analysis of the current presetting problems by the performance system framework. In chapter 6, the proposed redesign for the presetting process is presented. The content of the redesign is described and motivated. Furthermore, the impact of the redesign and the design validation are explained. The discussion and conclusion are presented in chapters 7 and 8.

2 Problem analysis

This chapter defines the problem addressed in this design project. Firstly, the company and problem context are described. Thereafter, the problem owner and system are analyzed. Subsequently, the stakeholders of the project are determined. Finally, the problem statement and design goal are provided.

2.1 Company description

Fokker Aerostructures is a leading specialist in the design, development and production of complex lightweight structure components for aviation, aerospace and defense. Fokker Aerostructures is a business unit of Fokker Technologies, a Dutch aerospace company founded in 1919 by aviation pioneer Anthony Fokker [1]. Since 2015 Fokker Technologies is a subsidiary of GKN aerospace, a global aerospace business consisting of 51 manufacturing locations and more than 17.000 employees [2]. Fokker Aerostructures has facilities in the Netherlands, Mexico and the United States. In the Netherlands, the company is situated in Papendrecht and Hoogeveen [3].

The design project is executed at Fokker Aerostructures Hoogeveen. At the site of Fokker Aerostructures Hoogeveen, fiber-reinforced polymeric parts (composites) are produced and assembled. Besides, lightweight metal parts are manufactured and metal components are combined with composites. Examples of manufactured products in Hoogeveen are the doors of the Lockheed Martin F35 Joint Strike Fighter (JSF), the J-nose of Airbus A380 and tail components of the Gulfstream G650 (figures 1-4).

Figure 1: F35 Joint Strike Fighter.

Figure 2: Gulfstream G650.

Figure 3: Airbus A380.

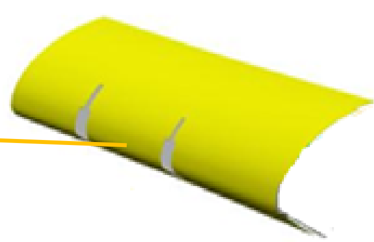

Figure 4: J-nose component.

2.2 Problem context

This design project focuses on the presetting process, an essential supportive process for composite milling and drilling (machining). At Fokker Aerostructures, composite products are milled and drilled by a CNC machine (figure 5). In order to fabricate the product, this machine utilizes various cutting tools such as mills, routers, drills, reamers and disc cutters. Since cutting tools are subject to wear, they are periodically replaced by new ones. Within the company, new cutting tools are prepared and checked by an independent presetting department. At this department, cutting tools are placed in a tool holder, forming a tool assembly.

Figure 5: CNC machine.

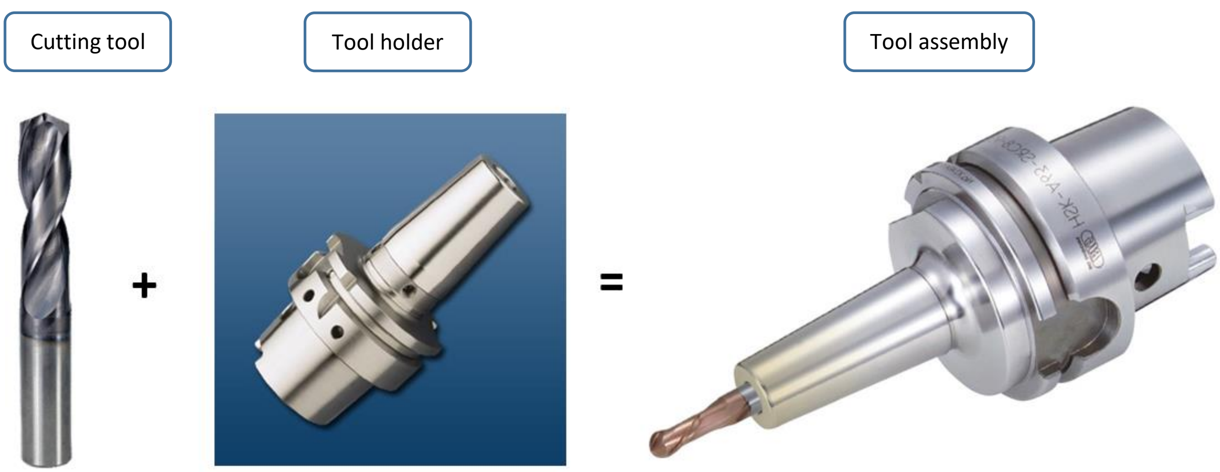

Figure 6: Formation of tool assembly.

The presetting operator starts the presetting process by selecting the right tool and holder from the warehouse. Subsequently, the operator assembles the cutting tool and the tool holder, resulting in a tool assembly (figure 6). After assembling, the tool assembly is measured in order to guarantee that its dimensions are conforming specifications. The length and diameter of the tool assembly are automatically measured on a laser-based measuring machine (figure 7). The tolerances for the dimensions of each tool assembly are described by a digital Tool Data Management (TDM) database.

The presetting operator has to make sure that the measurements are meeting these prescribed tolerances. The tool assemblies are then transported from the presetting department to the machining department, where the tool assemblies are put in the machine to process parts (figure 8).

Figure 7: Laser-based measuring machine.

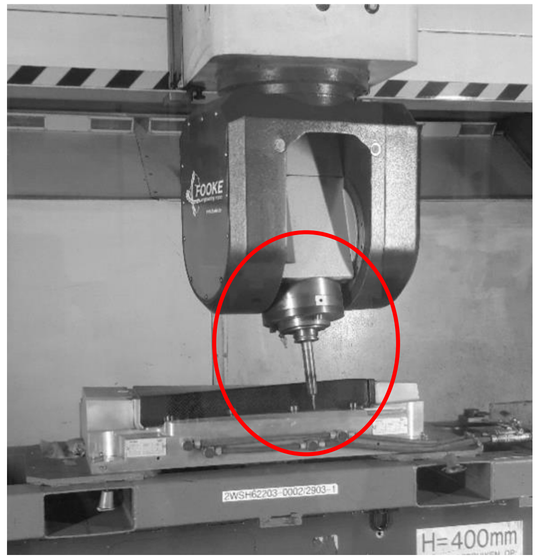

Figure 8: Tool assembly in CNC machine.

The technical management of Fokker Aerostructures notes that the presetting process is currently not executed as intended and that a lot of time is wasted because operators are performing additional activities:

At the moment, presetting operators often have difficulties to achieve the desired measurements for a tool assembly. As a result, presetting operators frequently perform additional activities to ensure that the tool assembly meets the TDM tolerances. When the tool assembly exceeds the tolerances, operators usually use a hammer to knock the cutting tool into position before they measure the assembly again. If this does not help, the operator generally reassembles the tool assembly, with or without replacing some of its components, to attain a conforming tool assembly. Hence, operators frequently have to do rework or additional activities to obtain a good tool assembly at the presetting department. Consequently, the tool assembly is often measured multiple times, before it satisfies the TDM specifications. If after multiple attempts the operator still cannot attain the desired measurements, the operator usually ignores the procedures for releasing a tool assembly. The operator then decides to send the tool assembly to machining, even though the measurements are exceeding the TDM tolerances. Presetting operators are expected to deliver tool assemblies meeting the tolerances of TDM and if the tolerances are exceeded, they should check and reassemble the tool assembly, however, in reality they first try to knock the cutting tool into position (to manipulate the measurement) before they reassemble the tool assembly whereas after several attempts they even ignore the TDM tolerances.

It was found that the machining department often receives cutting tools that should not have been released for processing: by collecting the data of released tool assemblies (data logging), it was found that 44% of the tool assemblies are currently not meeting the TDM tolerances. The dataset comprised of 384 non-unique tool assemblies that were released over a time period of three months. The complete dataset can be found in appendix A. By comparing the measurement data of tool assemblies with the tolerances from the TDM database, the proportion of non-conforming tool assemblies was computed.

Because operators frequently do rework or additional activities to obtain a good tool assembly, much time is wasted in presetting process. In order to quantify this, the time loss was measured in practice. The time needed to assemble and measure 30 different tool assemblies was clocked. The complete dataset can be found in appendix B. It turned out that it takes about 4 minutes to prepare a tool assembly without rework or additional activities. However, in case of problems during presetting, the extra time needed to finish the assembly varied between 1 and 6 minutes (i.e. wasted time). It was calculated that on average 1 minute is lost with the preparation of a tool assembly. This implies that 20% of the time is wasted on rework and additional activities.

At the moment, the presetting department prepares 54 tool assemblies per day. This means that almost one hour (54 minutes) per day is wasted in the presetting process. The presetting department currently needs 1.175 hours per year to prepare all tool assemblies for composite milling and drilling. Since 20% of this time in the process is actually waste, 235 hours per year can be saved when all additional activities and rework are eliminated from the presetting process. A presetting operator costs the company 75 euros per hour, meaning that 17.625 euros can be saved per year. As a result, Fokker Aerostructures can reduce its operational costs with 17.625 euros per year by eliminating these non-value adding activities from the presetting process.

2.3 Problem owner analysis

The problem owner is Remko Schra, the technical lead of composite parts production at Fokker Aerostructures Hoogeveen. He is responsible for the technology performance of the composite production facility in Hoogeveen. The problem owner wants to increase the efficiency of the presetting process, in order to save costs. His aim is to have a tool preparation process wherein operators do not have to execute additional activities such as reassembling tool assemblies or knocking on tool assemblies before measuring. In other words, the tool assembly should be conforming at the first measurement after assembling. Thus, rework and additional activities should be avoided. At present, the output of the presetting department amounts 12 tool assemblies per hour. However, considering the amount of time spent on rework, it can be concluded that the output of the presetting department can be increased to 15 tool assemblies per hour, when all additional activities are eliminated from the presetting process. Therefore, the problem owner wants to redesign the current presetting process in order to improve its output.

Beyond increasing the output and saving operational costs, the problem owner has another reason to redesign the presetting process. At the moment, the TDM tolerances are ignored on a regular basis, because 44% of the tool assemblies used in production are not conforming TDM. The impact of ignoring the tolerances of TDM is that the dimensions of new tool assemblies flowing into machining process are not controlled (limited). When the TDM tolerances are not handled, but operators decide by themselves whether the tool assembly is sufficiently accurate for production or not, the variation in tool assemblies depends on personal opinions rather than facts. As a result, the inflow variation is unpredictable, increasing the risk of tooling problems during machining, such as swaying cutting tools or tool breakage. Bearing in mind that Fokker Aerostructures constantly raises the bar for their production processes (capability), and therefore the necessity to properly control the machining process increases, it becomes increasingly important to control the variation of all parameters in the machining process, thus also the variation of incoming tool assemblies. Hence, it is also important to change the presetting process in such a way that released tool assemblies are always conforming TDM.

Another important aspect is that the exact presetting process is currently unclear to the problem owner. The presetting department is situated at the other side of the factory terrain, compared to the location of the machining department and problem owner. As a result of the distance, the cooperation between the two departments is low. In fact, the problem owner and involved machining department currently do not know how the tool assemblies, flowing into their machining process, are made. Because the presetting process is not known in enough detail, it is not clear which aspects cause the observed problems. Thus, the presetting process first has to be captured and analyzed to establish the factors causing the observed waste, before the presetting process can be improved (by a redesign).

2.4 System description & analysis

This section presents a thorough system analysis, by providing three levels of decomposition. The three levels include:

- The composite production process.
- The CNC milling and drilling process.
- The presetting process.

Composite production process

The system context of the presetting process is the composite production process, since the presetting department delivers tool assemblies for composite milling and drilling (machining). Figure 9 shows the composite production process schematically. The production process starts with the cutting of prepregs. Prepregs are thin layers of fibers, impregnated with uncured resin. After cutting these prepregs, the laminating process starts. In this production step, prepregs are stepwise placed in a mold such that a geometry (laminate) arises. During the various lamination steps, air is extracted from the laminate by placing the mold under vacuum. The mold including laminate is then put in an autoclave such that the prepreg material cures. After removing the cured geometry from the mold, the part is post-processed at the machining department. In this step, the geometry is milled to size. Furthermore, the part is drilled and manually finished. Because laminating is a manual process and curing includes complex chemical/thermal reactions, it is impossible to control the part's dimensions at these production steps, therefore, the final dimensions are established afterwards with milling/drilling. After machining, the part is measured and inspected. The last two production steps include the assembly of multiple parts into one product and the painting of the final product.

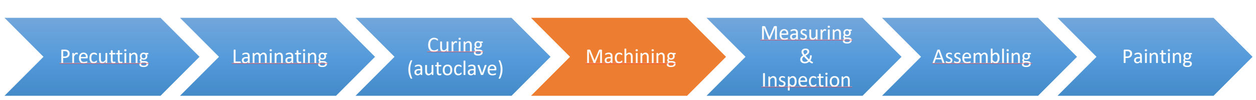

Figure 9: Composite production process.

CNC milling and drilling process

One of the proceedings at the machining production step (figure 9) is the CNC milling and drilling process. Figure 10 shows the system diagram of this process. The composite milling and drilling process has four main inputs: the gross product, jig, CNC program and the cutting tools (tool assemblies). The outputs of the process are the net product and waste.

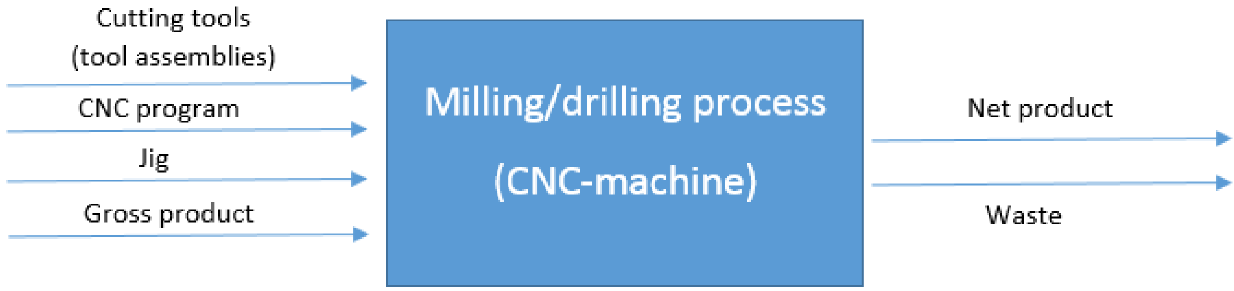

Figure 10: System diagram of the CNC milling/drilling process.

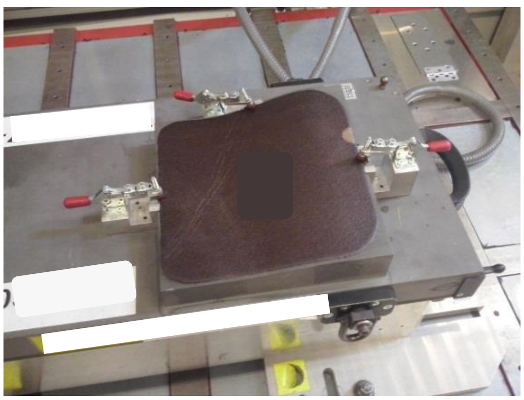

Figure 11: Gross product placed on jig.

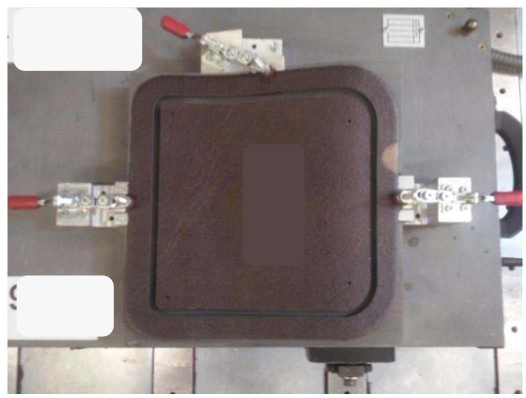

Figure 12: The net product and waste (placed on jig).

An operator starts the milling/drilling process by placing the gross product on a jig in the machine. The gross product is an oversized geometry (i.e. a too large laminated product) that has to be finished. The jig ensures that the product remains at the right position during processing (figure 11). Cutting tools (i.e. tool assemblies) are utilized to process products while a computer program executes the cutting operations (CNC program). During the milling/drilling process, the final dimensions of the product are established, by milling the contour of the product and drilling holes in the material. As a result, the finished product is called the net product (figure 12). After machining, the net product is sent to the measuring & inspection department whereas waste material is discarded.

Presetting process

Figure 13 shows the presetting process and its relation with the CNC milling and drilling process. The scope of the design project is the presetting process; consisting of the assembly of the tool holder/cutting tool and the measurement of the tool assembly. The project focuses on the operations performed in the presetting process. As a result, the system encompasses all materials, machines, men, methods and corresponding databases (TDM) used to execute the presetting process. The measurement method is also under consideration. The storage and procurement of cutting tools/tool holders, the installation of the tool assembly at the CNC machine and the milling/drilling process itself are outside the scope.

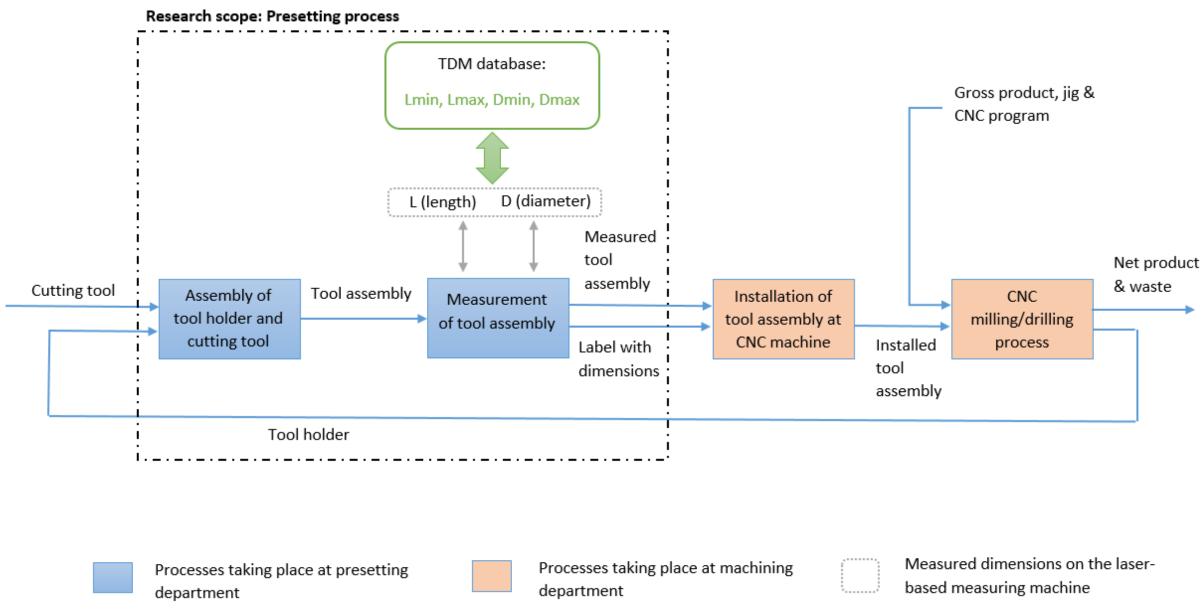

Figure 13: System diagram of the presetting process.

The system diagram schematically shows the measurements in the process and the function of TDM. When the assembly process is finished, the tool assembly is measured. The obtained length and diameter are called L and D (figure 13). The tolerances for the measured length and diameter set by TDM are expressed by L_{min}, L_{max}, D_{min} and D_{max}. As a result, the measured diameter and length should be between these boundaries to release the tool assembly for processing (send the assembly to machining). The requirements can shortly be expressed by the following equations:

$$L_{min} \leq L \leq L_{max} \quad (1)$$

$$D_{min} \leq D \leq D_{max} \quad (2)$$

If these two equations are satisfied the tool assembly is called "conforming TDM".

The activities at the presetting department are performed by 5 presetting operators. The presetting department has two similar laser-based systems for measuring the tool assemblies. Fokker Aerostructures utilizes 16 different tool holders for tool assemblies. In combination with a wide range of cutting tools, consisting of various lengths and diameters, the total number of unique tool assemblies equals 500. The 16 tool holders can be subdivided into two groups: collet chuck holders and shrink fit holders. Collet chuck holders fasten the cutting tool mechanically, by clamping the tool in a collet. Shrink fit holders secure the tool with an interference fit: by first heating the tool holder the inner diameter expands slightly such that the cutting tool can be placed and by subsequently cooling the holder the inside shrinks, fastening the cutting tool. Because there are two tool holder types, two different assembly processes are conducted at the presetting department. Furthermore, the presetting department prepares tool assemblies for six different CNC machines in production.

2.5 Stakeholder analysis

This section presents the stakeholder analysis. Wierenga (2010) defines a stakeholder as: "A person, group of persons, or institution affected by treating the problem". Since stakeholders are the source of goals and constraints for the project, identifying relevant stakeholders is important [4]. This work makes the distinction between direct- and indirect stakeholders. Stakeholders are called direct stakeholders if they have a clear stake and influence on the outcome of the project whereas stakeholders that only have a stake are considered as indirect stakeholders.

Direct stakeholders

This design project has the following direct stakeholders:

- **Presetting operators:** The presetting operators have a substantial impact on the output of the presetting process. They assemble and measure the tool assemblies and decide whether they send tool assemblies to the machining department. They often encounter difficulties at achieving the tolerances from TDM. Nevertheless, they are officially responsible for the tool assemblies used at machining. The presetting operators would like to have a better presetting process, such that they can always deliver the tool assemblies according to TDM, and do not have to execute rework or other additional activities anymore.
- **TDM tool administrator:** The TDM tool administrator sets the presetting tolerances in TDM. Because TDM directly controls the operations in the presetting process, the TDM database has to be analyzed to establish whether it functions well. Collaboration of the TDM tool administrator is therefore paramount. Since presetting operators currently encounter difficulties at achieving the TDM tolerances, the situation might arise that tolerances have to be modified as part of the redesign. Modifications in the TDM database have to be approved by the TDM administrator. Thus, the TDM administrator is an important stakeholder in this project. His stake is to have a good database that supports the presetting process.

Indirect stakeholders

The design project has the following indirect stakeholders:

- **Machining operators:** The machining operators have to work with the tool assemblies. In other words, they use the tool assemblies in production. They install the tool assemblies in the CNC machine. They pick up new tool assemblies from the presetting department and bring used tool assemblies back after processing. They are furthermore responsible for the tool stock at the CNC machine, so they order new tool assemblies at the presetting department. The machining operators want to avoid defects during milling/drilling, therefore, they would like to receive cutting tools with a high quality from the presetting department.
- **Process specialists of machining:** The process specialists of composite machining are responsible for the quality and performance of the composite milling/drilling process. Since tool assemblies are an input for composite milling/drilling, process specialists have to be involved when adjustments are made to the presetting process.

2.6 Problem definition & design goal

This section addresses the problem definition and corresponding design goal.

Problem statement

The problem is defined as: "Because presetting operators have difficulties to attain a good tool assembly at the presetting department, 20% of the time is wasted due to rework and additional activities whereas 44% of the tool assemblies are non-conforming, as a result, the output of the presetting department is limited to 12 tool assemblies per hour and unauthorized tool assemblies are used in production."

Design goal

The design goal is: "Propose a redesign for the presetting process of Fokker Aerostructures such that rework and additional activities can be reduced and all released tool assemblies are conforming TDM, within a time period of 5 months."

3 Methodology

This chapter addresses the research methodology of this investigation. Section 3.1 presents the research questions. The adopted research cycle is discussed in section 3.2. Section 3.3 introduces the main research method of this research: the human performance system framework. The operationalization of the research questions is explained in section 3.4.

3.1 Research questions

The main research question for this design project is:

<u>How can the presetting process of Fokker Aerostructures be redesigned, such that rework and additional activities are reduced and all released tool assemblies are conforming TDM?</u>

The following research questions should be answered, to reciprocate the main question:

1. How does the current presetting process look like?
2. Which factors cause the lack of performance (executing additional activities or rework and ignoring releasing procedures) in the presetting process?
3. Which countermeasures can be applied to improve the performance of the presetting process?
4. What is the best redesign for the presetting process of Fokker Aerostructures?

3.2 Research cycle

In order to organize an investigation, a research cycle can be used. This work follows the problem solving cycle of Van Aken (2012), since the research focuses on preparing a (re)design in a business context, encompassing a clear problem mess. The problem solving cycle is shown in figure 14. The cycle comprises of five phases: problem choice, diagnose (analyses), plan (design), action/implementation and evaluate. The problem mess interacts with all the phases, therefore it is depicted in the middle of the cycle. The problem solving cycle is an iterative cycle, because the phases are usually conducted repeatedly during a project [5]. Since the goal of this research is to propose a redesign for the presetting process, this work only executes the first three phases of the problem solving cycle: the problem choice, diagnose phase and plan step.

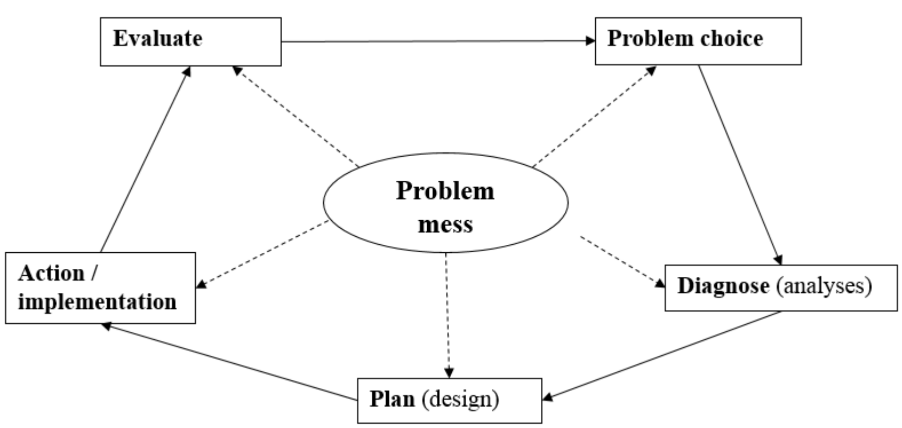

Figure 14: The problem solving cycle of Van Aken (2012) [5].

3.3 Research method

This section introduces the main research method of this research: the human performance system, a framework from the field of behavioral science that can be used to analyze and improve human performance. There are two reasons to utilize the human performance system as fundamental research method: firstly, the presetting process is largely a manual process, wherein the presetting operator plays a crucial role, thus a research method considering performance from a sociotechnical and human point of view is desired. Secondly, the factors causing performance problems, in the form of operators performing rework/additional activities and ignoring working procedures, are currently not clear. With the performance system framework, all factors contributing to the lack of human performance can be identified, because the model considers human performance from a holistic perspective. Therefore, the framework fits profoundly well to the case. Consequently, the framework is utilized as fundamental research method. The remainder of this section discusses the human performance system in more detail.

The human performance system is a tool to investigate human performance. It follows a sociotechnical view of performance [6]. It considers human performance as a system, wherein beyond the individual capabilities of the performer four other elements are affecting comprehensive performance. Consequently, the performance of a person is considered as a function of these five components [6] [7] [8] [9]. The model traces its roots back to the early years of behavioral science research by B.F. Skinner [7]. The framework has been validated through research and application since its origination in the 1950's [6]. Figure 15 shows the human performance system model, as proposed by Rummler and Brache (2012) [8].

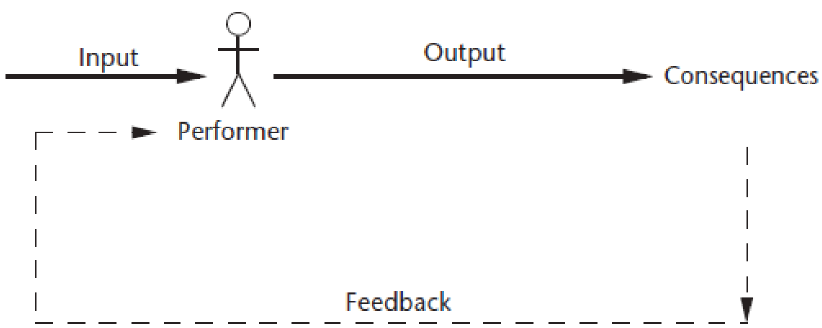

Figure 15: The human performance system model of Rummler and Brache (2012) [8].

The five components of the human performance system are [8]:

- **Inputs:** the raw materials, forms and assignments and customer requests that cause people to perform as well as the performers' resources, systems and procedures for executing a job.
- **Performers:** the individuals or groups who execute the job. In other words, the people who convert inputs into outputs.
- **Outputs:** the products produced by the performers, contributing to process and organization goals.
- **Consequences:** the positive and negative effects that performers experience when they produce an output. Whether a consequence is considered negative or positive depends on the unique perspective of each performer.
- **Feedback:** the information that tells the performers what and how well they are doing.

In the situation of performance issues, the focus is usually on the performer: It is widely believed that the individual performer has some deficiency in knowledge, skill or practice. However, performance problems often not arise from incapable performers, but occur as a result of some other system deficiency, such as a lack of feedback or poor input. Hence, performance is best controlled by focusing on the overall performance environment rather than the individual characteristics of the performer [6] [7] [8] [9] [10]. Research even indicates that the performer is the least likely cause of poor performance [6] [8]. By analyzing each component of the performance system model, the comprehensive performance can be improved because all environmental factors influencing the output are addressed [6] [8] [9].

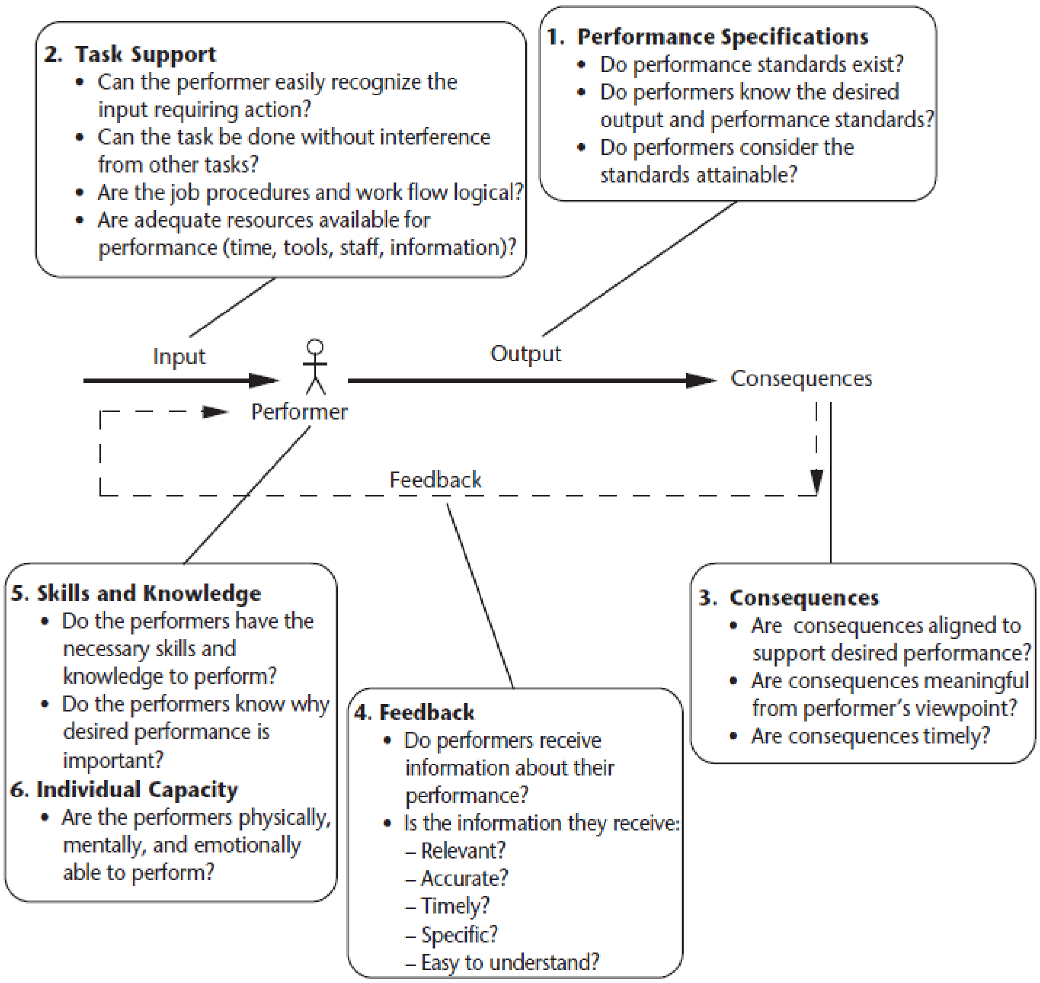

Figure 16: The six factors affecting the human performance system by Rummler and Brache (2012) [8].

Rummler and Brache (2012) identified six factors affecting the effectiveness and efficiency of a human performance system: performance specifications, task support, consequences, feedback, skills and knowledge and individual capacity (figure 16). They proposed for each factor research questions, to analyze every aspect of a human performance system. Consultants can apply these questions in practice to identify the factors hindering effective performance. Hence, the six factors and corresponding questions form a diagnostic tool for evaluating performance problems. In addition, the authors suggest actions to be taken to overcome a diagnosed deficiency within every factor. As a result the performance system can be used as well to improve the performance of a system or process [8].

Beyond Rummler and Brache (2012), Kepner and Tregoe (2015) also propose a performance system framework (figure 17). Although some terminology is different, the performance system model of Kepner and Tregoe is similar to the framework of Rummler and Brache (2012). This dissertation follows the model of Kepner and Tregoe (KT), because Fokker Aerostructures is familiar with KT: the company utilizes research methods of KT for continuous improvement and problem solving projects. Moreover, the engineers of Fokker Aerostructures are trained to apply the KT research tools whereas Kepner-Tregoe also supports Fokker during projects with its KT facilitators.

The KT performance system framework is denoted by the following five elements [6] [7]:

- **Situation:** the immediate setting in which the Performer works, encompassing:
    - the work environment
    - the performance expectations
    - the signals to perform (the cue or indicator that action needs to be taken)
- **Performer:** the individual or group expected to behave/perform
- **Response:** the specific, observable behavior(s) or action(s) of the Performer
- **Consequences:** the events that follow the Response and increase or decrease the probability that the behavior will happen again, given the same Situation. Consequences include events that impact both the Performer and organization.
- **Feedback:** the performance-based information the Performer receives about progress toward a goal. It guides the Performer in maintaining or changing his/her behavior.

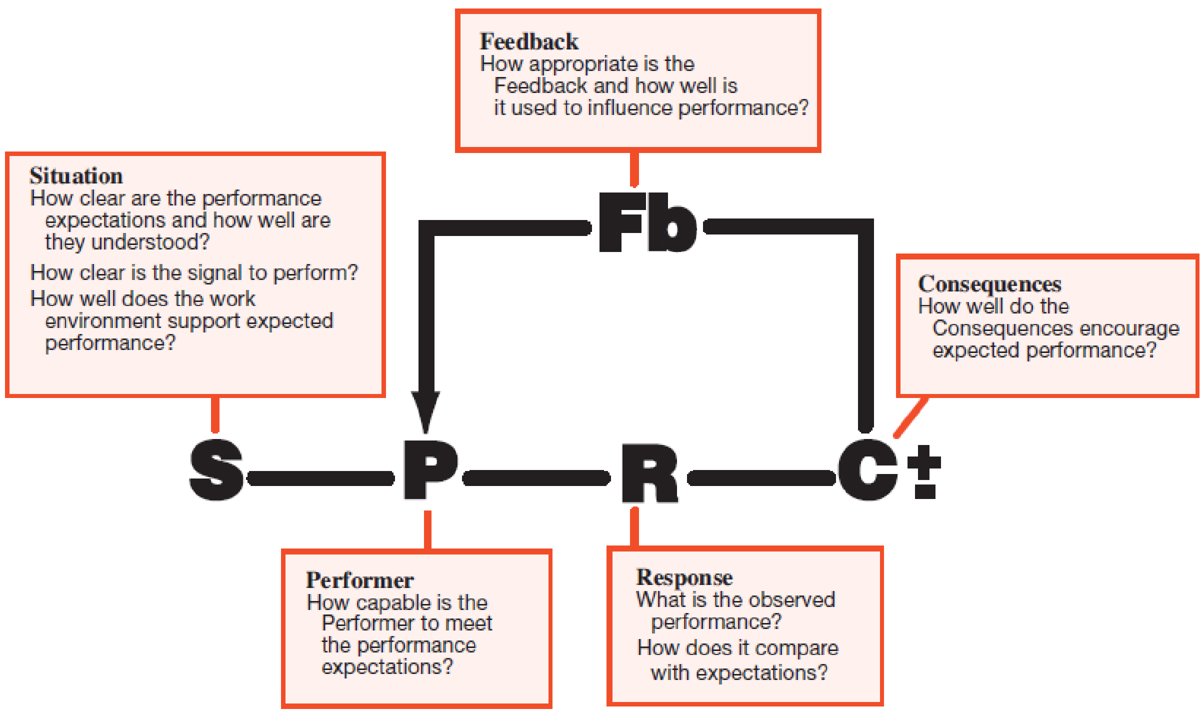

Figure 17: The performance system framework of Kepner and Tregoe (2015) [6].

Similar to Rummler and Brache (2012), Kepner and Tregoe (2015) also define research questions for analyzing the elements of the performance system (figure 17). These research questions are used as sub questions for answering research question 2. Section 3.4.2 elaborates on the operationalization of these sub questions.

3.4 Operationalization

In order to answer each research question, a stepwise plan is required. This section provides an overview of the key steps that should be performed to answer the research questions of section 3.1.

3.4.1 Research question 1

How does the current presetting process look like?

This research question should be answered first, because the exact presetting process is currently not known in enough detail by the problem owner (section 2.3) as well as the researcher.

In order to answer this research question, the following sub questions have to be answered.

- *1.1: Which materials/goods/assets are used in the presetting process?*
- *1.2: Which operations/activities are executed in the presetting process, and who performs them?*
- *1.3: Which procedures exist for operations in the presetting process?*
- *1.4: How is the tool assembly measured, and what is the role of TDM?*

The starting point should be gathering information by observing the presetting operators during the preparation and measurement of tool assemblies. In order to register the presetting process further, face-to-face interviews should be taken with presetting operators. The interview is a conversational practice where knowledge is generated through the interaction between an interviewer and an interviewee (or a group of interviewees) [11]. Since qualitative data has to be gathered, a semi-structured interview technique should be applied. In such an interview, the interviewer provides some structure based on his/her research interests and interview guide, but works flexibly with the guide and allows room for the interviewee's more spontaneous descriptions and narratives [11] [12]. The role of TDM has to be determined by interviewing the TDM tool administrator and presetting operators. After gathering the data, the presetting process should be documented. In order to describe and visualize the presetting process, process mapping shall be used. A process map is a graphic representation of a process, illustrating the sequence of tasks using a modified version of standard flowcharting symbols. In other words, the map of a work process is picture of how people are conducting their work. Process mapping is an approach from the Six Sigma toolbox [13]. In addition to the creation of flowcharts, the process should be further clarified by describing the process in words, supported by pictures. Once the entire process is clarified and documented, one can move to the second research question.

3.4.2 Research question 2

Which factors cause the lack of performance (executing additional activities or rework and ignoring releasing procedures) in the presetting process?

This research question has to be answered to establish the factors causing the performance problems in the presetting process. In order to answer this question, the presetting process is analyzed with the KT performance system. Therefore, the corresponding diagnostic questions from the model in section 3.3

(figure 17) are adopted as sub questions for answering research question 2. Hence, in order to answer this research question, the following sub questions have to be answered:

- *2.1: What is the observed performance?*
- *2.2: How does it compare with expectations?*
- *2.3: How clear are the performance expectations and how well are they understood?*
- *2.4: How does the performer view these expectations, are they considered attainable?*
- *2.5: How clear is the signal to perform?*
- *2.6: How well does the work environment support expected performance?*
- *2.7: How capable is the performer to meet the performance expectations?*
- *2.8: How well do the consequences encourage expected performance?*
- *2.9: How appropriate is the feedback and how well is it used to influence performance?*

Kepner and Tregoe (2015) provide a collection of underlying/supporting questions to answer the above listed sub questions. This collection of diagnostic questions can be found in appendix C. In order to answer each sub question, these underlying questions should be taken into account in the analysis. By answering the first research question (section 3.4.1), most of these sub questions can be already be answered. For the remainder of sub questions, data should be gathered by observing the presetting process and interviewing the presetting operators. Semi-structured interviews should be executed to analyze the presetting process based on the analytic questions of KT (appendix C). Subsequently, the assessment of the situation regarding each performance system factor should be made by the researcher himself in association with the company experts (KT educated employees) based on the gathered information. Nevertheless, the opinion of the presetting operators (Performer) regarding the attainability of the performance expectations have to be adopted literally in the performance system analysis (sub question 2.4).

3.4.3 Research question 3

Which countermeasures can be applied to improve the performance of the presetting process?

After answering the second research question, the deficiencies in the presetting process are known. In principle, every deficiency identified by the performance system suggests an improvement. Rummler and Brache (2012) and Kepner and Tregoe (2015) suggest actions to be taken to improve each factor of the performance system. In other words, the literature provides advice for countermeasures to enhance the presetting process. The proposed countermeasures by the literature should first be translated to presetting context. Subsequently, the feasibility of the suggested actions should be evaluated. Thereafter, in association with the KT engineers of Fokker Aerostructures, the countermeasures should be further developed such that they can be implemented in practice.

Therefore, in order to answer this research question, the following sub questions have to be answered:

- *3.1: How can, according to the literature, each deficiency in the presetting process be captured to improve the performance?*
- *3.2: How can these suggestions be translated into the situation of the presetting process, yielding applicable countermeasures?*

3.4.4 Research question 4

What is the best redesign for the presetting process of Fokker Aerostructures?

In order to answer this research question, the following sub questions have to be answered:

- *4.1: What are the potential countermeasures for the presetting process, following from the performance system analysis?*
- *4.2: What are the criteria for evaluating the various countermeasures?*
- *4.3: What are the weights of the criteria?*
- *4.4: What is the score (ranking) of each countermeasure on the determined criteria?*
- *4.5: What is the total weighted score of each countermeasure?*

After executing the performance system analysis (research question 2) and developing countermeasures based on the literature (research question 3), the potential countermeasures for the presetting process are established. Once the countermeasures are known, the best redesign has to be chosen. This shall be done with the aid of a weighted decision matrix. A weighted decision matrix is qualitative tool whereby options are ranked based on multiple criteria. Every option receives a score on each criterion, ranging from 1 (low/inferior) to 10 (high/superior). Moreover, the criteria are weighted based on their importance, therefore, the score on each criterion is multiplied by a weighting factor. Eventually, the alternative with the highest sum of weighted scores is considered as the best option [14]. The approach comes from the field multi-criteria decision-making (MCDM), a sub-discipline of operations research [15]. In order to evaluate the various solutions, the decision criteria (and their weighting factor) have to be determined in association with the problem owner. Therefore, the problem owner should be interviewed. Although the exact criterions should be determined by the problem owner, two aspects that certainly have to be included in the decision criteria are the improvement and costs of each solution (considering the business case). After establishing the criteria, each solution should be ranked upon fulfilment to the criteria. The ranking should be based as much as possible on facts, such as measurements or information from literature. Alternatively, the ranking of a solution should be estimated by the researcher or by experts if there is no factual data present. Finally, after ranking all the countermeasures and weighting the criteria, the best solution for Fokker Aerostructures will eventually be found with the decision matrix.

4 Presetting process description

This chapter provides a detailed description of the current presetting process. Consequently, the research questions of section 3.4.1 are addressed in this chapter. To create a detailed description, information has been gathered by observing and interviewing the presetting operators. In order to enhance the understanding of the presetting process, the presetting operations are visualized with the aid of images while the sequence of actions are depicted with process maps.

It turned out that the presetting process can roughly be divided into two parts: the assembly process and the measure process. The remainder of this chapter describes both processes into more detail (sections 4.1 and 4.2).

4.1 Assembly process

The presetting department prepares collet chuck holders and shrink fit holders (figures 18 and 19). For this reason, there are two main assembly processes: the assembly process for shrink fit holders and the mounting process of collet chuck holders. In addition, for each assembly process, there are two starting possibilities: one can start with an empty tool holder or commence with full tool holder, meaning that the old cutting tool first needs to be removed. Thus, there are two starting processes for shrink fit holders and collet chuck holders. Hence, there are 4 different assembly processes in the presetting process.

Figure 18: Collet chuck holder.

Figure 19: Shrink fit holder.

Figure 20 shows a flowchart of the four assembly processes. An enlarged version of this flowchart can be found in appendix L. The assembly steps corresponding to shrink fit holders are indicated in red, yellow and green whereas the operations for collet chuck holders are demonstrated in dark blue, light blue and purple. Furthermore, the different starting possibilities of the assembly processes are demonstrated in red, yellow, light blue and dark blue. Even though the starting operations are slightly different, when one uses an empty or full tool holder, after a while the assembly steps are exactly the same. In other words, the two starting processes merge into one assembly process for each tool holder. The similar assembly operations are indicated in green and purple. It can be observed that the red and yellow processes merge into the green process whereas the light blue and dark blue processes merge into purple process (figure 20).

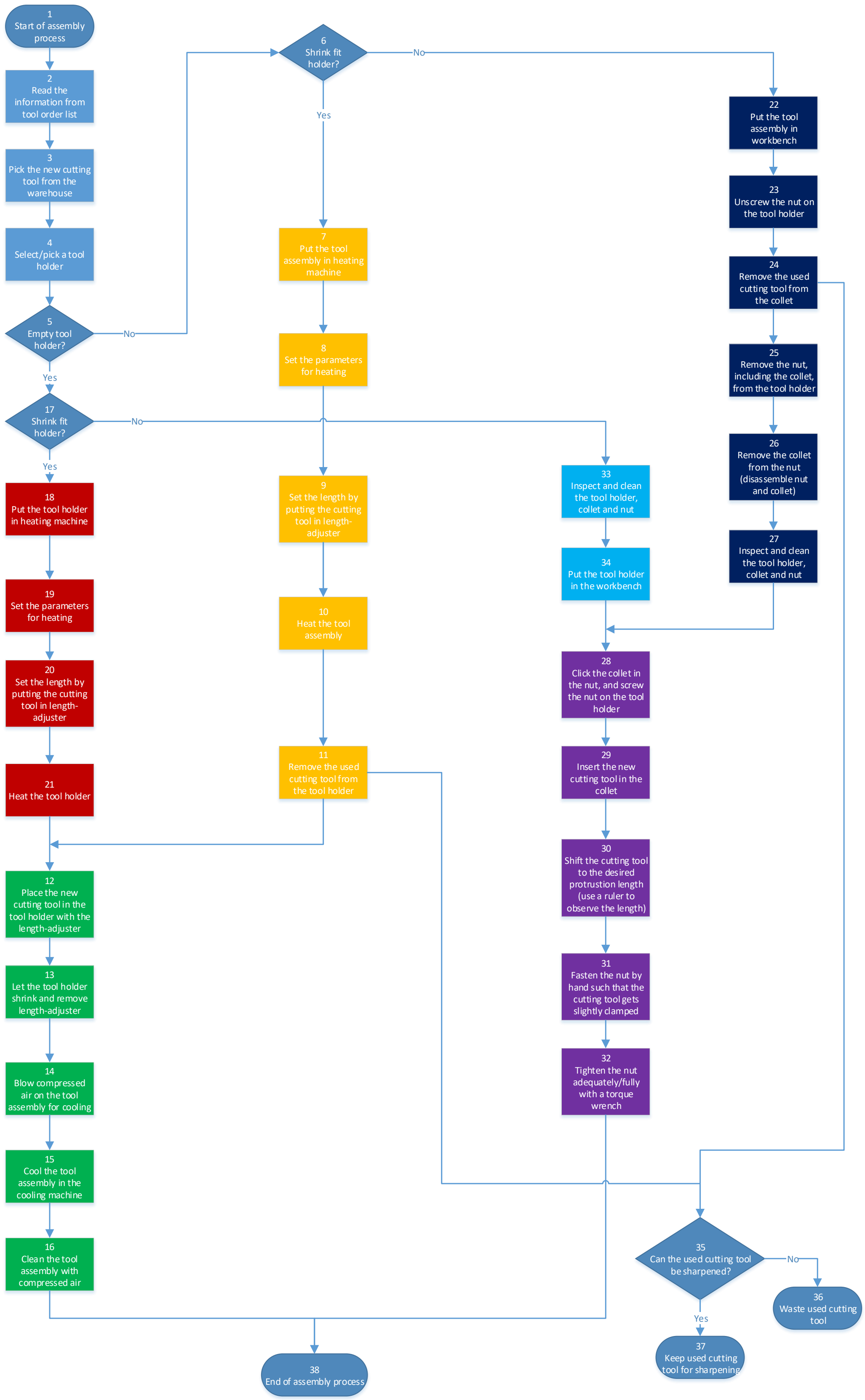

Figure 20: Flowchart of assembly process.

In the remainder of this section, the four assembly processes are further explained. In order to connect the described operations to the process map (figure 20), the steps in the flowchart have been numbered. The step numbers of the flowchart are indicated between brackets in the text.

The overall assembly process starts with the receipt of a tool order list (step 2). This list describes all needed tool assemblies at the machining department. At the order list, the characteristics of each tool assembly are described, including the type of cutting tool, tool holder and the desired presetting dimensions: L_{min}, L_{max}, D_{min}, D_{max} (as introduced in section 2.4). The presetting operator reads this information and subsequently picks the right cutting tool from the warehouse (step 3). The operator then searches for the right tool holder at the presetting department (step 4). Tool holders can be taken from a storage location, but they can also be found on a transportation car. Once the operator has the right tool holder (an empty or full tool holder) the operator starts mounting. From this point, the assembly process differs depending on the type of holder. In the following paragraphs the assembly processes for shrink fit holders and collet chuck holders are discussed in more detail.

Assembly process for shrink fit holders

In the situation of a shrink fit holder, the empty tool holder or used tool assembly (full tool holder) is first placed on a heating machine (figures 21 and 22, steps 7 and 18). The operator then sets the parameters for heating, because the heating time depends on the size of the shrink fit holder (steps 8 and 19). Thereafter, the worker puts the new cutting tool in a length-adjuster (figure 23). The length-adjuster is a special ruler, used to control the extension length of the cutting tool in the shrink holder. The operator sets the length-adjuster on the protrusion length that follows from the information on the tool order list (step 9 and 20). Subsequently, the presetting operator heats the empty tool holder or used tool assembly with the heating machine such that the tool holder expands (figure 24, steps 10 and 21). The new cutting tool is then placed in the tool holder with the aid of the length-adjuster (figure 26, step 12). In case of a full tool holder, the used (old) cutting tool is first removed from the holder (figure 25), before the new cutting tool is placed with the length-adjuster (step 11).

Figure 21: Heating machine.

Figure 22: Tool assembly placed on heating machine

Figure 23: Length-adjuster.

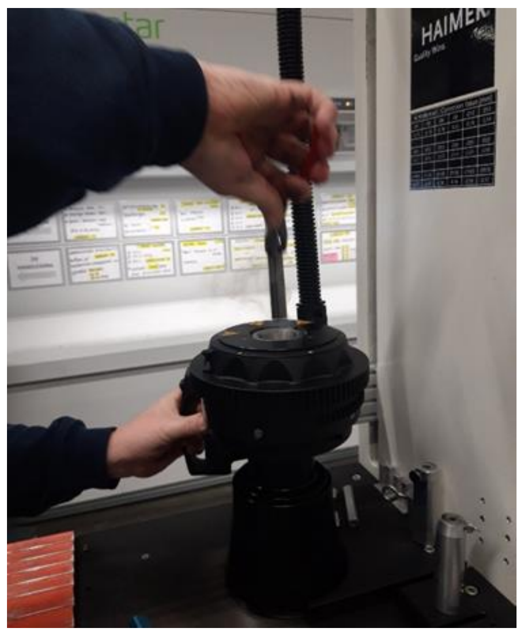

Figure 24: Heating of shrink fit holder.

Figure 25: Removal of used cutting tool.

Once the new cutting tool is placed in the holder, the operator keeps the tool on its place until the holder shrinks sufficiently (due to cooling) and the cutting tool gets clamped. The length-adjuster is then removed from the tool assembly (figure 27, step 13). Subsequently, the operator blows compressed air on the tool assembly for further cooling (step 14). Thereafter, the tool assembly is removed from the heating machine and thoroughly cooled in a cooling machine (step 15). In this machine the tool assembly is cooled down with coolant (figure 28). After cooling, the operator cleans the tool assembly with compressed air (figure 29, step 16). The tool assembly is then finished, and send to the measure process.

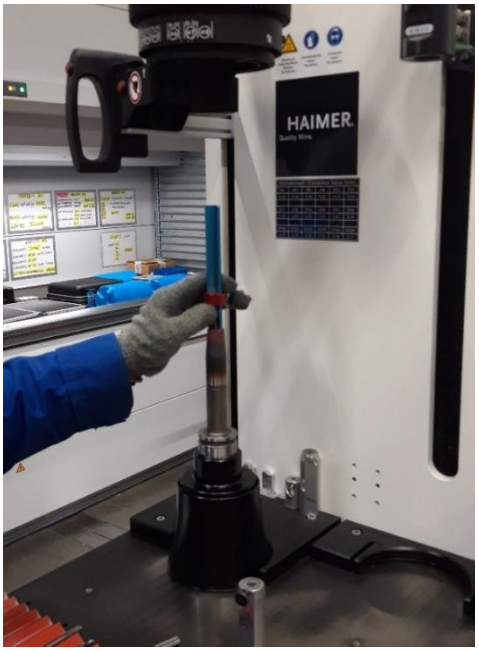

Figure 26: Placement of new cutting tool.

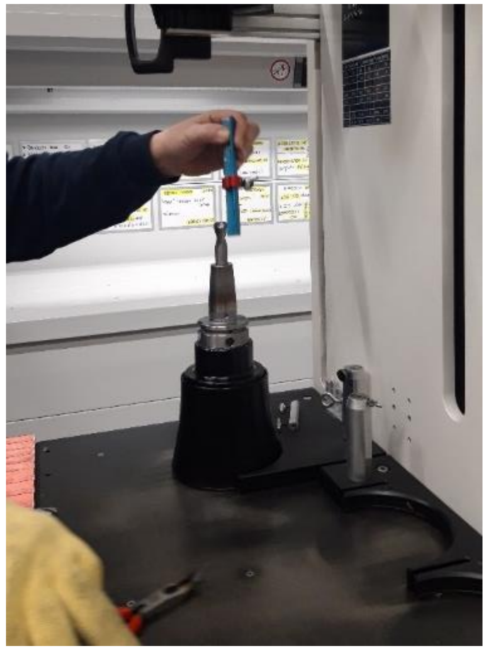

Figure 27: Removal of length-adjuster.

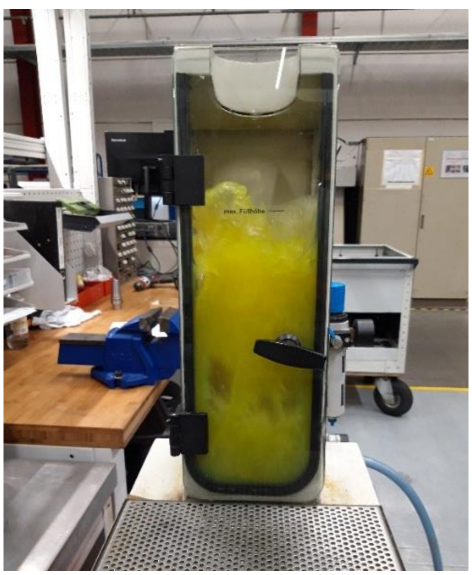

Figure 28: Cooling of tool assembly.

Figure 29: Cleaning of tool assembly.

Assembly process for collet chuck holders

In the situation of a collet chuck holder, a used tool assembly (full tool holder) is first put in a workbench (step 22). The operator then unscrews the nut on the tool holder and removes the used cutting tool from the collet (steps 23 and 24). The clamping nut (including the collet) is then removed from the tool holder and subsequently the collet is released from the nut (figures 30 and 31, steps 25 and 26). Thereafter, the operator inspects the tool holder, collet chuck and clamping nut (step 27). If necessary, the tool holder and/or its components are cleaned with compressed air or a polishing cloth. The collet chuck is then clicked in the nut and clamping nut is screwed on the tool holder (figure 32, step 28). Subsequently, the new cutting tool is inserted in the collet (figure 33, step 29). The operator then measures the extension length of the cutting tool, by holding a ruler next to it (figure 34). The worker subsequently shifts the cutting tool to the desired protrusion length and fastens the nut by hand, such that the cutting tool gets clamped (figure 35, steps 30 and 31). Thereafter, the clamping nut is further tightened to ensure that the cutting tool is fastened appropriately (step 32). This is achieved by using a wrench or special torque wrench (figure 36). Lastly, the tool assembly is removed from the workbench. The completed tool assembly is then send to the measure process.

For an empty tool holder, the initial steps are slightly different: the operator then first inspects and cleans (if necessary) the tool holder, collet chuck and nut before the tool holder is put in the workbench (steps 33 and 34). From the point that the tool holder is placed in the workbench and all components are ready for mounting, the remaining assembly steps are the same (the purple steps in figure 20).

Figure 30: Tool holder in placed in workbench.

Figure 31: Cutting tool, collet and clamping nut.

Figure 32: Nut (with collet) screwed on tool holder.

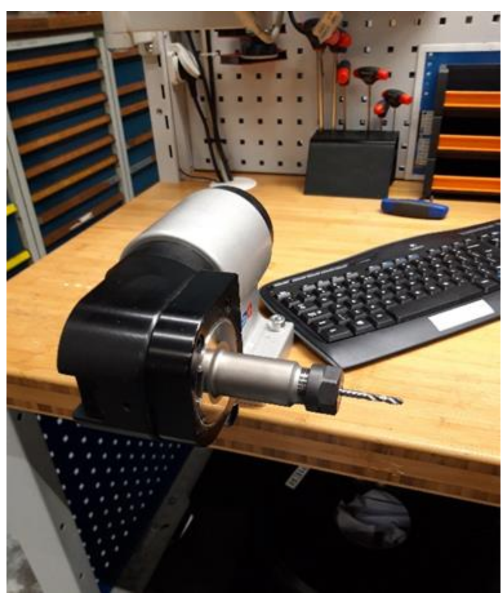

Figure 33: Cutting tool inserted in collet (holder).

Figure 34: Observing the length with ruler.

Figure 35: Fastening of the clamping nut by hand.

Figure 36: Full tightening of nut with torque wrench.

If the presetting operator picked a used tool assembly to obtain a tool holder (regardless the type of holder), he has to sort the used cutting tool after completing the new tool assembly (step 35). Used cutting tools are thrown away or sharpened at an external party. The cutting tools that have to be sharpened are collected in a special bin at the presetting department whereas the rest of the tools are put in a trash can (steps 36 and 37).

4.2 Measure process

Once the tool assembly is completed, the measure process commences. In contrast to the assembly process, the measure process is the same for all tool assemblies. Figure 37 shows a flowchart of the current measure process. An enlarged version of this flowchart can be found in appendix M. The green process steps on the left side demonstrate the performed actions when the tool assembly is conforming specifications at the first measuring attempt (i.e. the ideal scenario). The other process steps (indicated in yellow, red, grey, orange, purple, light blue, dark blue and dark green) illustrate the executed operations if a tool assembly is not immediately meeting the TDM tolerances.

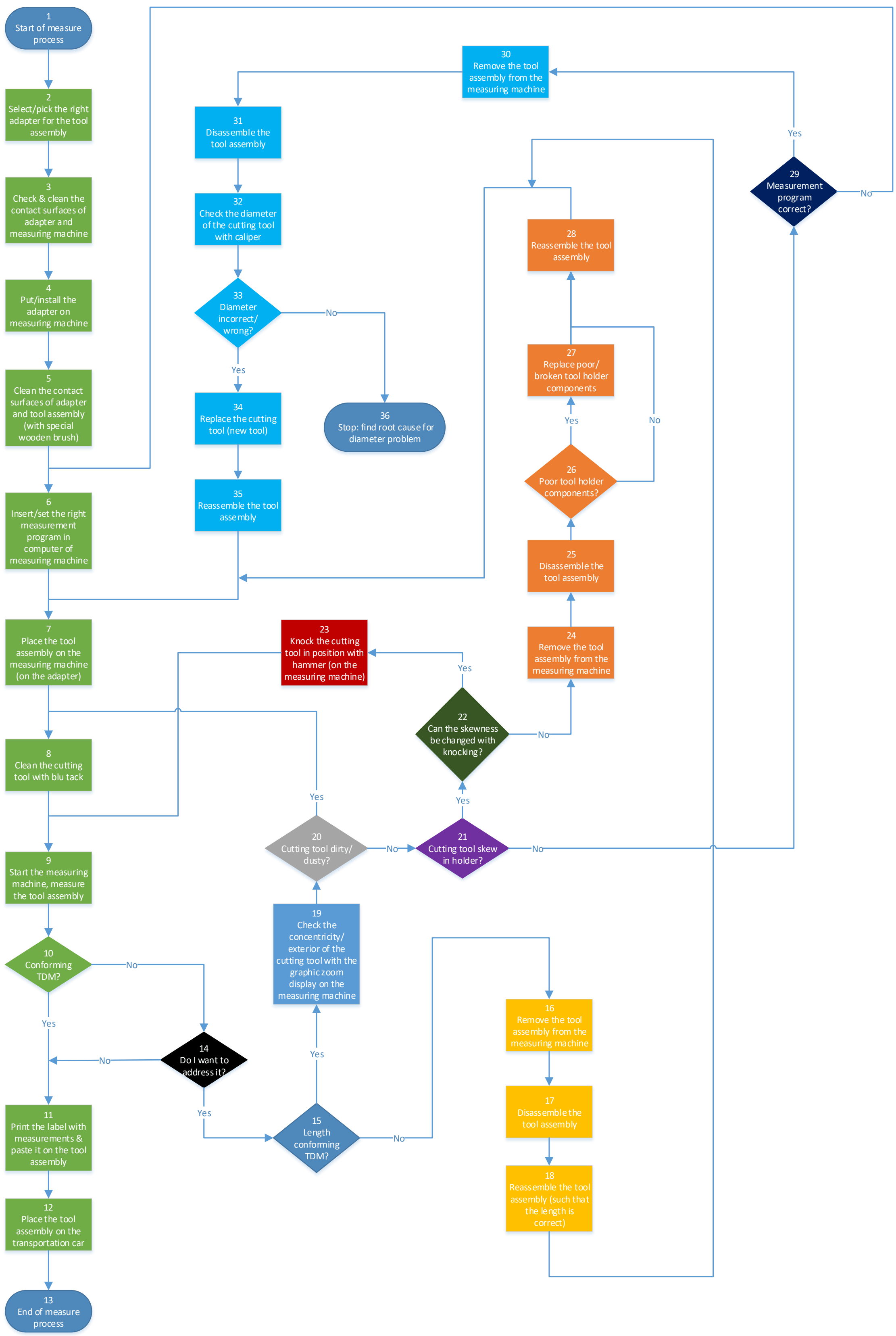

Figure 37: Flowchart of measure process.

The orange process steps demonstrate the reassembly procedure if a cutting tool is standing skew in the tool holder whereas the yellow sub process illustrates the actions in case of an incorrect length. The steps in light blue show the procedure if the wrong cutting tool is assembled. The red illustrated process step corresponds to knocking on the tool assembly. In the remainder of this section, the operations in the measure process are further explained. Similar to the process map of the assembly process (figure 20), the steps in this flowchart have also been numbered. The step numbers of the flowchart are indicated in the text.

The measure process starts by selecting a measuring machine, since there are two identical measuring machines at the presetting department (figure 38). After choosing a measuring machine, the operator picks the right adapter for putting the tool assembly on the base of the measuring machine (step 2). Subsequently, the worker checks and cleans the contact surfaces of the adapter and measuring machine, before he installs the adapter (step 3). The bottom of the adapter and the surface of the base are cleaned with a cloth. Once the adapter is installed at the measuring machine (figure 39, step 4), the operator cleans the contact surfaces of the adapter and the tool holder (step 5). The top of the adapter is cleaned with a customized wooden sweeper/brush (figure 40) whereas the bottom of the tool holder is cleaned with compressed air and a cloth. Subsequently, the operator selects the correct measurement program on the computer of the measuring machine (step 6). Thereafter, the operator places the tool assembly on the measuring machine and cleans the cutting tool with blu tack, to remove small dust particles from tool tip (figure 41, steps 7 and 8). The operator then starts the measuring machine, and the tool assembly is automatically measured (according to the chosen measuring program) (figure 42, step 9). Subsequently, the computer of the measuring machine automatically compares the obtained measurements with the tolerances of the TDM database (step 10). If the length and diameter are meeting the tolerances, the measuring machine approves the assembly and prints a label of the measurements. The operator then pastes this label on the tool assembly (step 11). Lastly, the operator removes the tool assembly from the measuring machine and places the assembly on the transportation car (step 12).

Figure 38: Laser-based measuring machine.

Figure 39: Adapter on machine.

Figure 40: Cleaning of adapter.

Figure 41: Cleaning of cutting tool.

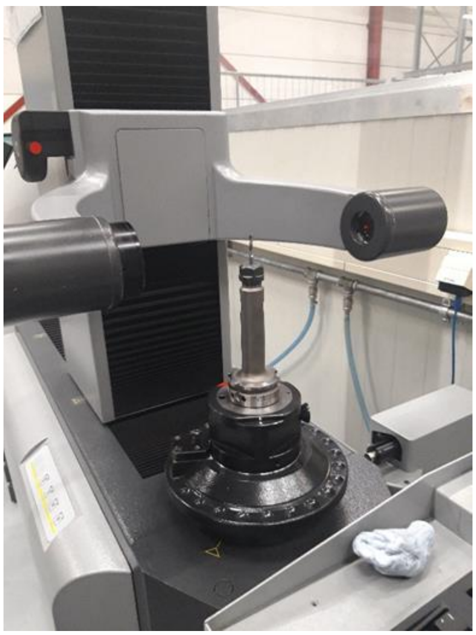

Figure 42: Measurement of tool assembly (laser).

The abovementioned story (steps 1 to 13) summarizes the measure process for the ideal scenario, when the tool assembly meets the tolerances at the first measurement. However, in practice, the measurements are often not meeting the tolerances at the first attempt, due to various reasons. In such a situation, the conducted operations are as follows:

In case of non-conforming measurement, the operator first checks whether the length or diameter is not meeting the tolerances (step 15). If the length of the tool assembly is incorrect, the operator checks the tool assembly. There are two scenarios for an incorrect length: A wrong tool holder has been assembled or the cutting tool is sticking out too much or less, in order words, the protrusion length is not correct. The operator then removes the tool assembly from the measuring machine, and reassembles the tool assembly such that the length is correct (steps 16, 17 and 18). The tool assembly is then put back on the measuring machine and measured again (i.e. continuation at step 7).

If the length is correct and the diameter not, the worker first checks whether the cutting tool is dirty (step 20). This is done with the aid of the graphical zoom display on the measuring machine (figure 43). This display shows an enlarged silhouette of the cutting tool's shape. The operator rotates the tool assembly by hand (the base of the measuring machine can rotate), and looks at the graphical zoom display to check whether there are dust particles present on the cutting tool. If there are dust particles present, the operator cleans the cutting tool with blu tack and measures the tool assembly again (i.e. continuation at step 8). If there are no dust particles present, the worker checks whether the cutting tool is standing skew in the tool holder (step 21). The same procedure as for determining dust particles can be used to observe the skewness. If the cutting tool is standing skew in the tool holder, the operator evaluates whether the skewness can be mitigated by knocking on the tool assembly (step 22). If the worker believes that knocking might help to decrease the skewness, he takes a hammer, and knocks the cutting tool in position (figure 44, step 23). By iteratively tapping on the side of the cutting tool, and looking on the graphical zoom display, the worker manually mitigates the skewness of the cutting tool in the tool holder. Thus, the operator is knocking on the tool assembly, when it is still positioned on the measuring machine. After knocking, the operator starts the measuring machine, and the assembly is measured again (i.e. continuation at step 9). This knocking procedure can be executed multiple times, until the tool assembly is conforming TDM or the operator believes that knocking does not help. If the operator believes that knocking makes no sense, he removes the tool assembly from the measuring machine (step 24). Subsequently, the tool assembly is disassembled and the worker checks the tool holder and its components (steps 25 and 26), if they are present (nut and collet). If some components are broken or in a bad condition, they are replaced (step 27). Otherwise, the same components are retained. The operator then reassembles the tool assembly (step 28). Eventually, the tool assembly is placed back on the machine, and measured again (i.e. continuation at step 7).

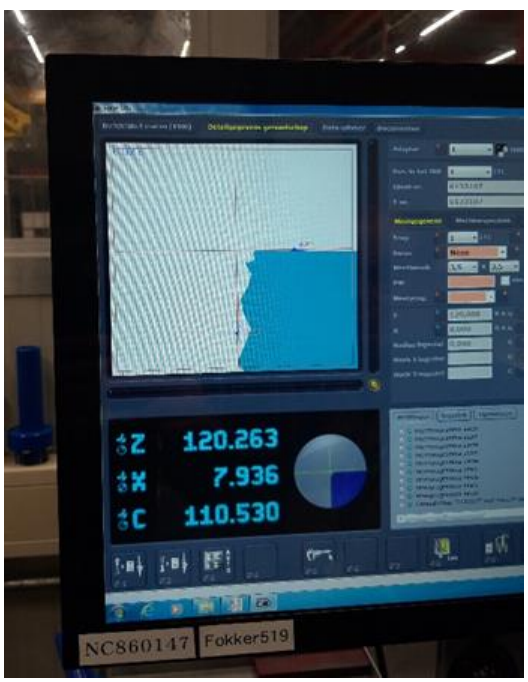

Figure 43: Graphical zoom display.

Figure 44: Knocking on the tool assembly.

If the cutting tool is not standing skew, the operator checks whether the correct measuring program is used for the measurement (step 29). If the wrong measuring program is installed, the operator corrects the program (i.e. repetition of step 6). If the program is correct, the tool assembly is removed from the measuring machine and disassembled (steps 30 and 31). The worker then checks the diameter of the cutting tool with a caliper (step 32). If the diameter of the cutting tool is wrong, the cutting tool is replaced (steps 33 and 34). Thereafter, the operator reassembles the tool assembly and measures the assembly again (step 35, and continuation at step 7). If the diameter of cutting tool is correct, the root cause of the non-conforming diameter is not immediately clear. The tool assembly is then put apart for further investigation, to find the root cause of the diameter problem (step 36).

Eventually, a critical factor in the current measure process is the manual approval option of the measuring machine. If the worker does not want to address (investigate or change) the non-conformance of a tool assembly, he can decide to manually approve the tool assembly, by pressing on an “OK”-button on the screen of the measuring machine (step 14). In other words, the operator can ignore the automatic disapproval of the measuring machine, and instead approve the assembly manually, when the assembly is not according TDM. Therefore, non-conforming tool assemblies can be released for machining.

5 Performance system analysis

This chapter presents the results of the performance system analysis. After describing the current presetting process (chapter 4), it became clear that beyond knocking, reassembling and ignoring the tolerances, another undesirable activity in the presetting process is the avoidance of the torque wrench. It turned out that some operators use the torque wrench to tighten the nut of a collet chuck holder whereas other operators rather use a normal wrench to fasten the nut. Since the operators are expected to always use the torque wrench, this behavior is also studied in the performance system analysis.

The information for the performance system analysis has been gathered by interviewing four presetting operators, the TDM tool administrator and the coordinator (executive manager) of the presetting department. In fact, semi-structured interviews were conducted, incorporating the analytic questions of Kepner and Tregoe (of section 3.4.2). The complete set of interviews can be found in appendix D. In addition, information has been gathered by observing the actions of the five presetting operators and the executive manager. On the other hand, measurements were integrated in the performance system analysis. Information from measurements was utilized to check/support the data from interviews. Insights from the data log file (section 2.2) were taken into account. Furthermore, 40 new measurements were conducted to better quantify the problems in the presetting process itself. Within this new set of measurements, the distinction between collet chuck holders and shrink fit holders was made. The researcher measured the time needed to prepare 20 collet chuck holders and 20 shrink fit holders, by observing two different presetting operators. A table of the measurement data can be found in appendix E. Based on this set of measurements the proportion of tool assemblies needing rework/additional activities was calculated. Furthermore, a better representation of the time lost in the presetting process was obtained (compared to the first calculation in section 2.2).

This remainder of this chapter is structured as follows: in the first part, the factors causing the lack of performance are identified with the performance system framework (section 5.1 to 5.5). This is done by addressing the diagnostic questions of Kepner and Tregoe per element of the performance system. As a result, the research questions of section 3.4.2 are addressed in the first five sections. In the last section of this chapter, the key findings of the performance system analysis are summarized, whereas the suggested actions by the literature are developed into applicable countermeasures for the presetting process of Fokker Aerostructures. Thus, the research questions of section 3.4.3 are addressed in section 5.6 of this chapter.

5.1 Response

What is the observed performance?

The observed performance is that operators do additional activities or rework to obtain a good tool assembly, and the releasing requirements are ignored. As a result, the current output of the presetting department is limited to 12 tool assemblies per hour whereas 44% of the tool assemblies are not conforming TDM (section 2.6).

The observed behavior is that operators knock on the tool assembly, ignore the TDM tolerances and do not always use the torque wrench. Furthermore, operators do rework such as reassembling and measuring again, although this is desired behavior, this response occurs too often, Fokker wants to have a presetting process wherein steps rarely have to be repeated. Knocking on tool assemblies is done by all the operators at the presetting department. Releasing unauthorized tool assemblies is also done by all presetting employees, although every operator has his own interpretation of when he should send them to machining. Half of the operators always use the torque wrench, the remainder of operators do not always use the wrench.

It was found that that additional activities, rework and ignoring the requirements mainly occur during the preparation of collet chuck holders. One operator explained that about 40% of the tool assemblies made with collet chuck holders are meeting the tolerances of TDM at the first measuring attempt. For tool assemblies made with shrink fit holders, approximately 95% of the tool assemblies are meeting the tolerances of TDM at the first time. The sample of measurements also confirmed that collet chuck holders are most problematic: It was found that 35% of the collet chuck holders were meeting the requirements at the first attempt whereas 85% of the shrink fit holders were satisfying the tolerances after one measurement. Besides, it was discovered that most of the time is wasted during the preparation of collet chuck holders. The average wasted time during preparation of a collet chuck holder amounts 2:40 minutes while the mean rework time of a shrink fit holder amounts 0:14 minutes. It furthermore turns out that almost always a non-conforming diameter hinders the tool assembly in meeting the TDM tolerances. By investigating the log file (section 2.2), it was discovered that 99.4% of the non-conforming tool assemblies had an unsatisfactory diameter. On the contrary, non-conforming lengths rarely occur (0.6%).

If the tool assembly's diameter is not conforming the TDM tolerances, it depends on the situation and the opinion of the operator how he addresses the problem. The options are knocking, reassembling (replacing or cleaning components) or ignoring the tolerances (assuming that the cutting tool is not dirty and that the right cutting tool is assembled). Sometimes the operator knocks multiple times on the assembly, sometimes knocking is followed by the reassembly of a tool assembly and another time the tool assembly is immediately reassembled or send to machining right away (by ignoring the tolerances). All operators were asked how often each scenario occurs in the situation of non-conforming measurement, but they could not (or did not want to) classify how many times every scenario occurs. Nevertheless, it is clear that knocking is exclusively done on collet chuck holders. From the data of the log file, it was found that 44% of the tool assemblies were released, even though they were not meeting the TDM requirements.

Moreover, the view on ignoring the TDM tolerances depends on the individual operator. One operator does a lot of effort to obtain a good tool assembly (reassembling, knocking, and measuring multiple times), while another worker releases the tool assembly after one non-conforming measurement. Furthermore, the operators explained that when they ignore TDM tolerances they take the application/use of a certain tool assembly into account to evaluate if a deviation (from the TDM tolerances) is acceptable/problematic or not. In other words, based on their own interpretation/belief of what accuracy is required at production (machining) for a certain tool assembly, they judge the measurement values and ignore the tolerances if they think it is acceptable. Some operators worked at machining in the past, as a result, they believe to know what accuracy is required for a certain cutting tool/tool assembly. However, not all presetting operators have experience at production and although they claim to know the exact destination of each tool assembly, they practically cannot know all the cutting operations in which a tool assembly is used, because tool assemblies are used for multiple products and in many different cutting procedures. In addition, there are approximately 500 different tool assemblies at the moment.

The impact of the undesired behavior on the organization is as follows: Due to knocking and reassembling, time is wasted in the presetting process (resulting in higher costs). The knocking on the tool assembly is done when it is still positioned on the measuring machine, therefore, this can damage the measuring machine. In fact, one operator believes that the measuring machine became less accurate over time, as a result of knocking. Additional repair costs contribute to higher operational costs. If the measuring machine becomes less accurate due to damage from knocking, this implies that the tool assemblies may not be correctly checked/assessed anymore. Moreover, knocking on the tool assembly can also lead to cutting tool breakage, which in fact results in higher operational costs for the presetting department.

The impact of ignoring the tolerances of TDM is that the dimensions of new tool assemblies flowing into machining process are not controlled. When the TDM tolerances are not handled, but operators decide by themselves whether the tool assembly is sufficiently accurate for production or not, the variation of tool assemblies used at machining depends on personal opinions rather than facts. As a result, the inflow variation is unpredictable, increasing the risk of tooling problems during machining, such as swaying cutting tools or tool breakage.

When the torque wrench is not used, two undesirable events can occur when the collet chuck is tightened only manually: If the nut is tightened too weakly, the cutting tool is not clamped sufficiently and therefore may sway during machining or even let loose. This can damage products during machining. If the nut is tightened too strongly, the collet chuck deforms or even breaks. When the collet breaks or deforms, the cutting tool is not clamped sufficiently and might also sway or let loose during machining. Broken or deformed collet chucks have to be replaced (leading to higher operational costs). Oftentimes, the operator does not notice that he deforms the collet, as a result, deformed collet chucks are not thrown away but are instead kept in stock. Thus, the condition of the collet chucks at the presetting department degrades over time.

How does it compare with expectations?

The desired response is releasing the tool assemblies according to the TDM tolerances (without knocking), and using the torque wrench (from the problem owner's point of view). In addition, rework is undesired i.e. the occurrence of rework should be as low as possible.

However, the performance expectations are currently not clearly defined. It is not established that the operator has to deliver the tool assemblies conforming to TDM. There is nothing stated about the amount of rework and it is not defined that the torque wrench should be used. The next paragraph addresses the current performance expectations in more detail.

5.2 Situation

How clear are the performance expectations and how well are they understood?

The TDM database specifies the components and presetting dimensions (tolerances) of each tool assembly. However, there is no work instruction or detailed document that describes all the necessary actions/steps for a good presetting process. In other words, it is defined what should be delivered, but not how it should be achieved. Thus, the expectations for the presetting process are not well described, because the expected actions for the presetting process are undefined. Besides, the expected output/end results of the presetting process are partly described. TDM defines what tool assembly should be delivered (which components and dimensions), however, it is not clearly/officially described that the operator is expected to deliver the tool assemblies always conforming the tolerances of TDM. It is not defined how many tool assemblies an operator should make within a certain time. Furthermore, it is not described what the operator should do in case of a non-conforming tool assembly. Besides, it is not stated that knocking is not allowed and that the operator should use the torque wrench. To put briefly, because the expected behavior is not defined, the current undesirable behavior (knocking, ignoring TDM tolerances and not using the torque wrench) is not officially forbidden (on paper).

The technical engineers of composite machining (working for the problem owner) expect the presetting department to deliver the tools based on the tolerances of TDM. The engineers usually have contact with the coordinator, and because the coordinator manages the presetting department, he is supposed to explain these expectations to his operators on the floor. Furthermore, it is presumed that the tool coordinator communicates the right expectations for the actions in the presetting process such that the desired output (conforming tool assemblies) can be achieved. Nevertheless, it turns out that the performance expectations are not well explained to the workers on the floor.

The operators said to know that they are expected to deliver tool assemblies conforming TDM, because the coordinator explained this to them. The coordinator said that he explained to his operators to use the torque wrench and that they have to deliver tool assemblies conforming TDM. Furthermore, the operators understand that they are expected to deliver all ordered tool assemblies before midnight. The coordinator explained to the operators that they are expected to complete all order lists on the same day. Except from that, the performance expectations have not been explained to the operators. The operators answered that the expectations about how they should assemble and measure a tool assembly are not explained to them. In other words, it is not explained what actions/behaviors are expected for presetting. To conclude, expectations are not well explained to the operators.

How does the Performer view these expectations? Are they considered attainable?

The operators find the requirements for releasing tool assemblies, the TDM tolerances not realistic. The operators replied that especially the tolerances for assemblies including a collet chuck holder are not attainable, because the diameter tolerances are set too tight. For shrink fit holders, the requirements can often be met, thus these tolerances are considered attainable. In general, the diameter tolerances cannot be satisfied for tool assemblies. The operators claimed that the current tolerances for collet chuck holders become more attainable, when they have good materials (tool holders) at hand. On the other hand, the expectation of using the torque wrench for all collet chuck holders is considered as attainable. The operators view the expectations of completing the ordered tool assemblies before the end of the day attainable.

The claim of the unrealistic diameter tolerances for collet chuck holders has also been validated technically. It turned out that the current diameter tolerances in TDM are technically unattainable, because the theoretical best diameter accuracy (runout) for the tool assembly according to supplier specifications already exceeds the current TDM diameter tolerances. Bearing in mind that the specified accuracy of a collet chuck holder by the supplier applies to a situation wherein the cutting tool is shortly sticking out of the holder and remembering that cutting tools are extended longer in practice, it can be concluded that this specified tool holding accuracy hardly can be achieved in reality. Hence, the diameter tolerances for collet chuck holders are technically unattainable while the operators also find them unrealistic.

How clear is the signal to perform?

An incoming tool order list indicates the need to act (preparing tool assemblies). The tool order lists are composed by the operators of the machining department. The signal is clear and consistent, because the tool order list precisely specifies what tool assembly is needed (cutting tool and holder), including the desired presetting requirements (length and diameter). The signal is also timely: the order lists are received before 1 PM whereas the tool assemblies have to be finished/ready before 11 PM on the same day. Thus, the presetting department has 10 hours to prepare all tool assemblies, after the signal to perform.

How well does the work environment support expected performance?

The coordinator explained that the presetting department has sufficient time and people to fulfill the presetting process for composite machining. The work environment is provided with high quality presetting machinery and equipment. All operators agreed that they have the best machines and equipment at hand for presetting. Hence, the machines and equipment are appropriate for the task of presetting.

However, there are some issues concerning the tool holders: sometimes the presetting operator cannot prepare/deliver the desired tool assembly because the right tool holder is not available (in stock) at the presetting department. In other words, there sometimes is a shortage of tool holders (or tool holder components). Moreover, the tool holders are not always sufficient for the task (achieving the TDM tolerances). With good shrink holders the expectations (releasing tolerances) can easily be attained. However, with good collet chuck holders the desired measurements still cannot always be achieved, because a collet chuck holder is physically/technically not suitable to obtain a very accurate tool assembly, as required by TDM. In other words, the current TDM tolerances are not matching the physical capability of a collet chuck holder. To put differently, collet chuck holders are not capable to always meet the current TDM tolerances.

Furthermore, the state of the collet chucks is not great. According to the operators 70% of all collet chucks are old (worn out) and therefore insufficient for achieving the requirements. One of the operators said that these old collet chucks are not accurate and should not be used anymore. However, these collet chucks are still used in practice because there are not enough new and good collets available at the presetting department. In other words, there is a shortage of good collet chucks. All operators replied that they rather use new collet chucks if these are available at the presetting department, but it often happens they are forced to use old/worn out collets because all good/new collets are already sent to production. It was claimed that the tolerances of TDM can hardly be met with old and worn out collets. The operators revealed that knocking is done more on old collet chucks than on new collet chucks.

One operator claimed that the high proportion of poor collets emerged from inadequate tightening of collet chuck holders in the past. Before the torque wrench was introduced (one year ago) the clamping nut was just manually tightened, enabling too strong tightening (and thus deformation of collets). Furthermore, the torque wrench is still not always used, hence, collet chucks are still deformed nowadays. Another mentioned cause is that operators sometimes use the wrong collet chuck for a tool assembly, because the right collet is out of stock. For instance, a cutting tool of 4.1 mm should be placed in a collet chuck of 4.5 mm, however, in case this collet is not available, the operator can alternatively pick a collet chuck of 4.0 mm and push the cutting tool in this collet, even though he knows this is not good because the collet gets deformed/damaged. It was suggested that the current discipline regarding cleaning also contributes to the poor condition of collet chucks. It was observed that the collet chucks are not always cleaned by the presetting operators before making a new tool assembly. It is well known that cleaning leads to better presetting results, however, it is also a crucial step to keep collet chucks in a good condition, since deposits at the slots and inside of the collet become difficult to remove after skipping the cleaning a couple of times. In addition, it was observed that poor collets are not actively replaced at the moment. In particular, operators are not stimulated to throw collet chucks quickly away. Therefore, old collet chucks remain at the presetting department.

Moreover, the operators said that there also exist a shortage in good tightening nuts for collet chuck holders. There are currently two type of nuts in circulation: a new type and old type of clamping nut. The operators explained that the new type (design) of tightening nut clamps the collet chuck better than the old type, resulting in a better (more accurate) tool assembly. Currently, 50% of the nuts in circulation are new nuts (according to the operators). All operators said they prefer to use the new type of nut, however, the new nuts are sometimes out of stock. Consequently, old nuts are also used.

The state of shrink fit holders is much better. There are generally no problems with shrink holders based on the state of the tool holders. Shrink fit holders are sooner replaced than collet chuck holders when they are not accurate anymore. The operators apply a rule of thumb that after heating the tool holder three times the shrink fit holder should be thrown away. However, it sporadically happens that a shrink holder is heated too often, but is not replaced and kept for use. Besides, the operators explained that the workplace is dirty/dusty because used tool assemblies are currently cleaned at the presetting department, since the machining department sends them back dirty. Used tool assemblies are cleaned with a polishing cloth and/or with air. After blowing with compressed air, composite powder/dust whirls around, polluting the machinery and equipment at the presetting department. This is unfavorable for a good presetting process, because the workplace should be clean to obtain the best presetting results. The measuring machine (including the contact surfaces of the adapter and tool holder) should be clean to measure correctly.

5.3 Performer

How capable is the Performer to meet performance expectations?

The prerequisite knowledge and skills for presetting are not specified. It is not established/documented what knowledge and skills are required for job success. Therefore, it cannot factually be assessed if a new or current operator is capable to meet the performance expectations. Consequently, there are no starting/entrance requirements regarding skills and knowledge for a new presetting operator. In other words, a new presetting operator is not trained before he starts working at the presetting department, so he has to learn on the job. The content of training on the job is not specified.

According to the coordinator, every operator at the presetting department is suited to the job, but this claim is not based on the assessment of prescribed competences/criteria for a presetting operator. The coordinator evaluates the operators based on their experience. All operators have multiple years of experience at the presetting department. In addition, all operators have knowledge about the measuring machine as well as the assembly and measure process. Based on this it is assumed that the operators have the required knowledge and skills for presetting.

5.4 Consequences

How well do the Consequences encourage expected Performance?

When the operator delivers every tool assembly conforming TDM (expected performance), without knocking on the tool assembly, the consequence for him is that he loses a lot of time (because he has to reassemble and replace the tool assembly various times), while there is still a possibility that he ultimately cannot deliver the tool assembly according to the requirements (since it is difficult to achieve the requirements). These are negative consequences for the presetting operator. When the operator loses much time on getting it right he cannot complete all ordered tool assemblies before the end of the day. The coordinator then complains that he has not delivered the tool assemblies on time (the expectation is that all assemblies are completed by the end of the day). The same applies to choosing not to deliver a tool assembly because it is not conforming TDM, the machining department (the manager of machining) then complains they need the tool assembly for production. All operators replied that they have to deliver the tool assemblies anyway (regardless the condition) because production is otherwise stopped. A positive consequence of sticking to TDM is that the operator cannot be seen as responsible for problems in production, because he has released it according to the requirements. However, the operator is not rewarded for delivering the tool assemblies conforming TDM. For some reason, there is no positive reaction from composite machining (or production management) that encourages the operator to work conforming to the TDM tolerances. The positive consequence of using the torque wrench is that the cutting tool is appropriately clamped and that the operator knows that he does not deform or damage the collet/nut. The negative consequence is that the operator has to perform an extra activity that costs him some more time. Sometimes the operator has to wait on a colleague, before the torque wrench is available, so this extra costs time.

On the contrary, a positive consequence of knocking on the tool assembly is that the operator can save time and thus work faster (prepare assemblies more per hour) while the tool assembly meets the TDM requirements (if knocking helps). In addition, the operator does not have to reassemble the tool assembly, which is also an annoying task for him. Furthermore, the operator can deliver all tool assemblies before end of the day such that the coordinator is satisfied, thus this is positive consequence for him. The tool assemblies are meeting the tolerances, so he has met the requirements for production (TDM). There are currently no negative consequences related to knocking because this does not lead to negative feedback from production. All operators replied that they have never heard anything from production about problems caused by knocking.

For ignoring the tolerances, the consequences are very similar to knocking: the positive consequence is that the operator can save time, work faster, and thus finish his work (the ordered assemblies) before the end of the day. There are no negative consequences because the operator is not punished for ignoring the tolerances. Furthermore, this behavior does not lead to more complains from production, so the operator is not discouraged about this. All operators replied that they have never had any complaints from production about releasing tool assemblies not meeting the tolerances of TDM.

The positive consequence of not using the torque wrench is that time can be saved. The negative consequence of not using the torque wrench is that the tool assembly might not be adequately clamped and causes damage to the product at production (machining). In the past, there have been complaints from machining that the tool assemblies caused defect products because they were not tightened appropriately. However, there have been only a few incidents, so the operators do not often get complaints from production if they do not use the torque wrench.

In conclusion, the consequences for desired (expected) performance are not supportive, the current consequences provoke alternative behavior more than the desired behavior. Since the negative consequences outweigh the positive consequences for the desired performance, the operators are discouraged to stick to TDM without knocking. Because of multiple positive consequences, the operators are encouraged to knock on the tool assembly or ignore the TDM tolerances. For the use of the torque wrench the consequences are more or less supportive, however, the operators are still sometimes not using it.

5.5 Feedback

How appropriate is the Feedback and how well is it used to influence performance?

By measuring the tool assembly after assembling, the presetting operators receive feedback about the physical assembly. The length and diameter are precisely measured; the machine provides measuring values with an accuracy of a thousandth of a millimeter. This information is used to influence performance, because operators sometimes (depending on the scenario) modify/change tool assemblies based on this data (e.g. reassembling and knocking).

Furthermore, the operators receive feedback about their working pace. The coordinator checks whether the order lists are completed before the end of the day. If the operators have not completed the order lists on time, he gives feedback to the operators. Nevertheless, there is no direct feedback provided to influence the behavior/actions of presetting operators. The operators are not actively coached to clean the tool holders, collets and nuts. No feedback is given about actively replacing tool holders (or components), if they are not sufficient anymore. The operators do not get feedback about using the right collet chuck for an assembly. The desired behavior of obeying the tolerances without knocking is not stimulated at the moment. The coordinator replied that he tells the operators to use the torque wrench. However, the operators do not always use the torque wrench, thus this feedback is not used (or not adopted by the operators). No feedback is given to prevent knocking or ignoring the TDM tolerances. Hence, there is currently no adequate feedback given to avoid the undesired behavior.

Moreover, the operators indirectly get feedback about their performance by complaints from production (machining). If there are defects at machining resulting from a tool assembly, an official NC (non-conformance) report is established and the coordinator is contacted about the issue/problem. The coordinator then investigates which presetting operator has prepared the concerned tool assembly (this data is administered) and discusses the defect/problem with the operator. The impact on production is explained to the operator and if it was the operators fault, he is held responsible. In other words, the operator receives feedback about his performance. NC's at production are also explained to the other operators in a periodical department meeting. At the moment, an annual performance appraisal is performed with each presetting operator. The performance of the operator is assessed based on the number of problems he caused at production, due to mistakes (NC's). In contrast, the operator is not judged based on his actions at the presetting department. The way of assembling (cleaning, using the torque wrench) or measuring (no knocking and obeying presetting tolerances) are not taken into account in the performance appraisal process.

To put briefly, the performance requirements are not completely covered by the current feedback. Feedback is provided about the working pace/delivery time and presetting mistakes, however, the presetting operators are not coached upon their behavior/actions. Nevertheless, for a good presetting process it is important that the operators are coached on their operations, because the executed actions at presetting highly affect the obtained presetting results.

5.6 Summary & proposed countermeasures

The performance system analysis identified deficiencies within all five performance components (response, situation, performer, consequences and feedback) of the current presetting process. In other words, each performance element regarding the presetting process provides room for improvement.

The current response (observed performance) is that operators do additional activities or rework to obtain a good tool assembly and the releasing requirements are ignored. As a result, the output of the presetting department is limited to 12 tool assemblies per hour whereas 44% of the tool assemblies are not conforming TDM. The observed behavior is that operators knock on the tool assembly, ignore the TDM tolerances and do not always use the torque wrench. It was found that operators encounter most difficulties during the preparation of collet chuck holders. It turned out that operators use their own interpretation to judge whether a tool assembly is acceptable for releasing. Moreover, each operator handles differently in the situation of a non-conforming tool assembly. The desired response (expected performance) is releasing the tool assemblies according to the TDM tolerances (without knocking), and using the torque wrench. In addition, rework is undesired i.e. the occurrence of rework should be as low as possible. This implies that the majority of tool assemblies should be conforming TDM at the first measuring attempt. According to the performance system theory, the response is affected by the other four performance components, thus, deficiencies within the other elements (situation, performer, consequences and feedback) are contributing to the current undesired response (performance).

The remainder of this section provides an overview of the observed performance deficiencies, the associated suggested actions by the literature and the translation of these countermeasures into the context of the presetting process (addressing the research questions of section 3.4.3):

- The performance expectations are not sufficiently clear because they are not well defined. The desired behavior for a good presetting process is not described. Furthermore, the desired output is partly specified (only the presetting dimensions are defined in TDM). In order to overcome this deficiency, literature advocates for process documentation or a standard work instruction [8]. Thus, the requirements for a good presetting process could be captured in a work instruction describing the desired behavior and end results (such as quantity and quality).

- A part of the established performance expectations is not attainable: the TDM diameter tolerances for collet chuck holders are unattainable, already from a technical point of view. Therefore, even the operator performs as desired, he still cannot always satisfy the performance expectations (TDM tolerances). Literature suggest that performance expectations should be consistent with the standard desired performance [6] [7]. Translated to the presetting process, this implies that the TDM diameter tolerances should be attainable in case of normal, good presetting performance. Briefly, the TDM diameter tolerances for collet chuck holders should be adjusted to match a correct presetting action/procedure.
- The work environment is not completely supportive because there are not sufficient resources available and not all resources are not appropriate for the task: sometimes there is a shortage in tool holders (and components). Furthermore, the state of collet chucks is not great. The majority of the collets are not sufficient for the task, because they are in a bad condition (deformed and worn out). In addition, half of the nuts are less supporting. According to the performance system literature, there should be sufficient and appropriate resources to support performance [6] [8]. Hence, with respect to the situation of the presetting department, the number of tool holders can be increased whereas poor collet chucks and nuts could be replaced to overcome this deficiency. An alternative solution for purchasing new collets and nuts might also be the complete replacement of collet chuck holders by a shrink fit holders.
- The work environment is not entirely supportive because the workplace is dirty due to current cleaning method for tool assemblies. Composite dust is currently deposited at the presetting department as a result of cleaning. The workplace should be clean to guarantee a good presetting process (the measuring machine should be clean). Literature suggest that factors impeding performance should be eliminated [6]. Thus, the current cleaning method should be modified to overcome this deficiency. This could be achieved by introducing an extraction system to suck composite dust away during cleaning, or by cleaning the tool assemblies at another location, outside the presetting department.
- The prerequisite knowledge and skills for the performer (presetting operator) are not specified. Although it is assumed that all operators are capable for the job (based on their long working experience), it factually cannot be assessed whether an operator is capable for the job. In addition, the entry requirements for a new operator are not defined. The literature proposes to establish a standardized education program (course) such that new operators are always trained in the same manner and that the necessary knowledge and skills for an operator are defined [7] [8]. Translated to the presetting case, a classroom training or on-the-job training program could be developed, addressing the assembly and measuring process.
- The existing consequences are not supporting the desired performance (releasing tool assemblies correctly, without knocking and using the torque wrench). Instead, the current consequences are provoking alternative behavior (knocking or ignoring tolerances). According to the literature, positive consequences should be added to the desired performance whereas negative consequences related to the desired behavior should be eliminated [6] [8]. In the situation of the presetting process, this could be done by rewarding presetting operators that

reassemble tool assemblies and obey the TDM tolerances, and accepting the longer preparation times instead of complaining about the working pace.

- The current feedback is not covering all performance requirements. At the moment, operators receive feedback about their working pace and about mistakes that led to problems at production. However, presetting operators are not coached on their daily operations, although this is important for the presetting performance. There is no adequate feedback provided to avoid undesired actions, to improve the current presetting performance. The literature suggests that feedback should be related to the desired output as well as to the actions/behavior to achieve this desired output. Furthermore, the feedback should include the consequences to the organization [6]. Translated to the presetting process, more feedback has to concern the operations of presetting operators. The operators should be triggered to conduct actions that lead to a better presetting performance. Key aspects are cleaning, actively replacing materials, using the torque wrench and releasing based on the TDM tolerances. Since most of these aspects are related to the assembly process of collet chuck holders, it can be concluded that feedback regarding the preparation of collet chuck holders is more crucial to improve the current presetting performance than feedback concerning shrink holders.

6 Proposed redesign

This chapter addresses the proposed redesign for the presetting process of Fokker Aerostructures. As a consequence, the research questions of section 3.4.4 are answered in this chapter. The chapter is structured as follows: in the first section, the choice of redesign is motivated. The second section explains the content of the redesign (concept). The impact of the redesign is addressed in the third section. The fourth section focuses on the validation of the design.

6.1 Choice of redesign

The performance system analysis revealed that most of the presetting problems are related to the preparation of collet chuck holders (chapter 5). The majority of the deficiencies mentioned by the interviewees are related to these tool holders. Furthermore, it was found that collet chuck holders hardly meet the TDM tolerances at the first measuring attempt (section 5.1). Consequently, most of the time is wasted during the preparation of these tool holders (measurements in section 5.1). For these reasons, it was decided to focus exclusively on improving the presetting process regarding collet chuck holders. As a result, the countermeasures from section 5.6 proposed for the entire presetting process (applying also to shrink fit holders) are now only considered in the context of presetting for collet chuck holders. This implies that the following solutions (countermeasures) can be applied to improve the performance of the presetting process with respect to collet chuck holders:

- Adjust the TDM diameter tolerances of collet chuck holders.
- Replace poor collet chucks and clamping nuts.
- Provide more coaching/feedback about the presetting operations/actions regarding collet chuck holders.
- Replace collet chuck holders completely by shrink fit holders (i.e. switch to shrink fit holders).
- Reward operators to reassemble non-conforming tool assemblies and to stick to the current TDM tolerances, accept the extra time needed to prepare tool assemblies with collet chuck holders. In other words, change the consequences, not the current process.
- Establish an education program for operators concerning the presetting process of collet chuck holders.
- Create process documentation, describing the desired actions and outputs for the presetting process of collet chuck holders.
- Change the cleaning approach/method for collet chuck holders.

The various solutions were evaluated with the aid of multi-criteria decision analysis (introduced in section 4.4.4). By interviewing the problem owner, the following criteria were established for assessing the solutions:

- Improvement**:** The proportion in which the solution reduces rework and additional activities (knocking and reassembling) and increases the capability to meet releasing specifications.
- Durability: The degree in which the solution is able to remain functional over time, without requiring extra maintenance or attention (labor).
- Non-recurring costs: The costs related to the design and development of the solution as well as the purchase costs. In other words, one-time investment costs.
- Recurring costs: The ongoing costs of the solution functioning in practice. In other words, operational expenses.

In order to assess the solutions adequately on these four criteria, information from multiple sources has been consulted. Firstly, the information from the performance system analysis was used, including the measurements regarding collet chuck holders and shrink fit holders. Secondly, the advice of a multidisciplinary group of experts was taken into account. The group of experts included two process specialists (engineers) of Fokker Aerostructures, a tool constructor from an external company (tool manufacturer) and a performance system specialist (KT coach). The experts were individually asked to give their opinion regarding the various potential solutions, by organizing four expert opinion sessions. Each expert was introduced to the problem and the main findings from the performance system analysis. Subsequently, the potential solutions and four criteria were summarized by the researcher. Eventually, the experts were asked to give their opinion about the various solutions, considering the four design criteria. Thirdly, information regarding costs was taken into account. The non-recurring and recurring costs of the various solutions were calculated, by inquiring the price of materials, appraising the working hours needed to design and develop the solutions, and estimating the operational costs (considering maintenance, replacement and extra labor). These calculations can be found in appendix F. Fourthly, information from literature was considered; trade journals from the field of tool holding and cutting tool technology were consulted, to acquire more knowledge about the presetting process of collet chuck holders [16] [17].

Based on this set of information, a weighted-decision matrix was created by the researcher to analyze the solutions for presetting process of collet chucks. The solutions were ranked upon fulfillment towards the four design criteria. Each solution received a score between 1 and 10, corresponding to its degree of (expected) satisfaction to the criterion. Hence, the higher the number, the better the solution performs on that requirement. Furthermore, the importance of the criterion is expressed by a weighting factor; the weights were determined by consulting the problem owner. The results of the evaluation are shown in figure 45.

Criterium	Weight	Adjust diameter tolerances TDM	Replace poor collets & nuts	Provide coaching and feedback	Switch to shrink fit holder	Keep current process, change consequences	Develop operator training program	Establish process documentation	New cleaning method
Improvement	4	10	6	4	8	1	4	1	2
Durability	1	10	5	7	8	1	3	1	7
Non-recurring costs	3	5	6	9	1	10	7	9	6
Recurring costs	2	9	6	6	1	2	8	10	6
Overall score		**83**	**59**	**62**	**45**	**39**	**56**	**52**	**45**

Figure 45: Weighted decision matrix.

The adjustment of diameter tolerances scores the highest on improvement (figure 45). Since the current diameter tolerances are unattainable, even from a technical point of view, much improvement can already be achieved by setting the diameter tolerances appropriately. Based on information from the tool holding field (trade journals and knowledge of an expert from a tool holding company) it was concluded that the current diameter tolerances are far too strict to become achieved in practice, even though the presetting process is perfectly executed. The adjustment of tolerances therefore received the highest score on performance improvement (rank of 10). Besides, it is also the most durable solution, because once the tolerances are set appropriately they remain functional over time, without any extra work. Switching to shrink fit holders is the second-best solution on improvement, because during the performance system analysis it was found that shrink fit holders are performing better than collet chuck holders (section 5.1), while shrink fit holders are also more durable than collet chucks. Consequently, fully switching to shrink fit holders scores an 8 on both improvement and durability whereas replacing poor collet chucks and nuts is ranked by 6 and 5 on those criteria respectively. However, the full replacement by shrink fit holders is by far the most expensive solution, compared to the other solutions. Therefore, this solution is ranked by 1 on both non-recurring and recurring costs (figure 45). The non-recurring costs are high since 330 new tool holders have be purchased with an individual cost price of about 200 euros (in comparison, the price of a new collet and nut amounts about 38 and 18 euros). In addition, approximately 167 tool assemblies have to be redesigned, meaning that the dimensions of all these tool assemblies change. Each changed tool assembly has to be checked, by simulating the dimensional change in all the CNC cutting programs it is used. The majority of tool assemblies are utilized for more than 30 different cutting operations. Hence, it requires much labor (workhours) to completely switch to shrink fit holders. Moreover, the recurring costs of using shrink fit holders are extremely high, since custom-made cutting tools have to be used instead of standard cutting tools. Shrink fit holders are only available in a limited number of clamping diameters: 6, 8, 10 and 12 mm. In contrast, collet chuck holders are versatile, since collets are interchangeable and available in a wide range of clamping diameters. Thus, the clamping diameter (range) of a collet chuck holder can be adjusted whereas for a shrink fit holder it is fixed. As a consequence, if one wants to assemble a cutting tool that has different diameter than the clamping diameter of a shrink fit holder, a custom-made tool has to be fabricated, to put it in a shrink fit holder. This tailored-made cutting tool has a larger diameter at the shaft than on the cutting section, and should be specially produced by a tool manufacturer. Consequently, such special cutting tool costs a lot more than a standard cutting tool having the same diameter at the shaft and cutting section (that can be clamped in a collet chuck holder). A standard cutting tool costs about 20 euros, whereas a customized cutting tool costs approximately 60 euros. By remembering that on a yearly basis around 4700 tool assemblies are made with collet chuck holders, it can concluded that the recurring costs increase extremely if one would completely switch to shrink fit holders (40*4700=188.000 euros).

It is widely believed that the presetting process can also be improved by increasing discipline of presetting operators. This was found in the literature [16] [17], in the performance system analysis and this was claimed by an expert in the field of tool holding. Therefore, providing feedback and developing an operator training program are both ranked by 4 on improvement (figure 45). Nevertheless, providing feedback is considered as a more durable solution than an education program, since it is believed that training of employees helps for some period, but the impact disappears over time, whereas coaching and feedback triggers employees constantly to improve during their work.

From the weighted decision matrix, it can be observed that the best overall solution is the adjustment of TDM diameter tolerances (figure 45). The second-best concept is providing feedback and the third-best solution is the replacement of poor collets/nuts. The worst alternative is changing the consequences and leaving the process further unchanged. Due to its high cost, switching to shrink fit holders is not an attractive solution for improving the presetting process of collet chuck holders. Notwithstanding, during the analysis it was discovered that there exists an essential interrelationship between four best solutions: adjusting the tolerances, replacing poor collets/nuts, providing feedback and educating employees. This relationship is demonstrated in figure 46. The green squares represent the solutions and the blue boxes denote the factors on which the solutions have impact. The diameter tolerances are connected to the capability of the presetting process, since they have to match the (required) capability of the process. The replacement of poor collets and clamping nuts influences the physical condition of materials. The provision of education, feedback and coaching contributes to the degree in which materials are properly used. Each factor is affected by the others and vice versa. For instance, the capability of the process depends on the state of the materials as well as the degree in which the materials are properly used. On the other hand, the state of materials and the degree of proper use are dependent on the desired capability of the process. In other words, the three factors should be in balance. This implies that the solutions should be implemented together to effectively improve the presetting process, rather than being applied on a standalone basis.

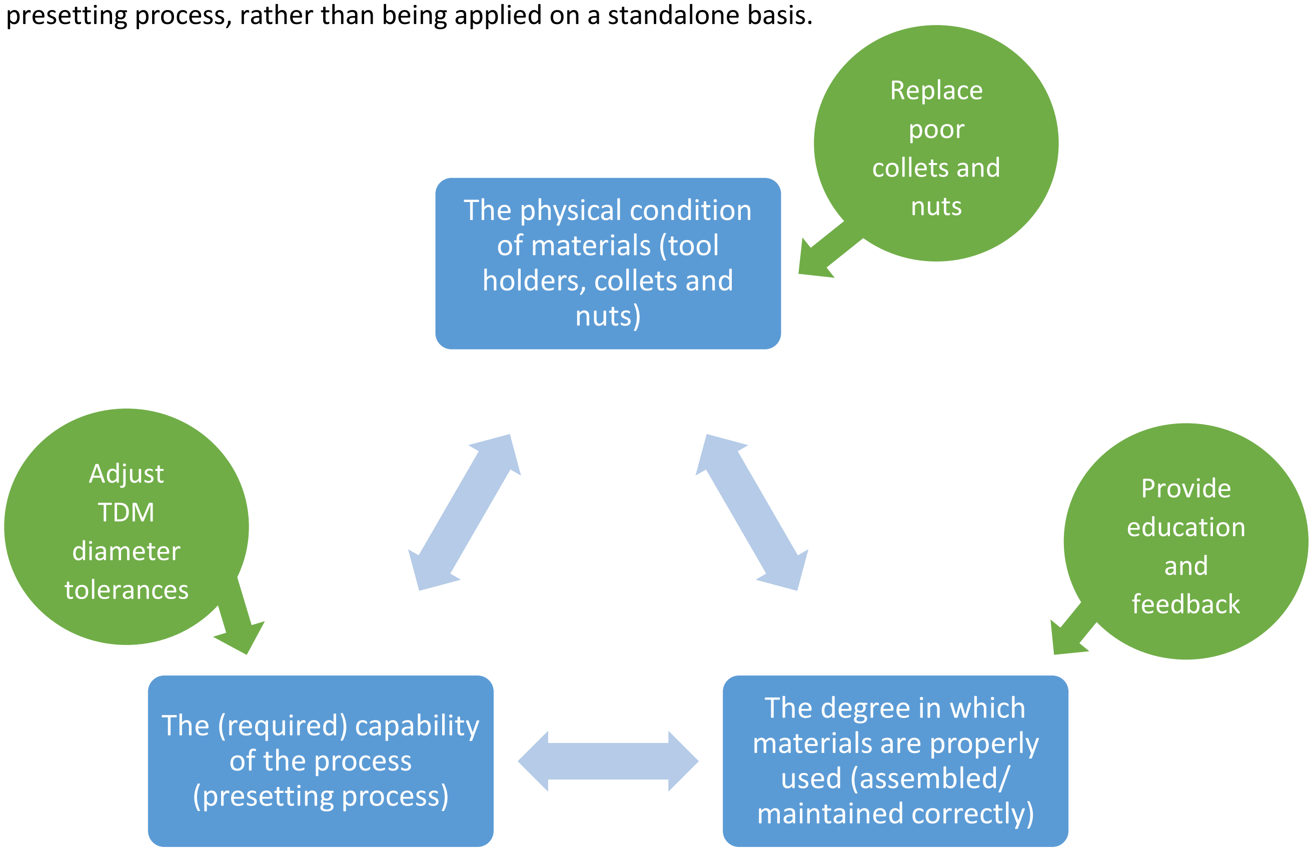

Figure 46: Model representing the relationship between four countermeasures.

Translated to the presetting process, first of all, the materials should be in good condition. Then, the diameter tolerances should be set in such a way that in case of proper use the TDM requirements can nearly always be satisfied. The TDM tolerances can then be applied to replace materials after one or two non-conforming measurements. In addition, the tolerances can be used to indicate improper assembly. However, in order to keep materials in good condition (after purchasing new collets and nuts) it is crucial to use them correctly, otherwise, they will degrade quickly over time, due to misuse. Therefore, it is paramount to provide education and feedback regarding the actions of operators during the preparation of collet chuck holders. The education and feedback should guarantee that operators use the materials as intended: i.e. tightening with the torque wrench, cleaning, and no knocking on tool assemblies. Besides, materials should be actively replaced and maintained to keep the physical condition of the materials high.

Ultimately, after multi-criteria decision analysis and discovery of the interrelationship between solutions, it can be concluded that a package of four countermeasures has to be applied to improve the presetting process regarding collet chuck holders:

- Adjust the TDM diameter tolerances for collet chuck holders.
- Replace poor collet chucks and clamping nuts
- Provide more coaching/feedback about the presetting operations/actions regarding collet chuck holders.
- Establish an education program for operators concerning the presetting process of collet chuck holders.

In the next section the content of redesign is further defined.

6.2 Redesign concept

This section reveals the content of the proposed redesign. In following subsections each component of the redesign is discussed. Section 6.2.1 elaborates on the proposed formula to adjust the diameter tolerances. Section 6.2.2 discusses the replacement of poor collets and clamping nuts. Lastly, the developed education and feedback procedure is explained in section 6.2.3.

6.2.1 Adjustment of diameter tolerances

In order to adjust the current diameter tolerances in TDM, this dissertation proposes a new formula and procedure to change the existing diameter tolerances for presetting of collet chuck holders.

In order to properly redesign the diameter tolerances, the existing TDM database was thoroughly investigated. First of all, the researcher tried to find the origin of the current tolerances, however, although many employees of Fokker Aerostructures were interviewed, this question remained unanswered: nobody knew the exact origination of the tolerance values in the TDM database, but is was confirmed that the values established in the early beginning (approximately 15 years ago) were the foundations for the massive database it is now. In fact, the database has been filled over the years by copying values from existing tool assemblies when a new tool assembly was added. However, the tool assemblies themselves as well as production requirements have changed over time.

By studying the existing diameter tolerances in TDM, two shortcomings were identified: Firstly, it was found that the current diameter tolerances do not take the dimensional variation of the cutting tool into account. However, the physical diameter of a cutting tool is seldom perfectly nominal, since there exist variation in the manufacturing process of cutting tools. Thus, the new diameter tolerances should account for this physical variation of the cutting tool. It was found that cutting tools are manufactured in such way that the diameter is smaller than or equals the nominal value of the tool. As a result, cutting tools are typically a bit smaller than their nominal diameter in practice. This should be included in the diameter tolerances. Secondly, the current diameter tolerances do not account for the variation that comes from the assembly in the tool holder. There exists variation in the assembly process; every time the tool is inserted in the tool holder it is positioned and clamped differently. This variability should also be included in the diameter tolerance for the tool assembly.

In order to overcome these two shortcomings in the current diameter tolerances, the following redesign was developed: Since it is known that cutting tools are usually smaller than their nominal value, it was decided to use the minimum diameter of the cutting tool as threshold for minimum diameter of the tool assembly. Beyond the dimensional variation of the cutting tool, the assembly variation of the tool holder increases the measured diameter of the tool assembly at the tool tip. Therefore, this variation should be added to the maximum diameter of cutting tool to obtain an appropriate maximum diameter threshold for the tool assembly. The assembly variation caused by the holder is assumed to be normally distributed around maximum diameter of the cutting tool (mean). For the company, it is common to use a range of 6 standard deviations to control the variation in a production process that is (considered) normally distributed. This means that the upper specification limit (USL) is set at 3 standard deviations above the mean of the process and the lower specification limit (LSL) is 3 standard deviations below the mean. Setting the thresholds in this way ensures that 99.73% of the parts are conforming specifications [18] [19] [20]. Nevertheless, in the situation of presetting tolerances, only the variation on the right-hand side of the mean is of importance (because the assembly variation is always measured positive, due to the rotational measurement of the diameter). Therefore, the maximum diameter threshold for tool assembly is set at 3 standard deviations above the maximum diameter of the cutting tool. Hence, the formulas to adjust the diameter tolerances are represented by:

$$D_{min} = C_{min} \quad (3)$$

$$D_{max} = C_{max} + 3 * \sigma_{assembly} \quad (4)$$

Where D_{min} and D_{max} are the minimum and maximum diameter for the tool assembly, thus the new TDM tolerances. C_{min} and C_{max} are the minimum and maximum diameter of the cutting tool while $\sigma_{assembly}$ is the assembly variation related to the tool holder. C_{min} and C_{max} are directly adopted from specifications of the tool manufacturer. In contrast, the assembly variation is empirically determined, based on measurements, since it is impossible to predict this variation theoretically. The measurements should be obtained by reassembling a (new) tool assembly multiple times after each other, and measuring its diameter each time. After collecting a sample of measurements, the assembly variation is represented by the standard deviation. A sample of at least 30 measurements should be collected to obtain a good estimation of the standard deviation [18]. In order to simulate the assembly variation in case of good presetting performance, it is crucial to utilize a completely new tool assembly, and to perform the assembly process correctly. Besides, the exact same presetting steps should be executed before each measurement.

It is believed that the empirical measurements do not have to be conducted for every single tool assembly, but instead the procedure can be applied to establish the assembly variation for entire groups of tool assemblies. In particular, the majority of tool assemblies are built with a standard collet chuck (ER16 collet). It is expected that by computing the assembly variation of a standard collet with a small, medium and large clamping diameter, the new diameter tolerances for most of the tool assemblies can be calculated.

6.2.2 Replacement of poor collets and clamping nuts

In order to replace the materials adequately, poor collets and clamping nuts have to be identified and be discarded. The judgement of materials can be made the best by the presetting operators themselves, since they have most experience with the materials. Subsequently, new collet chucks and tightening nuts have to be purchased. Bearing in mind that about 70% of the collets and 50% of the clamping nuts have to be replaced (section 5.2) and that there are 600 collets and nuts in circulation, approximately 420 collets and 300 nuts have to be replaced.

6.2.3 New education and feedback procedure

This section describes the education and feedback procedure regarding the presetting process of tool assemblies created with collet chuck holders. The objective of this procedure is twofold: (1) it emphasizes the key aspects to educate/inform employees regarding the presetting process of collet chuck holders and (2) provides the means to start coaching (giving feedback) at the presetting department, to retain performance improvements. Hence, Fokker Aerostrucutures can use this procedure to inform/educate their operators and managers concerning the presetting process and at the same time initiate the feedback on presetting operations. However, the exact organization of the coaching task (responsibility) and the development of a comprehensive operator education/training program (conforming HRM requirements) is outside the scope and should be further determined by the management of Fokker Aerostructures.

The remainder of this section is organized as follows: the first part of this section addresses the content of education and feedback by summarizing the foundations for a good presetting process. This is achieved by discussing the desired and undesired actions concerning the preparation of collet chuck holders. The second part of this section summarizes the fundamentals of feedback and coaching theory, retrieved from the literature. Thus, first the education and feedback content is specified and subsequently the manner in which feedback should be given is addressed.

1: Education and feedback content

In order to guarantee an excellent presetting process, it is important to pay attention to the following key aspects:

- Cleaning and replacing
- Assembling properly
- Measuring and releasing correctly

The next paragraphs elaborate further on these three aspects.

1.1: Cleaning and replacing

One of the aspects that is most often overlooked is the cleaning of materials. Nevertheless, cleaning influences the presetting performance. First of all, new collet chucks, tool holders and tightening nuts are provided of a rust-preventive coating by their supplier. This thick coating preserves the collet, tool holder or collet, however, it is terrible to leave on during machining. The preventive oil reduces the gripping force (of the collet and nut) and also affects the runout of the tool assembly (the tool runout should be as low as possible to achieve the best results at machining). Before using new materials, this coating should be removed. In order to do this adequately, a cleaning agent should be used [16].

Besides, it is essential to clean used tool holders, collets and nuts. During machining, the tool assembly picks up deposits such as composite dust, chips and dirt. In fact, foreign matter that is big enough to see will affect the performance of the tool assembly [17]. In order to attain the lowest runout, the contact surfaces of collet chuck, nut and inside of the tool holder should be clean such that they fit perfectly into each other (figures 47, 48 and 49). Furthermore, the inside and the slots of the collets should be clean. The slots enable the collet to collapse and hold the cutting tool, therefore, anything in between a slot that impedes this collapse will reduce the clamping force and increase runout of the tool assembly. Tool holders, collets and nuts should be cleaned by using a polishing cloth in combination with a cleaning agent. A lightweight brass brush could be used to remove deposits from the inside of collet. The slots can be cleaned with a thin metal or plastic blade. If a deposit cannot be removed from the collet or the nut, it is time to replace that collet or nut [16].

Figure 47: Cleaned collet chuck. *Figure 48: Cleaned clamping nut.* *Figure 49: Cleaned tool holder.*

In addition to cleaning of collets, it is recommended to check the materials on damage. This visual inspection takes little time and can be executed during the assembly process. The collet definitely has to be replaced if [16]:

- There is a gouge around the nose of the collet (this means that the collet and nut have been assembled incorrectly, resulting in collet damage).
- There are burrs on the collet.
- The collet has lost roundness, either in the hole or around the outside form.

In principle, collets and nuts are consumables; if there are any doubts regarding the quality of collets, nuts or tool holders, they should rather be replaced than be released for production [17].

1.2: Assembling properly

Beyond cleaning and replacing, another important aspect is proper assembly of the collet, nut and tool holder. First of all, tool assembly components should be mounted correctly. This implies that the collet is first pushed/clicked in the tightening nut, and then the nut with collet are put in the tool holder, by screwing the nut on top of the holder (figures 50 and 51). In an incorrect tool assembly, the collet is first put in the tool holder, then the nut is screwed onto the holder (figure 52). Improper assembly can permanently damage the concentricity of the collet and may damage the clamping nut. Consequently, it leads to poor tool runout [16] [21] [22] [23]. In addition, the right collet chuck should be used for the tool assembly. Collet chucks are have a predetermined clamping range, depending on their inner diameter. Most of the collets have a clamping range of 1 or 0.5 mm. However, instead of this clamping range usually the maximum clamping diameter is written on the outside of collet. One should thus be aware that a collet of 4 is suitable to clamp a diameter up to 4 mm. Although it is practically possible (after some pushing), one should never clamp an oversized cutting tool since this permanently deforms the inside of the collet [22]. For instance, a drill with a shaft of 4.1 mm should be clamped in a collet of 4.5 mm or 5 mm instead of a collet of 4 mm. In order to obtain the best performance, the shaft of the cutting tool should be fully inserted in the collet. Nevertheless, the cutting tool should never be inserted less than 2/3 of the collet bore length [16] [21] [22]. Inserting the tool not deeply in the collet leads to higher runout and less clamping force whereas the bottom of the collet is prone to deformation [16] [21].

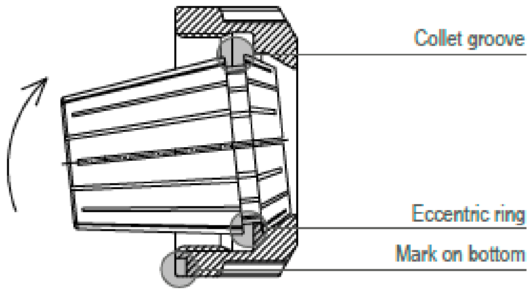

Figure 50: Clicking of the collet in the nut [22].

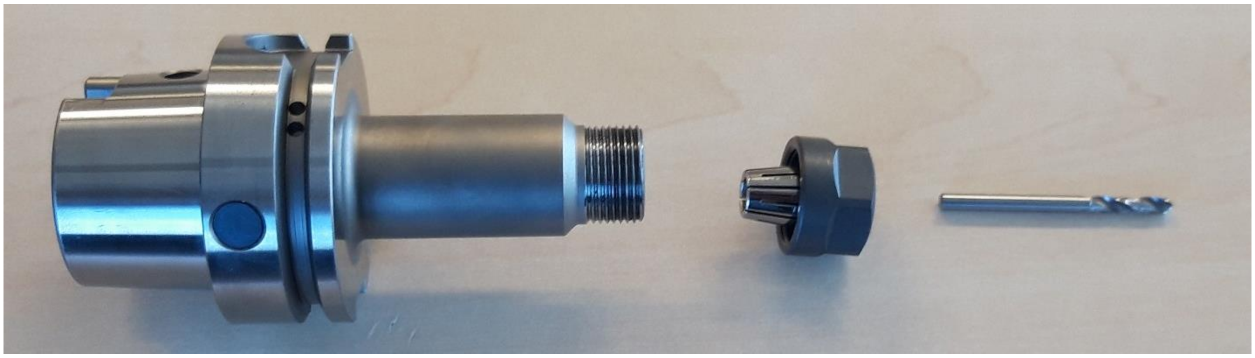

Figure 51: Correct assembly sequence.

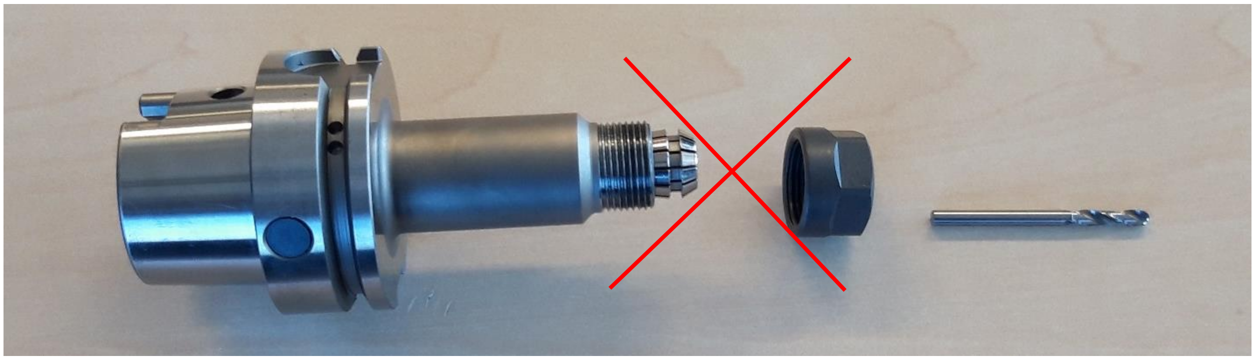

Figure 52: Incorrect assembly sequence.

Finally, another crucial element in the assembly process is the tightening of the clamping nut. It is widely believed that one should use a torque wrench, to avoid overtightening of the clamping nut, in order to achieve the best results [16] [17] [21] [24] [25]. Every clamping nut has a predetermined maximum tightening torque. Exceeding this torque does not lead to better clamping force, instead it leads to higher tool runout. In particular, if the nut is tightened too strongly, the collet chuck deforms or even breaks. Since the material of the cutting tool is harder than the material of the collet chuck (about 90 and 60 HRC), the inside of the collet deforms at the edge of the tool shaft (if the tool in not fully inserted in the collet). Besides, the collet twists in the clamping nut, causing deformation at the collet's top [16] [17]. Hence, one should always use a torque wrench (figure 53) instead of a normal wrench to fasten the clamping nut.

Figure 53: Torque wrench [25].

1.3: Measuring and releasing correctly

In order to control the runout variation of prepared tool assemblies, it is paramount that the operator strictly obeys the diameter tolerances of the TDM database for releasing. Otherwise, the desired accuracy for machining is not guaranteed anymore. Therefore, one should never ignore the TDM tolerances. In case the tool assembly does not meet the presetting tolerances, it should be reassembled before it is measured again. The means dissembling all components, cleaning and inspecting the collet, nut and holder thoroughly and eventually mounting them again. If after two measuring attempts, the tool assembly still does not meet the specifications, the tool assembly has to be replaced (discarded).

However, one should never knock on the tool assembly (neither with metal hammer or plastic tool), since this can damage the measuring machine and the tool assembly itself (for example, tool breakage). If one knocks on the tool assembly, while it is still positioned on the measuring machine, one indirectly knocks on the rotating base of the measuring machine, since the tool assembly is powerfully clamped on this base. In fact, the base is the origin of the measurement system; during measuring, the base rotates 360 degrees in order to measure the diameter of the tool assembly. In other words, by knocking on the tool assembly, one indirectly knocks on the vertical axis of the measuring machine. The measuring machine is designed to measure values at 0.001 mm, therefore, any additional load on the base should be avoided (according to the manufacturer). Hence, one should never knock on the measuring machine (figure 54).

Figure 54: Knocking on measuring machine.

2: Basics of feedback and coaching theory

This section provides the fundamentals of feedback and coaching theory, as proposed in the scientific literature.

Feedback is the information that employees receive that they can use to improve results and/or the underlying process. The purpose of feedback is to help employees to improve their performance. A common phenomenon in reality is that managers give feedback that is well-intentioned, but the message is too vague to be of practical use. In order to provide effective feedback, the task clarity has to be maximized meaning that the feedback message is:

- Specific: it should ensure the employee can relate it to identifiable behaviors or actions.
- Accurate: it should lead to helpful insights, not confusion or anger.
- Informative: it has to provide insight into how to do things differently and better.
- Controllable: it should relate to actions or behaviors that the employee can change.

One can distinguish between two types of feedback: positive and negative feedback. Positive feedback means explaining people what they are doing right (giving credits to employees), negative feedback implies correcting actions or results i.e. telling employees what they are doing wrong. Negative feedback triggers the employee to change results, or in a more sophisticated situation, alter the process/action that produced the result. On the contrary, by letting people know what there are doing right, employees continue performing it in that manner [26]. It is generally acknowledged that one should offer more positive than negative feedback [26] [27] [28] [29]. Providing too much negative feedback discourages employees and hurts motivation. A common rule of thumb is that for every time you correct an employee, you should tell them they are doing it right at least three times [28]. To coach effectively, a performance coach should keep this ratio in mind at providing direct feedback to employees about their performances [26]. When there is a problem, and negative feedback has to be given, one should consider starting with providing positive feedback and then offer suggestions on how the employee could be “even better if…”.The person still hears that you would like to see a change, but it is framed as a positive improvement instead of correcting a deficiency [27].

In summary, it is paramount to offer a broad assortment of feedback. This implies that information is pointing towards improvement of results as well as the processes that produce those results. In order to provide good feedback, one should ensure that the message satisfies the four clarity criteria: specific, accurate, informative and controllable. Lastly, the mix between positive and negative feedback should be taken into account to achieve the best results.

6.3 Impact of redesign

The redesign has the following impact on the presetting process. It is expected that providing feedback in combination with educating employees will guarantee that operators are always utilizing the materials correctly, therefore, some steps of assembly process change, after implementing the redesign. In the old situation, the steps of cleaning and tightening with the torque wrench were sometimes not executed. However, in the new situation, these steps will always be conducted under the condition of adequate feedback. Furthermore, the redesign eliminates knocking on the tool assemblies and avoids the ignorance of the TDM tolerances for collet chuck holders. Figure 55 shows the flowchart of new measuring process after implementing the redesign. It can be observed that the knocking and ignorance steps have disappeared (indicated by the red circle).

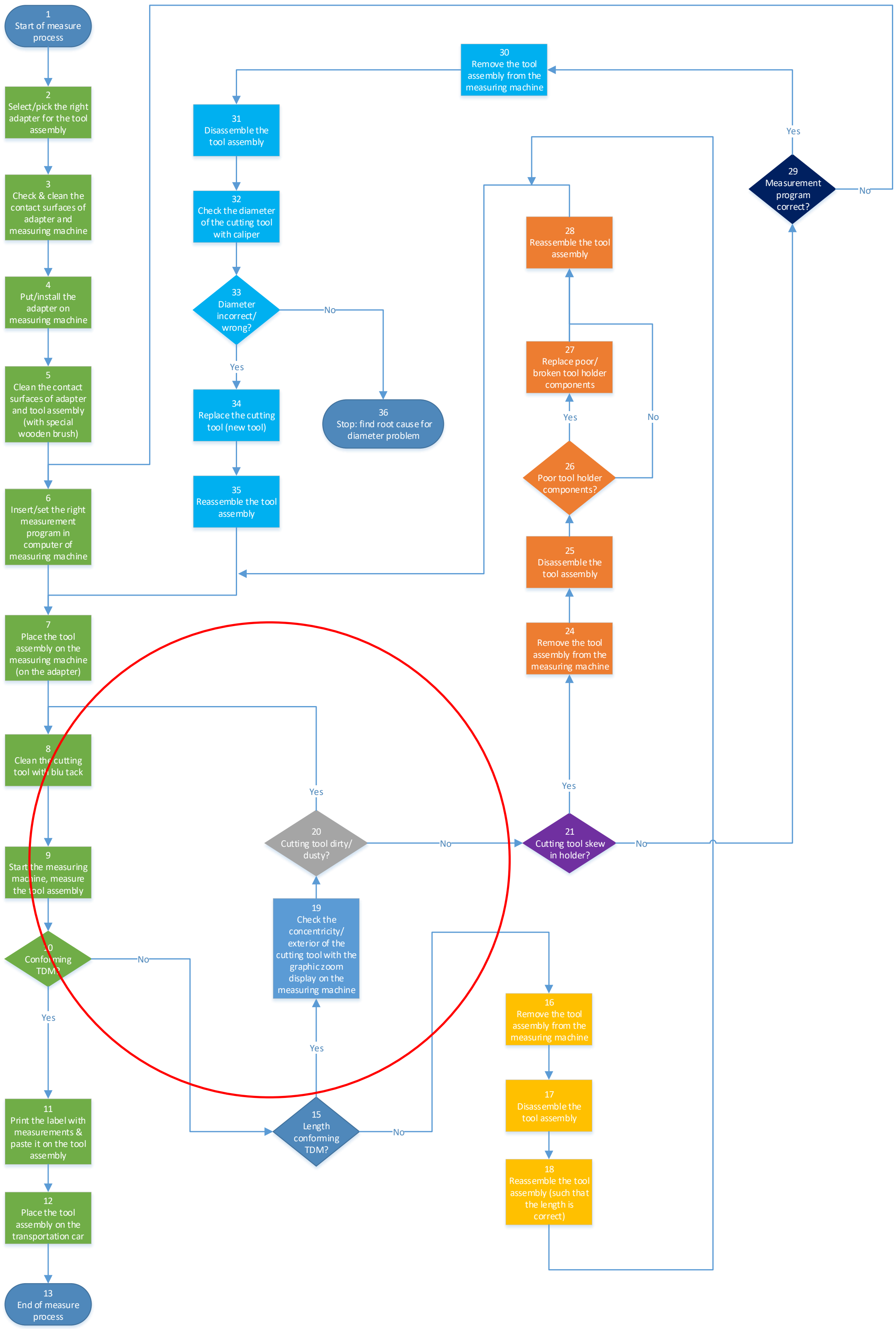

Figure 55: Flowchart of measure process, after redesign.

The redesign has the following impact on the end results. At the moment, 35% of the collet chuck holders is conforming TDM at the first measurement (figure 56) (section 5.1). After the final attempt, 47% of the tool assemblies are conforming TDM (considering the data from the log file). With the new presetting tolerances, 99.87% of the tool assemblies are expected to be conforming TDM at the first measuring attempt, under the condition of proper assembly and use of good materials (figure 57). The percentage follows from the probability density function corresponding to the diameter tolerance threshold chosen for the assembly variation (3 standard deviations above the mean), and holds on the assumption that the cutting tools are always between the minimum and maximum specified diameter of its supplier. Thus, one can improve from 35% to 99.87% at the first measuring attempt. As a result of the new tolerances and providing feedback and coaching, ignorance of the tolerances is avoided, thus 100% of the collet chuck holders are conforming specifications after the final measuring attempt (figure 57).

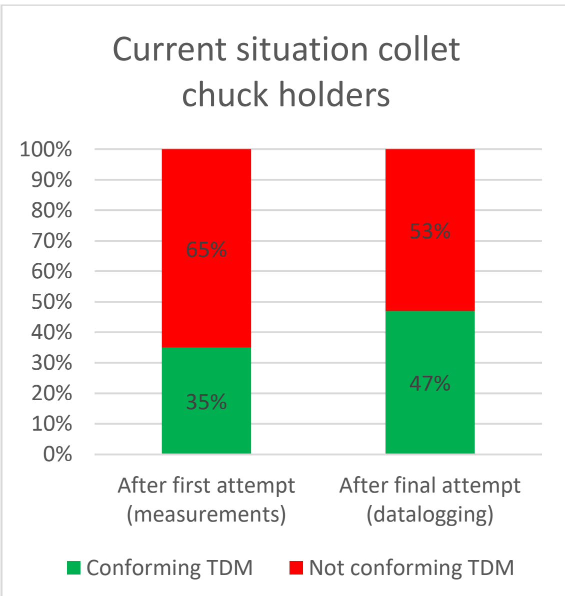

Figure 56: Current situation collet chuck holders.

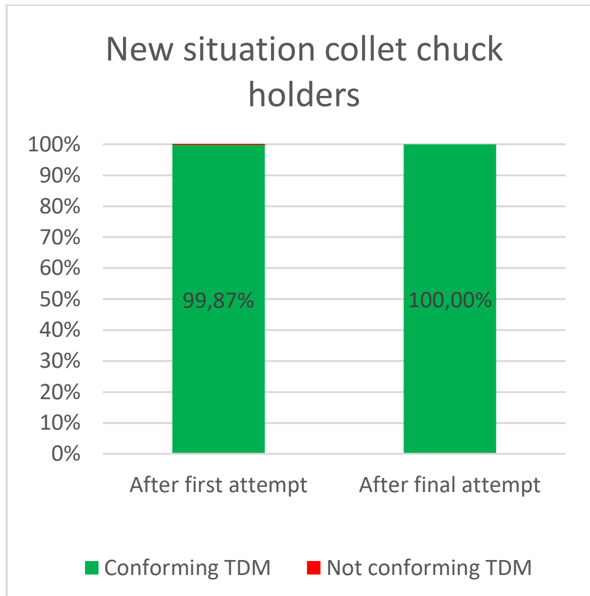

Figure 57: New situation collet chuck holders.

Furthermore, 2:40 minutes are currently wasted with the preparation of a collet chuck holder. The new design ensures that 99.87% the tool assemblies are meeting specifications right away, without losing time on rework or other activities such as knocking. In other words, with the redesign this time loss of 2:40 minutes can be avoided. The presetting department prepares 18 collet chucks per day, thus 48 minutes per day can be saved, implying that on annual basis 15.600 euros can be saved, if the redesign is applied to all the collet chuck holders. However, it is uncertain if the proposed redesign can be applied to all the tool assemblies with collet chuck holders. Nevertheless, by analyzing the TDM database and data log file (section 2.2), it was established that the redesign certainly works for 78% of the tool assemblies. The application on the rest of the tool assemblies should be further investigated in future research. Assuming the 78%, this means that Fokker Aerostructures can save at least 12.168 euros on a yearly basis. Figure 58 shows the cost-benefit diagram of the redesign under this scenario. The entire cost/benefit calculation can be found in appendix G. The investment costs amounts 29.088 euros and the yearly operational costs are 1710 euros. It can be observed that the breakeven point of the investment arises after 2.5 years. However, one should not forget that the figure only shows the cost savings regarding rework time. In fact, there are more advantages. Beyond saving time, the redesign also reduces the runout variation of prepared tool assemblies, which is beneficial for the machining process, whereas the avoidance of knocking is supposed to reduce maintenance on the measuring machine. Because these advantages are hard to express in terms of money, these were not taken into account in the cost/benefit diagram.

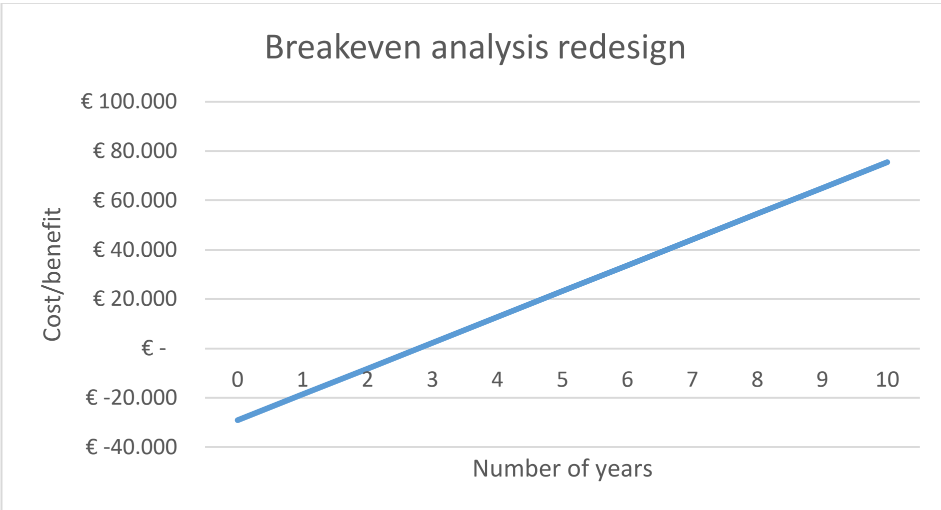

Figure 58: Cost/benefit diagram redesign (application of 78% of all assemblies).

The impact of the redesign on the entire presetting process is as follows: by considering the 2:40 and 0:14 minutes from performance system analysis (section 5.1), it follows that the total time loss can be reduced with 92%, by implementing the design. In the situation of applying the redesign on 78% of the tool assemblies, 71.7% of the time spent on rework can be avoided. By reconsidering the data log file (section 2.2), the impact of the proposed redesign on the total proportion of tool assemblies satisfying TDM was calculated. With data logging, it was found that 44% of all the tool assemblies released in the presetting process are currently not meeting the TDM tolerances (considering both shrink fit holders and collet chuck holders). In other words, 56% of all tool assemblies are currently conforming specifications. It was (re)computed that by exclusively improving the presetting process of collet chuck holders, meaning that all collet chucks are conforming TDM, this percentage can be increased from 56% to 85.2%. In the situation of applying the redesign to at least 78% of the collet chuck holders, the percentage can be increased to 81.1%.

6.4 Validation

This section addresses the validation of the redesign. The redesign was thoroughly validated by proving the improvement in the presetting process (section 6.4.1) and analyzing the suitability of measurement system, with respect to the redesign (section 6.4.2). Moreover, the implication of changing the releasing requirements on the machining process has been validated (section 6.4.3).

6.4.1 Presetting process improvement

In order to validate the presetting improvement of the redesign, the proposed concept has been tested in practice. This was done by applying the redesign on one specific tool assembly. The considered tool assembly comprised of a 4.2 mm drill, a collet chuck of 4.5 mm and a tool holder with a length of 100 mm (figure 59). This tool assembly was specifically chosen for the test because its size represents the average magnitude of a tool assembly at presetting. For the sake of uniformity, this tool assembly has been considered in all the validation tests.

Figure 59: Tool assembly used for validation.

First of all, the new diameter tolerances were determined. In order to calculate the new diameter tolerances, the specifications of the cutting tool were retrieved from the manufacturer. It turned out that the diameter of the drill varies between 4.182 and 4.200 mm, yielding the values of C_{min} and C_{max}. In order to obtain the assembly variation, the empirical procedure of section 6.2.1 was executed. Thus, one unique tool assembly (i.e. the same assembly) was reassembled and measured 12 times by three different operators, resulting in a sample of 36 measurements. Completely new materials were utilized in the test i.e. a new tool holder, collet chuck, clamping nut and cutting tool. The researcher instructed the operators before the start of the test, to ensure that the presetting process was correctly and similarly executed (according to the new education/feedback procedure of section 6.2.3). In addition, the researcher supervised and coached the operators during the test, to guarantee uniformity. Thus, each time the tool assembly was inspected and cleaned whereas the nut was fastened every time with a torque wrench. The set of measurements can be found in appendix H. A standard deviation ($\sigma_{assembly}$) of 0.0068 mm was computed. Substituting the numbers into equations (3) and (4) yields the following new diameter tolerances for presetting:

$$D_{min} = 4.182\ mm$$

$$D_{max} = 4.200 + 3 * 0.0068 = 4.220\ mm$$

Moreover, the set of measurements for determining $\sigma_{assembly}$ has also been used to evaluate the effect of the new redesign. As a matter of fact, this measurement set namely shows the capability of the process in the situation of excellent presetting performance (i.e. using good materials and excellently performing all the presetting steps). Figures 60 and 61 depict the diameter variation in the presetting process under good conditions, and demonstrate the current and new presetting tolerances respectively. The current and new diameter tolerances for the tool assembly are in both figures illustrated by two horizontal lines. Thus, figure 60 demonstrates the situation of implementing the redesign partly: replacing materials and providing education/feedback to guarantee an excellent process, but not changing the TDM tolerances.

Figure 60 confirms that the existing diameter tolerances are practically unattainable, since 44.4% of the samples are not between the two horizontal lines. Hence, even in the best scenario, meaning one uses new materials and performs perfectly, the current specifications still cannot always be achieved. This underlines once again the necessity to change the current TDM diameter tolerances (as claimed in section 6.2).

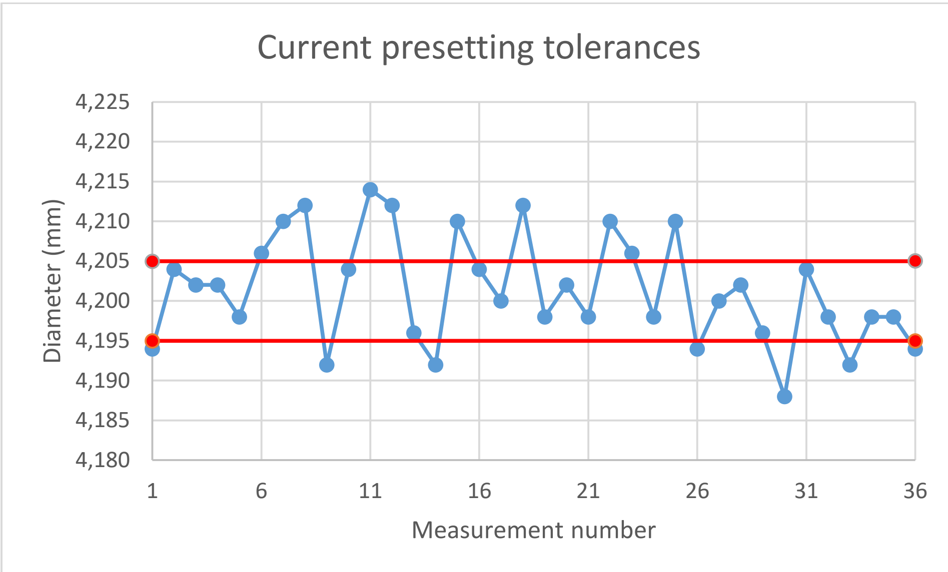

Figure 60: Good presetting process and current diameter tolerances.

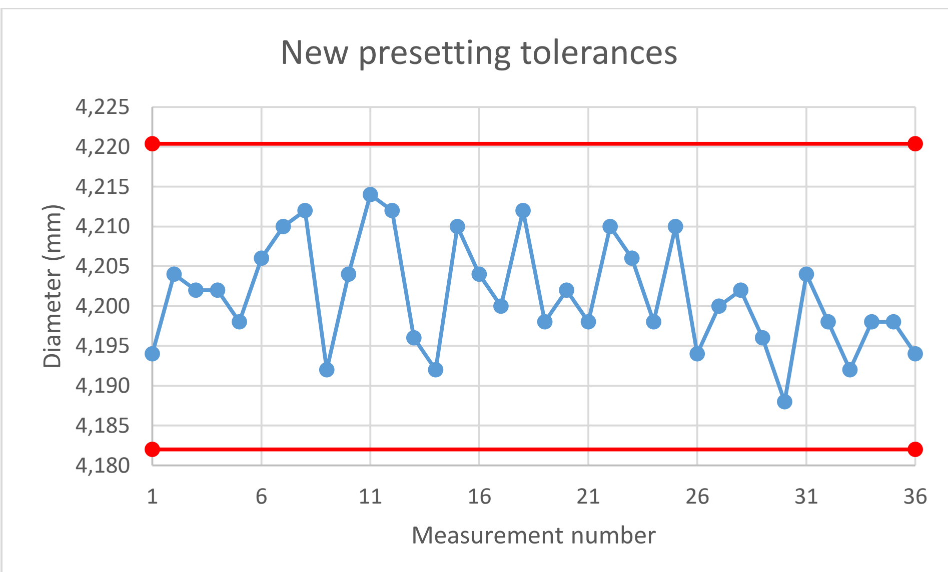

Figure 61: Good presetting process and new diameter tolerances.

Figure 61 demonstrates the new situation, after implementing the redesign, wherein the diameter tolerances are also adjusted. It can be observed that all measurements are in between the two red lines, meaning that all the prepared tool assemblies are meeting the specifications after one trial. This implies that with the proposed redesign, every tool assembly is conforming the specifications at the first measuring attempt. To put briefly, the results indicate that the proposed redesign adequately avoids rework and ensures that the assemblies are conforming TDM specifications.

The situation of wrong/poor presetting performance has also been considered. By reassembling and measuring a tool assembly 15 times, a second test sample was gathered. The same tool assembly was used for this test, however, the new collet chuck and tightening nut were replaced by a bad collet and clamping nut. Within this test, the tool assembly components were not cleaned before mounting. Nevertheless, the torque wrench was used to avoid collet/nut breakage during the test. The dataset can be found in appendix I. The variation in the process turned out to be as twice as large as in case of good conditions: the standard deviation was 0.0144 mm instead of 0.0068 mm. This proves that using good materials and cleaning the components leads to better presetting results. Figure 62 shows the diameter variation in case of poor presetting performance and whether the tool assemblies are meeting the new diameter tolerances. It can be concluded that in case of poor performance 26% of the tool assemblies are not meeting the new specifications. This implies that the new diameter thresholds are able to distinguish poor tool assemblies. When the tolerances are used to replace materials (by discarding components after two non-conforming measurements, section 6.2.3), this means that poor materials will be filtered out over time.

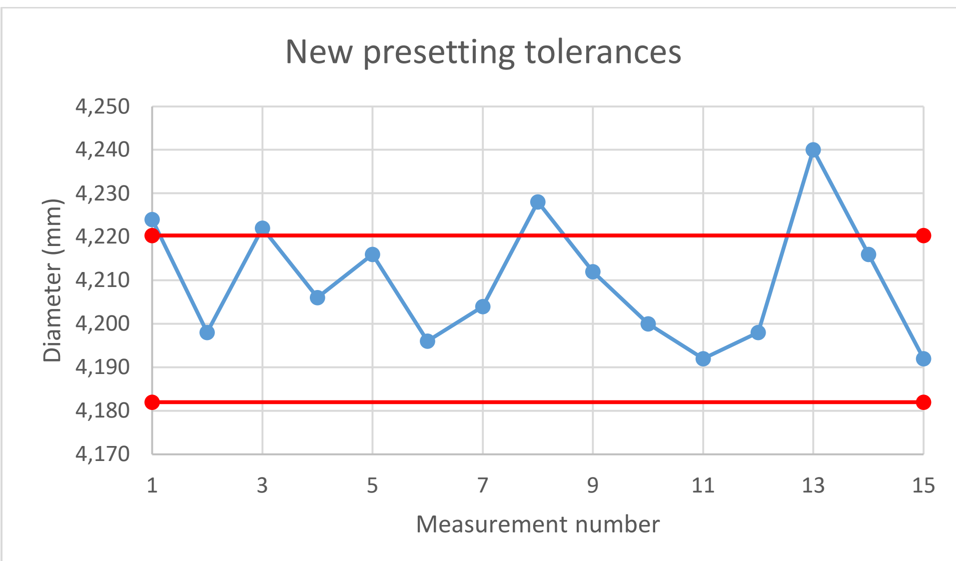

Figure 62: Poor presetting process and new diameter tolerances.

6.4.2 Measurement system verification

Since the combination of measured value and releasing requirements (TDM tolerances) determines whether the produced tool assembly is satisfactory or not, it should be validated whether the measurement system is sufficiently capable to measure the new tolerance range. In particular, the measurement system should be able to reliably establish whether the part is meeting or not meeting the specifications in reality. This ability depends on the variation in the measurement system as well as the desired measuring range. In order to evaluate this a Gage R&R study has been performed. Gage R&R analysis a statistical tool from the Six Sigma tool box. With a Gage R&R study the variation a measurement system can be investigated. This is achieved by examining the repeatability and reproducibility (R&R) of the system. The repeatability denotes how much variability in the measurement system is induced by the measuring device whereas reproducibility expresses how much variability in the system is caused by differences between operators [20] [30] [31]. With the aid Analysis of Variance (ANOVA), the R&R can be computed based on empirical measurements. The standard experimental design is to measure 10 different parts, three times by three different operators [20]. However, because the influence of the operator is expected to be low and one is highly interested in the variation caused by the measuring device itself, 3 parts (tool assemblies) were measured 9 times by 2 different operators. The set of measurements can be found in appendix J. The Gage R&R was computed with a statistical package, called Minitab 18. The key results of the Gage study are as follows:

Gage R&R

Process tolerance = 0.038

Source	StdDev (SD)	Study Var (5.15 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0014430	0.0074315	9.62	19.56
Repeatability	0.0012910	0.0066486	8.60	17.50
Reproducibility	0.0006447	0.0033202	4.30	8.74
Operator	0.0000000	0.0000000	0.00	0.00
Operator*Part	0.0006447	0.0033202	4.30	8.74
Part-To-Part	0.0149355	0.0769180	99.54	202.42
Total Variation	0.0150051	0.0772761	100.00	203.36

Number of Distinct Categories = 14

It was found that the total variation in the measurement system amounts 0.00144 mm (StdDev Total Gage R&R). It can be seen that more variation results from repeatability than reproducibility. Considering the D_{min} and D_{max} found in section 6.4.1, the process tolerance or range within the system reliably should measure is 0.038 mm. The comparison between the variation in the measurement system and this range corresponding to the process tolerance is depicted in the last column (%Tolerance (SV/Toler)). According to the widely accepted guidelines of the Automotive Industry Action Group (AIAG), a measurement system is acceptable if this percentage is below 30% [32]. It can be observed that the percentage is 19.56%, hence, the measurement system is capable to measure the new diameter tolerances reliably. This implies that the measurement system can adequately establish whether a part is conforming or not conforming the specifications (TDM diameter tolerances).

6.4.3 Implications for machining process

Eventually, a critical aspect regarding the proposed redesign are the implications of the changing the presetting tolerances on the machining process. Enlarging the TDM diameter tolerances for releasing tool assemblies should namely not lead to (new) problems in the CNC milling/drilling process. Even though it is outside the research scope, this topic has shortly been considered. By investigating the log file (described in section 2.2), the presetting diameters of used tool assemblies in the machining process were traced back. Figure 63 shows the diameters of 10 different tool assemblies that were used in production in a period of 3 months. The measurement dataset can be found in appendix K. It can be observed that 6 tool assemblies used at machining were not meeting the current TDM tolerances. In the case of the new presetting tolerances, 5 of these 6 assemblies would have been conforming releasing specifications. Lastly, one tool assembly that was used in production still exceeds the new presetting threshold. Since it is known that none of these 10 tool assemblies caused problems at machining, the expectation is that enlarging the diameter tolerances for presetting will not lead to more problems during machining. The same evaluation has been done for more tool assemblies in the log file, yielding the same insight. However, it is still a first indication, the exact impact of changing the tolerances on the machining process should be further determined in future research.

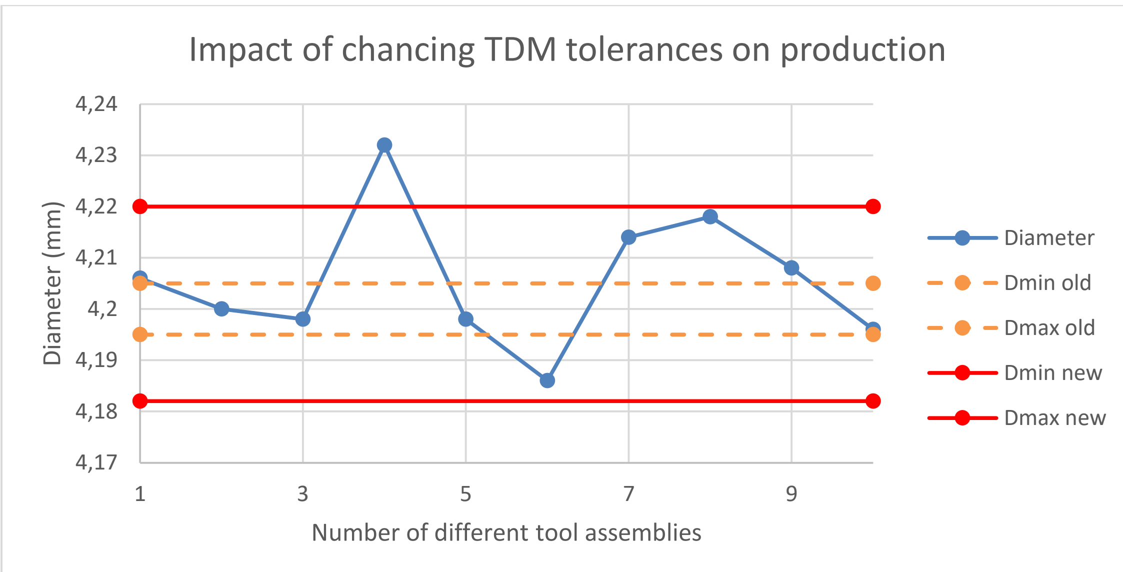

Figure 63: Impact of enlarging the TDM diameter tolerances.

7 Discussion

This chapter discusses the findings of this dissertation. Section 7.1 reflects on the results of this work. In section 7.2 the implications of the findings are addressed. The limitations of the design study and recommendations for future research are discussed in section 7.3.

7.1 Interpretation & reflection of results

This dissertation proposes a redesign for the presetting process of Fokker Aerostructures. Since it was found that most of the problems are related to the presetting process of collet chuck holders, a redesign for this part of the presetting process has been developed. The redesign includes four countermeasures: a formula to adjust the current diameter tolerances, the replacement of poor collets and clamping nuts and a new education and feedback procedure that can be used to educate and coach employees regarding the presetting process.

The impact of the redesign was theoretically computed by considering the time measurements and information from data logging (section 6.3). It was found that the redesign can be applied to at least 78% of the collet chuck holders. With an implementation of 78%, the time lost on rework can be reduced with 71.7%, meaning that Fokker can save 12.168 euros per year. Furthermore, the proportion of conforming tool assemblies can be increased from 56% to 81.1%. Besides, knocking is avoided by the redesign. The redesign has been validated in practice by implementation on one specific tool assembly (section 6.4). The measurements revealed that with the new redesign, all the tool assemblies are conforming TDM at the first measuring attempt. The findings indicate that by making sure that the process is correctly executed (feedback and education), the used materials are good (replacement of poor collets, nuts) and adjusting the diameter tolerances with the formula, one can nearly always attain the releasing specifications. Hence, the first impression is that proposed redesign adequately avoids rework and ensures that the assemblies are conforming the TDM specifications. Based on the results in practice, it can be expected that the theoretically computed improvement can be realized. Thus, the first impression is that the redesign leads to the improvement calculated in section 6.3.

The findings of sections 6.3 and 6.4 are based on the belief that one guarantees that the all the presetting steps are correctly executed, by providing adequate feedback and coaching. In other words, it is expected that the operators will follow the new education and feedback procedure. It should be mentioned that the intrinsic motivation of the operator also impacts the degree in which the presetting process is excellently executed. Moreover, operators will receive just periodically feedback and coaching, if the redesign is applied in practice. The actions of operators cannot be continuously supervised neither coached. On the other hand, it is believed that when the diameter tolerances become practically attainable (by applying the formula) this will tremendously affect the motivation of the presetting operators, because much frustration will be taken away, if presetting tolerances can be satisfied after good performance. Therefore, it is expected that coaching should be sufficient to stimulate the operator to conduct the presetting operations as desired. In the new situation, it is namely advantageous for the operator to execute the process correctly, because this will help him to better attain the TDM tolerances.

7.2 Implications of findings

This study has the following implications. First of all, it was established that currently 44% of the tool assemblies flowing into the machining process of Fokker are uncontrolled, because they are not released based on the TDM tolerances (section 2.2). Because Fokker Aerostructures wants to control the variation in the machining process, the implication is that the company needs to pay attention to this aspect. This study determined that the current diameter tolerances for collet chuck holders are technically unattainable (sections 5.2 and 6.1). In particular, it was measured that even when the presetting process is perfectly executed, the TDM tolerances still cannot be attained (section 6.4.1). This implies that Fokker definitely has to change the TDM database such that diameter tolerances support the presetting operations. Briefly, an implication is that the company needs to focus on the attainability of their process requirements. It was also found that the state of presetting materials and the performed operations inhibit the potential of presetting process for collet chuck holders. This means that the company needs to replace the materials and spend more effort on the operations in the presetting process, if Fokker wants to increase the presetting process of collet chuck holders.

The following implications are envisioned regarding the implementation of the redesign. The redesign includes a formula to adjust the TDM diameter tolerances for collet chuck holders. In fact, by applying the procedure and formula (section 6.2.1) the diameter tolerances for the presetting of collet chuck holders will be increased. As a consequence, the range of acceptable tool assembly diameters will become larger, meaning that more variation in the measured diameter is officially acceptable (as demonstrated in figures 60 and 61, section 6.4.1). In other words, tool assemblies with more diameter variability can flow into the machining process. This seems to add more variation to the machining process. However, because at the moment the existing smaller (tighter) diameter tolerances are not strictly used to decide whether a tool assembly should be released or not, the current inflow variation is even higher than the new presetting tolerances would accept (section 6.4.3). Therefore, the new diameter tolerances are supposed to reduce the variation in diameters slightly, but the most important thing is that the diameter variation will be controlled and limited based on facts, instead of being dependent on the opinion of the presetting operator. The redesign also includes a new education and feedback procedure that should be adopted to make sure that the process is correctly executed. An implication of applying the design is that the management and supervision at presetting department will be changed. At present, time is the most important aspect for managing the presetting process (section 5.4), however, if the supervision and coaching are based on the new feedback and coaching procedure of section 6.2.3, the focus on quality will be increased, thus the mindset at the presetting department will be changed.

7.3 Limitations & future research

This design study has the following limitations: first, the performance system analysis (chapter 5) is largely based on information from interviews. As a result, the findings resulting from the performance system analysis are subject to interpretation of the interviewees. Due the lack of quantitative data and time limitations, not all the claims could be verified with numerical data, and information from interviews has directly been adopted in some cases. For instance, in the performance system analysis it was established that 70% and 50% of the collets and nuts are not supporting, this is finding is exclusively based on claims of the operators (section 5.2). Furthermore, the performance system analysis integrates numerical data: the average rework time per type of tool holder and the proportion of tool assemblies meeting TDM at the first measuring attempt were calculated based on a sample of 40 time measurements. Hence, one should bear in mind that the findings regarding rework time and corresponding time savings are based on these 40 time measurements. With respect to computed impact of the redesign, two assumptions have been made (section 6.3). It is assumed that the assembly variation is normally distributed and supposed that the diameter of the cutting tool is always between the boundaries defined by the manufacturer (C_{min} and C_{max}) leading to a theoretical (statistical) conformance percentage of 99.87%. However, the exact dimensions of cutting tools in practice are unknown. Therefore, it is recommended to investigate the dimensions of cutting tools in practice in future research. Briefly, it should be verified whether the cutting tools are satisfying the dimensions defined by the supplier. The proposed redesign has been validated in practice, by measuring the assembly variation of one single tool assembly (section 6.4.1). In addition, the same set of measurements for determining the assembly variation has been utilized to validate the design in case of good presetting performance. The validation in this work only provides a first indication of the impact of the redesign. In order to obtain a better indication of the exact improvement in practice, it is recommended to conduct more experiments, by testing the redesign on multiple tool assemblies. It was found that the adjustment of diameter tolerances, according to the proposed formula, does not negatively affect the machining process (section 6.4.3). However, this proof was based on data over a period three months (data log file, section 2.2.). Therefore, it is recommended to further investigate the impact of changing the TDM tolerances on the machining process.

In this work, a redesign has been proposed for collet chuck holders. Because the proposed design only focuses on the presetting process of collet chuck holders, still not all the tool assemblies are conforming the TDM specifications. Therefore, it is recommended to continue the design investigation to also improve the presetting process regarding shrink fit holders. In fact, the process description (chapter 4) and performance system analysis (chapter 5) in this research already provide a decent starting point for redesigning the presetting process of shrink fit holders. It is recommended evaluate whether the proposed redesign for collet chuck holders is applicable to the situation of shrink fit holders, rather than entirely starting from scratch.

8 Conclusion

In this dissertation a design study was conducted concerning the presetting process of Fokker Aerostructures. The objective of the design investigation was to propose redesign for the presetting process of Fokker Aerostructures such that rework and additional activities can be reduced and all released tool assemblies are conforming TDM. After conducting the design project, the following can be concluded:

The main conclusion is that most improvement in the presetting process can be gained by enhancing the presetting process of collet chuck holders. It was found that the majority of rework and additional activities can be avoided by improving the presetting process regarding collet chuck holders (sections 5.1 and 6.3). Moreover, it was established that the proportion of conforming tool assemblies mostly can be increased by focusing on the collet chuck holders (sections 5.1 and 6.3). For this reason, a redesign for this part of the presetting process has been developed.

With regard to presetting process of collet chuck holders, it can be concluded that the most important cause of the high proportion of rework and non-conforming tool assemblies is the unattainably of the current diameter tolerances. It was discovered that the current diameter tolerances are technically unattainable; even though the presetting operator performs perfectly, he still cannot always attain the tolerances. Furthermore, it can be concluded the condition of presetting materials (collets and clamping nuts) and the current presetting operations also contribute to the proportion of rework and non-conforming tool assemblies. Besides, it was found that the TDM tolerances, presetting materials and conducted operations are interrelated to each other. It can therefore be concluded that in order to adequately improve the presetting performance of collet chuck holders these three aspects have to be improved together, instead of being addressed on a standalone basis.

It can be concluded that the best redesign for the presetting process regarding collet chuck holders is a package of four countermeasures: a new formula to adjust the current diameter tolerances of TDM, the replacement of poor collets and clamping nuts and a new education and feedback procedure that can be used to educate and coach employees regarding the presetting operations. Although it was found that shrink fit holders are performing better than collet chuck holders, it can be concluded that completely switching to shrink fit holders is not an attractive option for improving the presetting process of collet chuck holders since the non-recurring and recurring costs are much higher than the obtained presetting advantages. Validation in practice demonstrated that with the proposed redesign, every tool assembly meets the specifications at the first measuring attempt. Hence, the first impression is that by (slightly) adjusting the diameter tolerances and making sure that the process is correctly executed and the used materials are good, one can nearly always attain the TDM tolerances, implying that rework and additional activities are avoided and that all the assemblies are conforming TDM specifications. It was found that the redesign can be applied to at least 78% of the tool assemblies with collet chuck holders. This implies that Fokker Aerostructures can save at least 12.168 euros on a yearly basis and earn the investment back within 3 years. Furthermore, it was computed that the total proportion of tool assemblies meeting the TDM tolerances can be increased from 56% to 81.1% whereas the total amount of rework can be reduced with 71.7% (in the scenario of implementation on 78% of the tool assemblies). The first indication is that the diameter tolerances can be adjusted, without negatively affecting the machining process. However, the exact impact on machining should be determined in future research.

Reflecting back to the design goal (section 2.6), it can be concluded that the design goal is partly achieved, because the proposed redesign considerably reduces the rework and additional activities, but still not all tool assemblies are conforming TDM, since the proposed redesign only changes the presetting process of collet chuck holders. In other words, if Fokker Aerostructures wants to have all tool assemblies conforming the TDM specifications, the presetting process of shrink fit holders should also be addressed.

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10 Appendices

10.1 Appendix A: Dataset data logging (log file)

Tool#	L (mm)	Lmin (mm)	Lmax (mm)	Lmeasured (mm)	Betw. Lmin/Lmax?	D (mm)	Dmin (mm)	Dmax (mm)	Dmeasured (mm)	Betw. Dmin/Dmax?	Conforming TDM?
7105381	170	150	153	151,443	yes	10,050	10,052	10,057	10,056	yes	yes
7108202	175	175	178	175,272	yes	3,000	2,750	3,000	3,000	yes	yes
7108202	175	175	178	176,984	yes	3,000	2,750	3,000	2,994	yes	yes
7108502	116	116	119	118,163	yes	2,500	2,495	2,505	2,508	no	no
7108502	116	116	119	118,042	yes	2,500	2,495	2,505	2,506	no	no
7108502	116	116	119	117,903	yes	2,500	2,495	2,505	2,500	yes	yes
7108502	116	116	119	116,990	yes	2,500	2,495	2,505	2,516	no	no
7108502	116	116	119	118,091	yes	2,500	2,495	2,505	2,502	yes	yes
7108502	116	116	119	118,043	yes	2,500	2,495	2,505	2,492	no	no
7108502	116	116	119	117,663	yes	2,500	2,495	2,505	2,500	yes	yes
7108502	116	116	119	118,017	yes	2,500	2,495	2,505	2,502	yes	yes
7108502	116	116	119	117,966	yes	2,500	2,495	2,505	2,492	no	no
7108503	120	120	123	121,652	yes	3,200	3,195	3,205	3,212	no	no
7108504	125	125	128	125,569	yes	3,300	3,295	3,305	3,294	no	no
7108504	125	125	128	125,307	yes	3,300	3,295	3,305	3,296	yes	yes
7108504	125	125	128	126,895	yes	3,300	3,295	3,305	3,294	no	no
7108504	125	125	128	126,444	yes	3,300	3,295	3,305	3,284	no	no
7108504	125	125	128	126,746	yes	3,300	3,295	3,305	3,296	yes	yes
7108504	125	125	128	126,411	yes	3,300	3,295	3,305	3,300	yes	yes
7108506	135	135	138	135,171	yes	4,000	3,995	4,005	3,980	no	no
7108506	135	135	138	137,391	yes	4,000	3,995	4,005	3,974	no	no
7108506	135	135	138	136,603	yes	4,000	3,995	4,005	4,004	yes	yes
7108506	135	135	138	137,531	yes	4,000	3,995	4,005	3,980	no	no
7108506	135	135	138	136,747	yes	4,000	3,995	4,005	4,016	no	no
7108506	135	135	138	136,660	yes	4,000	3,995	4,005	4,016	no	no
7108506	135	135	138	137,666	yes	4,000	3,995	4,005	3,998	yes	yes
7108506	135	135	138	137,062	yes	4,000	3,995	4,005	3,982	no	no
7108506	135	135	138	137,204	yes	4,000	3,995	4,005	3,976	no	no
7108506	135	135	138	135,098	yes	4,000	3,995	4,005	3,998	yes	yes
7108506	135	135	138	137,326	yes	4,000	3,995	4,005	4,028	no	no
7108508	135	135	138	136,104	yes	4,200	4,195	4,205	4,206	no	no
7108508	135	135	138	135,855	yes	4,200	4,195	4,205	4,200	yes	yes
7108508	135	135	138	135,767	yes	4,200	4,195	4,205	4,198	yes	yes
7108508	135	135	138	136,421	yes	4,200	4,195	4,205	4,232	no	no

7108508	135	135	138	136,263	yes	4,200	4,195	4,205	4,198	yes	yes
7108508	135	135	138	136,123	yes	4,200	4,195	4,205	4,186	no	no
7108508	135	135	138	136,693	yes	4,200	4,195	4,205	4,214	no	no
7108508	135	135	138	135,888	yes	4,200	4,195	4,205	4,218	no	no
7108508	135	135	138	137,106	yes	4,200	4,195	4,205	4,208	no	no
7108508	135	135	138	136,043	yes	4,200	4,195	4,205	4,196	yes	yes
7108509	130	130	133	130,497	yes	4,800	4,795	4,805	4,792	no	no
7108509	130	130	133	131,105	yes	4,800	4,795	4,805	4,800	yes	yes
7108509	130	130	133	131,632	yes	4,800	4,795	4,805	4,794	no	no
7108509	130	130	133	131,726	yes	4,800	4,795	4,805	4,786	no	no
7108509	130	130	133	131,463	yes	4,800	4,795	4,805	4,806	no	no
7108509	130	130	133	131,410	yes	4,800	4,795	4,805	4,804	yes	yes
7108509	130	130	133	131,378	yes	4,800	4,795	4,805	4,800	yes	yes
7108512	130	130	133	132,582	yes	5,100	5,095	5,105	5,106	no	no
7108514	135	135	142	136,792	yes	6,000	5,995	6,005	6,002	yes	yes
7108514	135	135	142	140,845	yes	6,000	5,995	6,005	5,984	no	no
7108514	135	135	142	141,535	yes	6,000	5,995	6,005	5,988	no	no
7108514	135	135	142	141,262	yes	6,000	5,995	6,005	5,982	no	no
7108514	135	135	142	140,970	yes	6,000	5,995	6,005	6,006	no	no
7108514	135	135	142	137,172	yes	6,000	5,995	6,005	5,992	no	no
7108514	135	135	142	141,763	yes	6,000	5,995	6,005	5,974	no	no
7108514	135	135	142	141,024	yes	6,000	5,995	6,005	5,974	no	no
7108514	135	135	142	141,494	yes	6,000	5,995	6,005	6,022	no	no
7108514	135	135	142	137,272	yes	6,000	5,995	6,005	6,000	yes	yes
7108517	153	153	157	156,257	yes	8,000	7,950	8,050	7,988	yes	yes
7108517	153	153	157	155,067	yes	8,000	7,950	8,050	7,982	yes	yes
7108517	153	153	157	156,014	yes	8,000	7,950	8,050	8,012	yes	yes
7108521	132	132	134	132,927	yes	4,400	4,395	4,405	4,386	no	no
7108538	130	130	133	131,595	yes	4,300	4,295	4,305	4,280	no	no
7108538	130	130	133	131,300	yes	4,300	4,295	4,305	4,296	yes	yes
7108538	130	130	133	131,385	yes	4,300	4,295	4,305	4,294	no	no
7108538	130	130	133	131,600	yes	4,300	4,295	4,305	4,280	no	no
7108538	130	130	133	131,399	yes	4,300	4,295	4,305	4,296	yes	yes
7108762	125	125	128	127,249	yes	2,500	2,495	2,505	2,492	no	no
7108762	125	125	128	126,835	yes	2,500	2,495	2,505	2,490	no	no
7108762	125	125	128	127,997	yes	2,500	2,495	2,505	2,496	yes	yes
7108762	125	125	128	127,018	yes	2,500	2,495	2,505	2,518	no	no
7108762	125	125	128	127,681	yes	2,500	2,495	2,505	2,498	yes	yes
7108762	125	125	128	126,735	yes	2,500	2,495	2,505	2,496	yes	yes
7108763	130	130	133	131,008	yes	3,200	3,195	3,205	3,202	yes	yes
7108763	130	130	133	131,311	yes	3,200	3,195	3,205	3,206	no	no

7108763	130	130	133	131,040	yes	3,200	3,195	3,205	3,198	yes	yes
7108763	130	130	133	131,180	yes	3,200	3,195	3,205	3,194	no	no
7108763	130	130	133	130,642	yes	3,200	3,195	3,205	3,230	no	no
7108765	133	133	136	134,889	yes	5,600	5,586	5,600	5,602	no	no
7108765	133	133	136	133,372	yes	5,600	5,586	5,600	5,600	yes	yes
7108767	136	136	139	137,257	yes	6,600	6,560	6,650	6,622	yes	yes
7108767	136	136	139	136,669	yes	6,600	6,560	6,650	6,618	yes	yes
7108767	136	136	139	137,264	yes	6,600	6,560	6,650	6,610	yes	yes
7108767	136	136	139	136,753	yes	6,600	6,560	6,650	6,634	yes	yes
7108767	136	136	139	137,740	yes	6,600	6,560	6,650	6,646	yes	yes
7108767	136	136	139	136,876	yes	6,600	6,560	6,650	6,604	yes	yes
7108767	136	136	139	137,098	yes	6,600	6,560	6,650	6,608	yes	yes
7108767	136	136	139	136,519	yes	6,600	6,560	6,650	6,588	yes	yes
7108767	136	136	139	137,457	yes	6,600	6,560	6,650	6,594	yes	yes
7108767	136	136	139	136,652	yes	6,600	6,560	6,650	6,600	yes	yes
7108767	136	136	139	136,690	yes	6,600	6,560	6,650	6,634	yes	yes
7108769	132	132	137	136,058	yes	6,350	6,350	6,414	6,354	yes	yes
7108769	132	132	137	135,943	yes	6,350	6,350	6,414	6,378	yes	yes
7108902	160	160	163	160,439	yes	9,520	9,510	9,530	9,870	no	no
7108902	160	160	163	162,261	yes	9,520	9,510	9,530	9,692	no	no
7108902	160	160	163	162,130	yes	9,520	9,510	9,530	9,450	no	no
7108902	160	160	163	162,293	yes	9,520	9,510	9,530	9,518	yes	yes
7108902	160	160	163	162,776	yes	9,520	9,510	9,530	9,692	no	no
7109501	180	180	183	182,819	yes	2,100	2,095	2,105	2,102	yes	yes
7109501	180	180	183	180,560	yes	2,100	2,095	2,105	2,088	no	no
7109501	180	180	183	180,456	yes	2,100	2,095	2,105	2,108	no	no
7109501	180	180	183	181,264	yes	2,100	2,095	2,105	2,098	yes	yes
7109501	180	180	183	181,597	yes	2,100	2,095	2,105	2,098	yes	yes
7109501	180	180	183	180,411	yes	2,100	2,095	2,105	2,114	no	no
7109501	180	180	183	181,761	yes	2,100	2,095	2,105	2,098	yes	yes
7109501	180	180	183	180,464	yes	2,100	2,095	2,105	2,134	no	no
7109503	180	180	183	180,204	yes	2,500	2,495	2,505	2,500	yes	yes
7109503	180	180	183	180,470	yes	2,500	2,495	2,505	2,490	no	no
7109503	180	180	183	182,366	yes	2,500	2,495	2,505	2,502	yes	yes
7109503	180	180	183	180,640	yes	2,500	2,495	2,505	2,432	no	no
7109503	180	180	183	181,398	yes	2,500	2,495	2,505	2,500	yes	yes
7109506	195	195	198	196,746	yes	4,000	3,995	4,005	4,000	yes	yes
7109506	195	195	198	197,363	yes	4,000	3,995	4,005	3,956	no	no
7109506	195	195	198	197,363	yes	4,000	3,995	4,005	3,956	no	no
7109514	195	195	202	196,079	yes	6,000	5,995	6,005	6,012	no	no
7109514	195	195	202	197,254	yes	6,000	5,995	6,005	5,986	no	no

7109514	195	195	202	199,000	yes	6,000	5,995	6,005	5,996	yes	yes
7109514	195	195	202	196,079	yes	6,000	5,995	6,005	6,012	no	no
7109525	195	195	198	196,343	yes	5,400	5,395	5,405	5,410	no	no
7109538	190	190	193	191,006	yes	4,300	4,295	4,305	4,284	no	no
7109538	190	190	193	191,531	yes	4,300	4,295	4,305	4,298	yes	yes
7109538	190	190	193	191,063	yes	4,300	4,295	4,305	4,302	yes	yes
7109538	190	190	193	191,062	yes	4,300	4,295	4,305	4,290	no	no
7109538	190	190	193	191,513	yes	4,300	4,295	4,305	4,294	no	no
7109538	190	190	193	191,524	yes	4,300	4,295	4,305	4,296	yes	yes
7109573	189	189	192	190,753	yes	4,300	4,282	4,300	4,310	no	no
7109573	189	189	192	190,479	yes	4,300	4,282	4,300	4,304	no	no
7109578	193	193	198	196,412	yes	5,800	5,782	5,800	5,790	yes	yes
7109578	193	193	198	194,607	yes	5,800	5,782	5,800	5,816	no	no
7109578	193	193	198	193,439	yes	5,800	5,782	5,800	5,788	yes	yes
7109578	193	193	198	194,316	yes	5,800	5,782	5,800	5,788	yes	yes
7109578	193	193	198	194,204	yes	5,800	5,782	5,800	5,794	yes	yes
7109763	190	190	193	191,607	yes	3,200	3,195	3,205	3,214	no	no
7112051	180	180	183	181,750	yes	2,000	1,995	2,005	2,122	no	no
7133107	120	120	123	121,472	yes	8,000	7,750	8,000	7,970	yes	yes
7133107	120	120	123	121,331	yes	8,000	7,750	8,000	7,980	yes	yes
7133107	120	120	123	121,371	yes	8,000	7,750	8,000	7,950	yes	yes
7133117	120	120	123	121,291	yes	8,000	7,750	8,000	7,980	yes	yes
7133117	120	120	123	121,331	yes	8,000	7,750	8,000	7,974	yes	yes
7133117	120	120	123	121,265	yes	8,000	7,750	8,000	7,968	yes	yes
7133117	120	120	123	121,280	yes	8,000	7,750	8,000	7,972	yes	yes
7133117	120	120	123	121,431	yes	8,000	7,750	8,000	7,964	yes	yes
7133117	120	120	123	121,330	yes	8,000	7,750	8,000	7,900	yes	yes
7133120	170	170	173	170,945	yes	6,000	5,980	6,000	5,982	yes	yes
7133120	170	170	173	171,421	yes	6,000	5,980	6,000	5,976	no	no
7133120	170	170	173	171,288	yes	6,000	5,980	6,000	5,976	no	no
7133120	170	170	173	171,282	yes	6,000	5,980	6,000	5,978	no	no
7133120	170	170	173	171,492	yes	6,000	5,980	6,000	5,974	no	no
7133120	170	170	173	171,266	yes	6,000	5,980	6,000	5,974	no	no
7133120	170	170	173	171,312	yes	6,000	5,980	6,000	5,996	yes	yes
7133120	170	170	173	171,312	yes	6,000	5,980	6,000	5,996	yes	yes
7133121	170	170	173	170,929	yes	8,000	7,980	8,000	7,948	no	no
7133121	170	170	173	171,367	yes	8,000	7,980	8,000	7,980	yes	yes
7133121	170	170	173	171,164	yes	8,000	7,980	8,000	7,984	yes	yes
7133121	170	170	173	171,547	yes	8,000	7,980	8,000	7,978	no	no
7133121	170	170	173	171,291	yes	8,000	7,980	8,000	8,008	no	no
7133121	170	170	173	171,432	yes	8,000	7,980	8,000	8,002	no	no

7133121	170	170	173	171,226	yes	8,000	7,980	8,000	7,988	yes	yes
7133122	162	162	165	162,891	yes	10,000	9,980	10,000	9,968	no	no
7133122	162	162	165	162,920	yes	10,000	9,980	10,000	9,974	no	no
7133122	162	162	165	162,448	yes	10,000	9,980	10,000	9,960	no	no
7133122	162	162	165	162,522	yes	10,000	9,980	10,000	9,972	no	no
7133122	162	162	165	162,888	yes	10,000	9,980	10,000	9,996	yes	yes
7133122	162	162	165	162,859	yes	10,000	9,980	10,000	9,994	yes	yes
7133400	110	110	113	111,433	yes	3,315	3,309	3,315	3,316	no	no
7133400	110	110	113	111,757	yes	3,315	3,309	3,315	3,310	yes	yes
7133400	110	110	113	110,404	yes	3,315	3,309	3,315	3,314	yes	yes
7133400	110	110	113	111,567	yes	3,315	3,309	3,315	3,288	no	no
7133400	110	110	113	111,357	yes	3,315	3,309	3,315	3,300	no	no
7133401	110	110	113	111,290	yes	4,205	4,205	4,235	4,198	no	no
7133401	110	110	113	111,231	yes	4,205	4,205	4,235	4,204	no	no
7133402	110	110	113	111,235	yes	5,100	5,092	5,100	5,104	no	no
7133402	110	110	113	111,792	yes	5,100	5,092	5,100	5,120	no	no
7133402	110	110	113	111,175	yes	5,100	5,092	5,100	5,092	yes	yes
7133402	110	110	113	110,952	yes	5,100	5,092	5,100	5,086	no	no
7133402	110	110	113	111,209	yes	5,100	5,092	5,100	5,100	yes	yes
7133463	103	103	106	104,655	yes	3,300	3,288	3,300	3,286	no	no
7133463	103	103	106	105,151	yes	3,300	3,288	3,300	3,322	no	no
7133463	103	103	106	103,766	yes	3,300	3,288	3,300	3,310	no	no
7133463	103	103	106	108,999	no	3,300	3,288	3,300	3,294	yes	no
7133467	109	109	112	110,051	yes	4,830	4,818	4,830	4,830	yes	yes
7133468	109	109	112	110,750	yes	4,860	4,848	4,860	4,852	yes	yes
7133468	109	109	112	110,360	yes	4,860	4,848	4,860	4,872	no	no
7133468	109	109	112	110,799	yes	4,860	4,848	4,860	4,852	yes	yes
7133468	109	109	112	110,153	yes	4,860	4,848	4,860	4,866	no	no
7133468	109	109	112	109,897	yes	4,860	4,848	4,860	4,850	yes	yes
7133468	109	109	112	110,193	yes	4,860	4,848	4,860	4,856	yes	yes
7133468	109	109	112	110,051	yes	4,860	4,848	4,860	4,860	yes	yes
7133468	109	109	112	109,907	yes	4,860	4,848	4,860	4,854	yes	yes
7133468	109	109	112	109,911	yes	4,860	4,848	4,860	4,856	yes	yes
7133468	109	109	112	110,204	yes	4,860	4,848	4,860	4,862	no	no
7133468	109	109	112	110,231	yes	4,860	4,848	4,860	4,872	no	no
7133468	109	109	112	110,968	yes	4,860	4,848	4,860	4,878	no	no
7133468	109	109	112	110,001	yes	4,860	4,848	4,860	4,846	no	no
7133468	109	109	112	110,219	yes	4,860	4,848	4,860	4,860	yes	yes
7133468	109	109	112	110,528	yes	4,860	4,848	4,860	4,858	yes	yes
7133468	109	109	112	110,845	yes	4,860	4,848	4,860	4,850	yes	yes
7133469	109	109	112	110,063	yes	5,100	5,088	5,100	5,098	yes	yes

7133469	109	109	112	110,355	yes	5,100	5,088	5,100	5,100	yes	yes
7133469	109	109	112	109,861	yes	5,100	5,088	5,100	5,092	yes	yes
7133470	115	115	118	116,103	yes	5,350	5,338	5,350	5,318	no	no
7133473	110	110	113	112,397	yes	6,400	6,385	6,400	6,402	no	no
7133473	110	110	113	111,787	yes	6,400	6,385	6,400	6,384	no	no
7133473	110	110	113	111,660	yes	6,400	6,385	6,400	6,402	no	no
7133473	110	110	113	110,820	yes	6,400	6,385	6,400	6,388	yes	yes
7133473	110	110	113	111,452	yes	6,400	6,385	6,400	6,394	yes	yes
7133473	110	110	113	111,260	yes	6,400	6,385	6,400	6,364	no	no
7133473	110	110	113	111,797	yes	6,400	6,385	6,400	6,388	yes	yes
7133473	110	110	113	110,921	yes	6,400	6,385	6,400	6,396	yes	yes
7133473	110	110	113	111,050	yes	6,400	6,385	6,400	6,396	yes	yes
7133473	110	110	113	111,393	yes	6,400	6,385	6,400	6,406	no	no
7133473	110	110	113	112,279	yes	6,400	6,385	6,400	6,396	yes	yes
7133473	110	110	113	110,652	yes	6,400	6,385	6,400	6,398	yes	yes
7133473	110	110	113	110,700	yes	6,400	6,385	6,400	6,382	no	no
7133473	110	110	113	111,139	yes	6,400	6,385	6,400	6,404	no	no
7133475	110	110	113	111,987	yes	6,650	6,635	6,650	6,656	no	no
7133479	170	170	173	170,923	yes	4,800	4,801	4,808	4,798	no	no
7133816	108	108	111	109,042	yes	5,050	5,000	5,100	5,052	yes	yes
7133873	111	111	114	112,000	yes	8,000	7,985	8,000	7,978	no	no
7133873	111	111	114	111,900	yes	8,000	7,985	8,000	8,000	yes	yes
7133873	111	111	114	111,916	yes	8,000	7,985	8,000	8,002	no	no
7133876	110	110	113	111,073	yes	8,000	7,985	8,000	7,990	yes	yes
7133876	110	110	113	111,030	yes	8,000	7,985	8,000	7,998	yes	yes
7133876	110	110	113	111,283	yes	8,000	7,985	8,000	8,002	no	no
7133876	110	110	113	110,753	yes	8,000	7,985	8,000	7,998	yes	yes
7133876	110	110	113	111,110	yes	8,000	7,985	8,000	7,994	yes	yes
7133876	110	110	113	111,217	yes	8,000	7,985	8,000	8,000	yes	yes
7133876	110	110	113	111,759	yes	8,000	7,985	8,000	7,984	no	no
7133876	110	110	113	112,411	yes	8,000	7,985	8,000	8,002	no	no
7133876	110	110	113	111,361	yes	8,000	7,985	8,000	8,016	no	no
7133876	110	110	113	110,931	yes	8,000	7,985	8,000	8,008	no	no
7133876	110	110	113	111,056	yes	8,000	7,985	8,000	7,988	yes	yes
7133876	110	110	113	112,013	yes	8,000	7,985	8,000	8,012	no	no
7133880	110	110	113	111,373	yes	8,000	7,750	8,000	7,984	yes	yes
7133917	200	200	203	201,113	yes	8,000	7,750	8,000	7,978	yes	yes
7133917	200	200	203	201,127	yes	8,000	7,750	8,000	7,970	yes	yes
7133917	200	200	203	200,660	yes	8,000	7,750	8,000	8,014	no	no
7133917	200	200	203	201,739	yes	8,000	7,750	8,000	7,982	yes	yes
7133917	200	200	203	200,743	yes	8,000	7,750	8,000	7,940	yes	yes

7133917	200	200	203	201,199	yes	8,000	7,750	8,000	7,984	yes	yes
7133917	200	200	203	201,211	yes	8,000	7,750	8,000	7,998	yes	yes
7133917	200	200	203	201,401	yes	8,000	7,750	8,000	7,984	yes	yes
7133917	200	200	203	201,077	yes	8,000	7,750	8,000	7,930	yes	yes
7133917	200	200	203	201,114	yes	8,000	7,750	8,000	7,964	yes	yes
7133917	200	200	203	201,272	yes	8,000	7,750	8,000	7,984	yes	yes
7133917	200	200	203	201,414	yes	8,000	7,750	8,000	7,966	yes	yes
7133917	200	200	203	201,304	yes	8,000	7,750	8,000	7,966	yes	yes
7133917	200	200	203	200,861	yes	8,000	7,750	8,000	7,968	yes	yes
7133917	200	200	203	201,386	yes	8,000	7,750	8,000	7,950	yes	yes
7133917	200	200	203	201,220	yes	8,000	7,750	8,000	7,988	yes	yes
7133917	200	200	203	201,182	yes	8,000	7,750	8,000	7,940	yes	yes
7133917	200	200	203	201,518	yes	8,000	7,750	8,000	7,860	yes	yes
7133917	200	200	203	201,580	yes	8,000	7,750	8,000	7,984	yes	yes
7133917	200	200	203	201,335	yes	8,000	7,750	8,000	7,998	yes	yes
7133917	200	200	203	201,735	yes	8,000	7,750	8,000	7,970	yes	yes
7133917	200	200	203	201,358	yes	8,000	7,750	8,000	7,948	yes	yes
7133917	200	200	203	201,425	yes	8,000	7,750	8,000	7,940	yes	yes
7133917	200	200	203	200,961	yes	8,000	7,750	8,000	7,978	yes	yes
7133917	200	200	203	201,424	yes	8,000	7,750	8,000	7,940	yes	yes
7133917	200	200	203	201,646	yes	8,000	7,750	8,000	7,998	yes	yes
7133917	200	200	203	201,264	yes	8,000	7,750	8,000	7,940	yes	yes
7133917	200	200	203	200,360	yes	8,000	7,750	8,000	7,910	yes	yes
7133917	200	200	203	201,216	yes	8,000	7,750	8,000	7,964	yes	yes
7133917	200	200	203	201,104	yes	8,000	7,750	8,000	7,990	yes	yes
7133917	200	200	203	200,643	yes	8,000	7,750	8,000	7,974	yes	yes
7133917	200	200	203	201,344	yes	8,000	7,750	8,000	7,890	yes	yes
7133917	200	200	203	201,651	yes	8,000	7,750	8,000	7,996	yes	yes
7133917	200	200	203	201,066	yes	8,000	7,750	8,000	7,992	yes	yes
7133917	200	200	203	201,116	yes	8,000	7,750	8,000	7,950	yes	yes
7133917	200	200	203	200,966	yes	8,000	7,750	8,000	7,914	yes	yes
7133917	200	200	203	201,501	yes	8,000	7,750	8,000	7,974	yes	yes
7133917	200	200	203	201,018	yes	8,000	7,750	8,000	7,932	yes	yes
7133917	200	200	203	201,710	yes	8,000	7,750	8,000	7,974	yes	yes
7133917	200	200	203	201,288	yes	8,000	7,750	8,000	8,016	no	no
7133917	200	200	203	200,569	yes	8,000	7,750	8,000	7,978	yes	yes
7133917	200	200	203	201,222	yes	8,000	7,750	8,000	7,980	yes	yes
7133917	200	200	203	201,149	yes	8,000	7,750	8,000	7,968	yes	yes
7133925	224	224	227	225,115	yes	6,000	5,942	6,000	6,000	yes	yes
7133925	224	224	227	224,705	yes	6,000	5,942	6,000	5,962	yes	yes
7133925	224	224	227	226,348	yes	6,000	5,942	6,000	5,986	yes	yes

7133925	224	224	227	225,088	yes	6,000	5,942	6,000	5,986	yes	yes
7133925	224	224	227	227,287	no	6,000	5,942	6,000	6,014	no	no
7133930	195	195	198	195,379	yes	12,000	11,930	12,000	11,966	yes	yes
7133930	195	195	198	196,006	yes	12,000	11,930	12,000	11,972	yes	yes
7133930	195	195	198	196,253	yes	12,000	11,930	12,000	11,998	yes	yes
7133963	183	183	186	185,035	yes	3,300	3,288	3,300	3,298	yes	yes
7133965	189	189	192	190,398	yes	4,210	4,198	4,210	4,212	no	no
7133965	189	189	192	189,681	yes	4,210	4,198	4,210	4,208	yes	yes
7133965	189	189	192	191,552	yes	4,210	4,198	4,210	4,224	no	no
7133968	189	189	192	190,224	yes	4,860	4,848	4,860	4,862	no	no
7133971	174	174	177	174,929	yes	3,000	2,990	3,000	2,992	yes	yes
7133975	190	190	193	191,156	yes	8,000	7,985	8,000	7,996	yes	yes
7133976	190	190	193	190,730	yes	8,000	7,985	8,000	8,002	no	no
7133976	190	190	193	191,427	yes	8,000	7,985	8,000	7,982	no	no
7133977	224	224	227	226,101	yes	6,000	5,988	6,000	5,972	no	no
7133977	224	224	227	225,277	yes	6,000	5,988	6,000	5,968	no	no
7133977	224	224	227	226,049	yes	6,000	5,988	6,000	6,008	no	no
7133980	109	109	112	109,705	yes	4,180	4,166	4,241	4,186	yes	yes
7133980	109	109	112	110,286	yes	4,180	4,166	4,241	4,196	yes	yes
7133980	109	109	112	110,348	yes	4,180	4,166	4,241	4,168	yes	yes
7133980	109	109	112	110,929	yes	4,180	4,166	4,241	4,192	yes	yes
7133980	109	109	112	111,553	yes	4,180	4,166	4,241	4,184	yes	yes
7133980	109	109	112	111,119	yes	4,180	4,166	4,241	4,180	yes	yes
7133980	109	109	112	110,472	yes	4,180	4,166	4,241	4,168	yes	yes
7133987	229	229	232	230,651	yes	4,180	4,168	4,180	4,174	yes	yes
7133998	210	208	212	209,082	yes	8,000	7,750	8,000	8,012	no	no
7134117	258	258	261	258,857	yes	8,000	7,750	8,000	7,948	yes	yes
7134117	258	258	261	258,937	yes	8,000	7,750	8,000	7,938	yes	yes
7134117	258	258	261	258,452	yes	8,000	7,750	8,000	7,964	yes	yes
7134117	258	258	261	259,090	yes	8,000	7,750	8,000	7,960	yes	yes
7134117	258	258	261	258,622	yes	8,000	7,750	8,000	7,920	yes	yes
7134117	258	258	261	259,106	yes	8,000	7,750	8,000	7,960	yes	yes
7134117	258	258	261	258,697	yes	8,000	7,750	8,000	7,970	yes	yes
7134117	258	258	261	259,168	yes	8,000	7,750	8,000	7,978	yes	yes
7134117	258	258	261	258,847	yes	8,000	7,750	8,000	7,938	yes	yes
7134117	258	258	261	258,606	yes	8,000	7,750	8,000	7,956	yes	yes
7134117	258	258	261	258,869	yes	8,000	7,750	8,000	7,930	yes	yes
7134121	263	263	266	264,514	yes	8,000	7,980	8,000	8,028	no	no
7134121	263	263	266	264,484	yes	8,000	7,980	8,000	7,962	no	no
7134121	263	263	266	264,820	yes	8,000	7,980	8,000	7,980	yes	yes
7134121	263	263	266	264,285	yes	8,000	7,980	8,000	7,966	no	no

7134121	263	263	266	264,904	yes	8,000	7,980	8,000	7,976	no	no
7134121	263	263	266	264,569	yes	8,000	7,980	8,000	7,976	no	no
7134121	263	263	266	265,418	yes	8,000	7,980	8,000	7,978	no	no
7134121	263	263	266	263,942	yes	8,000	7,980	8,000	7,998	yes	yes
7134121	263	263	266	264,736	yes	8,000	7,980	8,000	8,014	no	no
7134121	263	263	266	264,330	yes	8,000	7,980	8,000	7,998	yes	yes
7134121	263	263	266	264,095	yes	8,000	7,980	8,000	7,968	no	no
7134121	263	263	266	264,404	yes	8,000	7,980	8,000	7,996	yes	yes
7134121	263	263	266	265,983	yes	8,000	7,980	8,000	8,018	no	no
7134121	263	263	266	264,951	yes	8,000	7,980	8,000	7,980	yes	yes
7134121	263	263	266	264,639	yes	8,000	7,980	8,000	8,014	no	no
7134121	263	263	266	264,168	yes	8,000	7,980	8,000	8,008	no	no
7134121	263	263	266	264,432	yes	8,000	7,980	8,000	8,004	no	no
7134121	263	263	266	264,460	yes	8,000	7,980	8,000	8,000	yes	yes
7134121	263	263	266	264,968	yes	8,000	7,980	8,000	7,978	no	no
7134121	263	263	266	264,943	yes	8,000	7,980	8,000	7,974	no	no
7134121	263	263	266	263,760	yes	8,000	7,980	8,000	7,960	no	no
7134121	263	263	266	264,574	yes	8,000	7,980	8,000	7,994	yes	yes
7134121	263	263	266	264,288	yes	8,000	7,980	8,000	8,028	no	no
7134121	263	263	266	264,511	yes	8,000	7,980	8,000	8,024	no	no
7134121	263	263	266	264,862	yes	8,000	7,980	8,000	8,000	yes	yes
7134121	263	263	266	265,097	yes	8,000	7,980	8,000	7,964	no	no
7134121	263	263	266	264,481	yes	8,000	7,980	8,000	7,996	yes	yes
7134121	263	263	266	264,682	yes	8,000	7,980	8,000	8,006	no	no
7134121	263	263	266	264,481	yes	8,000	7,980	8,000	7,996	yes	yes
7134121	263	263	266	265,027	yes	8,000	7,980	8,000	8,028	no	no
7134126	300	300	303	301,360	yes	8,000	7,942	8,000	7,996	yes	yes
7134126	300	300	303	302,101	yes	8,000	7,942	8,000	8,000	yes	yes
7134825	295	295	298	296,838	yes	6,000	5,942	6,000	5,974	yes	yes
7134825	295	295	298	296,037	yes	6,000	5,942	6,000	6,012	no	no
7134825	295	295	298	296,030	yes	6,000	5,942	6,000	6,000	yes	yes
7134825	295	295	298	296,516	yes	6,000	5,942	6,000	6,014	no	no
7134825	295	295	298	296,823	yes	6,000	5,942	6,000	5,994	yes	yes
7134876	260	260	263	261,020	yes	8,000	7,985	8,000	8,004	no	no
7134925	304	304	306	305,659	yes	6,000	5,942	6,000	5,996	yes	yes
7134925	304	304	306	305,181	yes	6,000	5,942	6,000	6,010	no	no
7134925	304	304	306	306,208	no	6,000	5,942	6,000	6,008	no	no
7134963	240	240	243	240,672	yes	3,300	3,288	3,300	3,290	yes	yes
7134963	240	240	243	241,933	yes	3,300	3,288	3,300	3,298	yes	yes
7134963	240	240	243	241,037	yes	3,300	3,288	3,300	3,290	yes	yes
7134964	299	299	302	301,361	yes	4,202	4,202	4,210	4,184	no	no

7134964	299	299	302	300,427	yes	4,202	4,202	4,210	4,216	no	no
7134964	299	299	302	299,948	yes	4,202	4,202	4,210	4,208	yes	yes
7134964	299	299	302	301,627	yes	4,202	4,202	4,210	4,210	yes	yes
7134964	299	299	302	300,051	yes	4,202	4,202	4,210	4,206	yes	yes
7134964	299	299	302	299,955	yes	4,202	4,202	4,210	4,208	yes	yes
7134968	299	299	302	300,271	yes	4,860	4,852	4,860	4,868	no	no
7134969	299	299	302	301,634	yes	5,100	5,088	5,100	5,120	no	no
7134969	299	299	302	301,210	yes	5,100	5,088	5,100	5,098	yes	yes
7134969	299	299	302	301,095	yes	5,100	5,088	5,100	5,118	no	no
7134969	299	299	302	300,786	yes	5,100	5,088	5,100	5,114	no	no
7134969	299	299	302	300,340	yes	5,100	5,088	5,100	5,092	yes	yes
7134973	300	300	303	301,384	yes	6,400	6,385	6,400	6,402	no	no
7134980	239	239	242	241,364	yes	4,180	4,168	4,180	4,196	no	no
7134980	239	239	242	241,470	yes	4,180	4,168	4,180	4,166	no	no
7134980	239	239	242	239,992	yes	4,180	4,168	4,180	4,180	yes	yes
7134980	239	239	242	241,321	yes	4,180	4,168	4,180	4,178	yes	yes
7137400	190	190	193	191,320	yes	3,309	3,309	3,315	3,314	yes	yes
7137400	190	190	193	190,356	yes	3,309	3,309	3,315	3,304	no	no
7137469	189	189	202	190,027	yes	5,100	5,088	5,100	5,096	yes	yes
7137473	190	190	193	190,643	yes	6,400	6,385	6,400	6,404	no	no
7137473	190	190	193	191,248	yes	6,400	6,385	6,400	6,404	no	no
7137473	190	190	193	191,040	yes	6,400	6,385	6,400	6,392	yes	yes

10.2 Appendix B: Time measurements business case

Average time: 00:01:02 (hh:mm:ss)

Sum of times: 00:30:47 (hh:mm:ss)

Measurement	Rework time (hh:mm:ss)
1	00:04:48
2	00:00:00
3	00:01:22
4	00:00:00
5	00:02:10
6	00:03:05
7	00:00:00
8	00:05:50
9	00:00:00
10	00:00:00
11	00:00:00
12	00:01:49
13	00:00:00
14	00:02:31
15	00:00:00
16	00:00:00
17	00:00:00
18	00:01:15
19	00:00:00
20	00:00:00
21	00:00:00
22	00:00:00
23	00:03:57
24	00:00:00
25	00:02:03
26	00:00:00
27	00:00:00
28	00:00:56
29	00:00:00
30	00:01:01

10.3 Appendix C: Supporting diagnostic questions by Kepner and Tregoe

This appendix cites the list of diagnostic questions provided by Kepner and Tregoe for a performance system analysis [6]:

Questions to analyze the Response:

What is the observed performance?

How does it compare with expectations?

- What actions(s) or behaviors(s) have we observed?
- What have we seen instead of the desired Response? What alternative Responses have we observed?
- What results or outputs have been achieved?
- How do these compare with expected outputs described in performance expectations?
- How can the observed behavior be described specifically and accurately?
- How could we describe the desired Response to other people so that all of them could replicate the behaviors and output?
- How could we describe what action we observed to someone unfamiliar with the action or required behavior?
- What would a video of the observed behavior show?
- How has behavior varied over time?
- How many times has this behavior been seen?
- How consistent is this behavior?
- What elements of this undesired or alternative Response are always observed?
- What is the impact of the undesired or alternative Response on the organization?

Choose a second Response to create a basis for comparison. Compare the Responses to identify the performance gap. For a performance below expectation, select a Performer in the same Situation who has achieved or exceeded expectations. For a performance above expectation, choose a Performer at or below expectation. In either case, if one is not available, make the comparison with the ideal or expected performance.

Questions to compare Responses:

- How does the performance we are analyzing differ from the comparison performance?
- What specifically are the differences?
- How can the gap be quantified?
- How could the difference be described to an impartial observer?

Questions to analyze performance expectations:

How clear are the performance expectations and how well are they understood?

- What exists to describe what is expected of the Performer?
- How specific are the descriptions of outputs and end results, and of associated behaviors or actions?

- What are the appropriate measures of success (consider measures relating to the requirements for quality, quantity, cost, and timeliness)? Which of these, singly or combination, apply to each output?
- What level of performance is acceptable? What are the performance standards?
- How well are the expectations explained to the Performer?
- How well are specific measures and standards of expected performance clarified?
- What evidence exists that the Performer's preferred communication style was considered when discussing expectations?
- How well has the discussion of performance expectations been adjusted for compatibility with the Performer's preferred communication style, while retaining all necessary information?
- How well do these expectations math those for others, and for the organization?
- What does the Performer understand about expectations?
- What is the level of agreement about expectations between the Performer and performance coach?
- How does the Performer view these expectations? Are they considered attainable?
- How have the requirements changed since the last discussion about expectations?

Questions to analyze signals:

How clear is the signal to perform?

- What indicates the need to act?
- On whom or on what does the signal depend?
- How well can the Performer recognize when to perform?
- How clear, consistent, and timely is the signal?
- What level of judgement is required to interpret the signal?

Questions to analyze the work environment:

How well does the work environment support expected performance?

- What steps should be taken and tasks completed to accomplish the job?
- How well are these steps organized to create the best work flow?
- Where are steps duplicated or missing? Where are there inadequate interfaces between steps?
- How effective is the workflow?
- How well do job procedures and documentation match the work flow?
- How easy is it to complete the required documentation?
- What is the input necessary to complete the task? Is the input received by the Performer adequate? Is it accurate delivered at the right time?
- How are multiple or competing priorities clarified? What guidance exists for the Performer?
- What resources are provided to complete the job (people, equipment, tools, time, forms, information, space, money)? Are these resources available when required? Are they sufficient for the tasks?

- How supportive is the physical setting?
- What aspects of the physical environment impede performance?

Questions to analyze the Performer component:

How capable is the Performer to meet performance expectations?

- What are the prerequisite knowledge and skills for job success?
- How well are the knowledge and skill requirements understood?
- How well do the Performer's knowledge and skills match those required?
- What is being done to fill any gaps?
- How have these requirements changed since the job was originally designed?
- What aspects of knowledge and skills are required infrequently?
- How well does the Performer understand why the performance is expected?
- What preferred communication styles are best suited to this job?
- What benefits might other preferred communication styles bring to performance?
- What are the physical, emotional, or intellectual requirements for this job?
- What personal limitations to success might exist? (Test for specific information on physical, emotional, or intellectual difficulties and avoid labelling.)
- What evidence exists for concerns of this nature on other occasions when this Performer completed the job?
- What is the evidence for any temporary problems in these areas?
- What special circumstances might be causing a temporary problem?
- Overall, how well suited is this person to the job?

Questions to analyze Consequences:

How well do the Consequences encourage expected Performance?

- What happens to the Performer when the action or behavior is completed?
- What Consequences are in place, planned or not?
- What Consequences support alternative Responses, rather than expected performance?
- How does this specific Performer feel about these results of performance? Encouraged or discouraged?
- How significant are the Consequences to this Performer?
- How can the Consequences be made more personal?
- How appropriate are the Consequences, given the Performer's preferred communication style?
- How quickly do these events occur after the Response?
- How consistent are these Consequences over time for the same Response?
- What consequences can the Performer anticipate, based on previous performance?
- What is the impact on the organization? Positive or negative?
- How consistent are the Consequences to the Performer with organization results?
- How do the Consequences influence performance?

- On balance, how supportive are the Consequences of the desired performance?

Questions to analyze feedback:

How appropriate is the Feedback and how well is it used to influence performance?

- What information is received about performance?
- What information is given about results and about actions or behaviors?
- How closely is the information related to the organization Consequences?
- How completely are performance requirements covered? Is information on measures associated with all aspects of performance communicated?
- How well does the Feedback cover information on aspects of performance to be maintained on those to be modified?
- How is the delivery of Feedback tailored to fit the Performer's preferred communication style?
- How often is feedback given or available?
- How quickly is the information communicated after performance?
- How specific and accurate is the information?
- How has the accuracy of the Feedback been confirmed with the Performer?
- How easily and consistently can the information be interpreted?
- What steps have been taken to ensure the coach and the Performer have the same interpretation of the Feedback?
- How has the Performer's agreement with the feedback been tested?
- How well can information significant to performance be separated from all other available information?
- How well does the Feedback cover progress tracked over time?
- What is source of performance information? What should be the source?
- How constructive is the delivery of Feedback?
- How well does the Feedback combine sound analysis and effective coaching? (Does the Feedback include information on performance? Is the the Feedback delivered in a supportive manner?)
- What actions has the Performer agreed to take based on the Feedback? How was agreement reached?

10.4 Appendix D: Interviews performance system analysis

This appendix describes the performance system analysis by addressing the de diagnostic questions of Kepner and Tregoe. The underlying information was gathered via semi-structured interviews and observations at the presetting department. Four presetting operators have been interviewed as well as the coordinator of the presetting department (the executive manager of the presetting department). In addition, the TDM tool administrator has been questioned. In this document, the operators listed as operator 1, 2, 3 and 4 to denote every individual claim per operator.

<u>Questions to analyze the Response:</u>

What is the observed performance?

How does it compare with expectations?

What actions(s) or behaviors(s) have we observed?

See the process description of the presetting process (research question 1)

What have we seen instead of the desired Response? What alternative Responses have we observed?

Operators knock on the tool assembly, ignore the TDM tolerances, and do not always use the torque wrench. Furthermore, operators have to do rework such as measuring again and reassembling tool assemblies, although this is desired response, this response occurs too often, Fokker wants to have a presetting process wherein steps rarely have to be repeated.

The desired response is no knocking, obeying the TDM tolerances and using the torque wrench (from the perspective of the problem owner). In addition, rework is undesired i.e. the occurrence of rework should be as low as possible.

What results or outputs have been achieved?

The current output of the presetting department is around 12 tool assemblies per hour and 44% of the tool assemblies are not conforming TDM.

How do these compare with expected outputs described in performance expectations?

The performance expectations are currently not clearly defined. It is not established that the operator has to deliver the tool assemblies according to TDM (0% non-conforming). Nothing is stated about the desired output per hour (number of tool assemblies per hour). There is nothing stated about the amount of rework, what is acceptable. Moreover, it is not defined that the torque wrench should be used.

How can the observed behavior be described specifically and accurately?

How could we describe the desired Response to other people so that all of them could replicate the behaviors and output?

With process maps and a description in text including photos of the various activities. Fokker uses a standard TPD/PI format, this can also be used to describe the process to strangers.

How could we describe what action we observed to someone unfamiliar with the action or required behavior?

With process maps and a description in text including photos of the various activities

What would a video of the observed behavior show?

How has behavior varied over time?

The operators and coordinator explained that the torque wrench was added to the presetting process one year ago; from that point, the operators had to execute the tightening with the torque master. A new heating machine and measuring machine were installed at the presetting department two years ago. However, the steps in the presetting process remained unchanged.

How many times has this behavior been seen?

How consistent is this behavior?

Operator 1 explained that 40% of the tool assemblies made with collet chuck holder are meeting the tolerances of TDM at the first measuring attempt. For tool assemblies made with shrink fit holders, 95% of the tool assemblies are meeting the tolerances of TDM at the first time. It was furthermore said that it is nearly always a non-conforming diameter that makes the tool assembly not meeting the TDM tolerances.

If the tool assembly's diameter is not conforming the TDM tolerances, it depends on the situation and the opinion of the operator how he addresses the problem. The options are knocking, reassembling (replacing or cleaning components) or ignoring the tolerances (assuming that the cutting tool is not dirty and that the right cutting tool is assembled). Sometimes the operator knocks multiple times on the assembly, sometimes knocking is followed by the reassembly of a tool assembly and another time the tool assembly is immediately reassembled or send to machining right away (TDM is then ignored). All operators were asked how often each scenario occurs in the situation of non-conforming measurement, but they could not (or did not want to) classify how many times every scenario occurs. It is clear that knocking is mostly done on collet chuck holders, because for shrink fit holders this does not help.

Moreover, the coordinator explained that there are some differences between operators. He explained that the view on ignoring the TDM tolerances depends on the individual operator. One operator does a lot of effort to obtain a good tool assembly (reassembling, knocking, and measuring multiple times), while another worker releases the tool assembly after one non-conforming measurement. Furthermore, all interviewed operators explained that when they ignore TDM tolerances they take the application/use of a certain tool assembly into account to evaluate if a deviation (from the TDM tolerances) is acceptable/problematic or not. In other words, based on their own interpretation/belief of what accuracy is required at production (for machining) for a certain tool assembly, they judge the measurement values and ignore the tolerances if they think it is acceptable. Some operators worked at machining in the past, as a result, they believe to know what accuracy is required for a certain cutting tool/tool assembly. However, not all presetting operators have experience at production and although they claim to know the exact destination/use of each tool assembly, they practically cannot know all the cutting operations for which a tool assembly is used, because tool assemblies are used for multiple products and in different cutting procedures. In addition, there are approximately 500 different tool assemblies.

What elements of this undesired or alternative Response are always observed?

Knocking on tool assemblies is done by all the operators at the presetting department. Releasing unauthorized tool assemblies is also done by all operators, although every operator has his own interpretation of when he should send them to machining. All operators replied to always use the torque wrench for tightening the nut of a collet chuck holder. However, it was observed that sometimes the nut is only tightened manually. Operator 3 explained that he sometimes disassembles collet chuck holders that were not properly tightened (too weakly or too strongly) by one of his colleagues. Operator 2 explained that he does not use the torque wrench when the wrench is not available because a colleague is using it. On the other hand, it was also observed that the torque wrench is not used even when it is available (Operator 4). To put briefly, the torque wrench is not always used.

What is the impact of the undesired or alternative Response on the organization?

As a result of rework and additional activities (knocking and reassembling), time is wasted in the presetting process (resulting in higher operational costs). The knocking on the tool assembly is done when it is still positioned on the measuring machine, therefore, this might damage the measuring machine. One operator believes that the measuring machine became less accurate over time, as a result of knocking. The costs of repairing damage to a measuring machine are considerably high. If the measuring machine becomes less accurate due to damage from knocking, this implies that the tool assemblies may not be correctly checked/assessed anymore. Inaccurate/wrong tool assemblies can then be send to machining. Moreover, knocking on the tool assembly can also lead to cutting tool breakage, which in fact results in higher operational costs for the presetting department.

The impact of ignoring the tolerances of TDM is that the dimensions of new tool assemblies flowing into machining process are not controlled. When the TDM tolerances are not handled, but operators decide by themselves whether the tool assembly is sufficiently accurate for production or not, the variation of tool assemblies used at machining depends on personal opinions rather than facts. As a result, the inflow variation is unpredictable, increasing the risk of tooling problems during machining, such as swaying cutting tools or tool breakage.

When the torque wrench is not used, two undesirable events can occur when the collet chuck is tightened only manually: If the nut is tightened too weakly, the cutting tool is not clamped sufficiently and therefore may sway during machining or even let loose. This can damage products during machining. If the nut is tightened too strongly, the collet chuck deforms or even breaks. When the collet breaks or deforms, the cutting tool is not clamped sufficiently and might also sway or let loose during machining. Broken or deformed collet chucks have to be replaced (leading to higher operational costs). Oftentimes, the operator does not notice that he deforms the collet, as a result, deformed collet chucks are not thrown away but kept in stock. Thus, the quality of the collet chucks at the presetting department degrades over time.

Questions to compare Responses:

How does the performance we are analyzing differ from the comparison performance?

This operator prepares more tool assemblies per hour than the others.

What specifically are the differences?

This operator easily prepares more than 15 tool assemblies per hour, but more assemblies are not meeting the TDM tolerances.

How can the gap be quantified?

This operator more often ignores the TDM tolerances, and barely spends time on correcting/changing the non-conformance of a tool assembly. Therefore, he saves a lot of time and is able to prepare more tool assemblies per hour. However, the quality of his output (tool assemblies) is lower.

How could the difference be described to an impartial observer?

This individual focuses more on quantity than quality.

Questions to analyze performance expectations:

How clear are the performance expectations and how well are they understood?

What exists to describe what is expected of the Performer?

How specific are the descriptions of outputs and end results, and of associated behaviors or actions?

The TDM database specifies the components and presetting dimensions (tolerances) of each tool assembly. There exists a report that shortly describes the presetting process. This report was sent to one of Fokker's customers to clarify the presetting process after a defect product. It describes the various tool holder types and very curtly some of the assembly and measure steps (written as a telegraph). Thus, the core steps are very shortly discussed in the report. However, it is not a work instruction for an operator (process documentation). It is absolutely not reproducible, a stranger would not be able to execute the presetting process based on the descriptions of this report. Furthermore, there exists a user manual for the computer of the measuring machine. It explains how to use the computer software of the measuring machine. Hence, it is very briefly reported what is done at the presetting department, but not how it should be done. Thus, the expectations for the presetting process are not well described, because there is no work instruction or detailed document that describes all the necessary actions/behaviors for a good presetting process. Besides, the expected output/end results of the presetting process are partly described. TDM defines what tool assembly should be delivered (which components and dimensions) however, it is not clearly/officially described that the operator is expected to deliver the tool assemblies always conforming the tolerances of TDM. It is not defined how many tool assemblies an operator should make within a certain time.

Furthermore, it is not stated that knocking is not allowed and that the operator should use the torque wrench. Because the presetting process is not well described, it is not stated what the operator should do in case of a non-conforming tool assembly.

What are the appropriate measures of success (consider measures relating to the requirements for quality, quantity, cost, and timeliness)? Which of these, singly or combination, apply to each output?

What level of performance is acceptable? What are the performance standards?

How well are the expectations explained to the Performer?

The technical engineers of composite machining (working for the problem owner) expect the presetting department to deliver the tools based on the tolerances of TDM. The engineers usually have contact with the coordinator, and because the coordinator manages/coordinates the presetting department, he is supposed to explain these expectations to his operators on the floor. Furthermore, it is supposed that the tool coordinator communicates the right expectations for the actions/behaviors in the presetting process such that the desired output (conforming tool assemblies) can be achieved. Nevertheless, it turns out that the performance expectations are not well explained to the workers on the floor.

The operators said to know that they are expected to deliver tool assemblies conforming TDM, because the coordinator explained this to them. The coordinator said that he explained to his operators to use the torque wrench and that they have to deliver tool assemblies conforming TDM. Furthermore, the operators understand that they are expected to deliver all ordered tool assemblies before midnight. The coordinator explained to the operators that they are expected to complete all order lists on the same day. Except from that, the performance expectations have not been explained to the operators. The operators answered that the expectations about how they should assemble and measure a tool assembly are not explained to them. In other words, it is not explained what actions/behaviors are expected for presetting. To conclude, expectations are not well explained to the operators.

How well are specific measures and standards of expected performance clarified?

What evidence exists that the Performer's preferred communication style was considered when discussing expectations?

How well has the discussion of performance expectations been adjusted for compatibility with the Performer's preferred communication style, while retaining all necessary information?

How well do these expectations match those for others, and for the organization?

What does the Performer understand about expectations?

What is the level of agreement about expectations between the Performer and performance coach?

How does the Performer view these expectations? Are they considered attainable?

All operators explained that they find the expectation of releasing all tool assemblies conforming TDM not attainable/realistic. The operators find the requirements for releasing tool assemblies, the TDM tolerances, often not realistic. The operators replied that especially the tolerances for assemblies including a collet chuck holder are not attainable, because the diameter tolerances are set too tight. For shrink fit holders, the requirements can often be met, thus these tolerances are considered attainable.

In particular, the diameter tolerances cannot be satisfied for tool assemblies. The coordinator also views the TDM tolerances not attainable. Operators 1, 2 and 3 replied that the current tolerances for collet chuck holders become more attainable, when they have good materials (tool holders) at hand. This point is further discussed at the work environment part of the analysis.

Moreover, the expectation of using the torque wrench for all collet chuck holders is considered as attainable. All operators view the expectations of completing the ordered tool assemblies before the end of the day attainable.

How have the requirements changed since the last discussion about expectations?

Operators 3 and 4 replied that in the past, some tolerances were changed, after complaining to the coordinator. Most of these modifications included wrong presetting values (mistakes), instead of correct values that were unattainable during measuring. In other words, the majority of the presetting tolerances in TDM have never been adjusted.

The reason for this is that the TDM tool administrator who sets the presetting tolerances is situated at the other side of the factory terrain and as a result the collaboration (and communication) between the TDM administrator and presetting department is low. The operators at the presetting department believe that complaining, or indicating problems does not help, because the TDM administrator or engineers from composite production do not listen to them. On the other hand, the TDM administrator explained that he is rarely asked to adjust tolerances in TDM by the presetting department, although he asked/told to the presetting operators to communicate problems regarding TDM to him. Furthermore, adjustments in TDM are difficult to make because modified tool assemblies (dimensions) need to be evaluated in various simulation programs, before an adjustment is approved for production. The reason for this is that a tool assembly is used for cutting various products, and that every CNC program should be checked to assess whether parameters can be modified.

Questions to analyze signals:

How clear is the signal to perform?

What indicates the need to act?

An incoming tool order list indicates the need to act (preparing tool assemblies)

On whom or on what does the signal depend?

The tool order lists are composed by the operators of the machining department. The content of the order list depends on the needed/used tool assemblies for production (machining).

How well can the Performer recognize when to perform?

The performer is expected to start as soon as possible with the preparation of the tool assemblies for composite machining, after finishing the tool assemblies for metal machining.

How clear, consistent, and timely is the signal?

The signal is clear and consistent, because the tool order list precisely specifies what tool assembly is needed (cutting tool and holder), including the desired presetting requirements (length and diameter). The signal is also timely. There is an agreement between the presetting department and the machining department regarding the ordering time of tool assemblies. The order list has to be send to the presetting department before 1 PM whereas the tool assemblies have to be finished/ready before 11 PM on the same day. Thus, the presetting department has 10 hours after the signal to perform, to prepare all tool assemblies.

What level of judgement is required to interpret the signal?

No judgement is needed, an incoming order means that the operator has to prepare the defined tool assemblies on the list before the end of the day.

Questions to analyze the work environment:

How well does the work environment support expected performance?

What steps should be taken and tasks completed to accomplish the job?

See the answer on research question 1.

How well are these steps organized to create the best work flow?

Where are steps duplicated or missing? Where are there inadequate interfaces between steps?

There are no steps duplicated in the process, only in the situation when the tool assembly is not meeting the tolerances from TDM, some steps of the measuring (and sometimes assembling) process are repeated.

How effective is the workflow?

The effectiveness of the workflow depends on the characteristics of the operator: One worker assembles and measures one tool assembly at a time whereas another operator first assembles all tool assemblies, and then measures all assemblies after each other (said the coordinator). In the latter situation, the workflow is more effective. Some operators cool shrink holders down in batches whereas others cool each tool assembly independently. In the situation of a non-conforming tool assembly, the workflow is quite effective because the operator can distinguish the type of cause with the graphical zoom display. He can than act upon that to solve the problem. On the other hand, it might take several attempts to get the tool assembly conforming specifications.

How well do job procedures and documentation match the work flow?

How easy is it to complete the required documentation?

It is easy to complete the documentation in the presetting process. The tool order list is automatically printed. The computer of the measuring machine automatically prints the tool delivery list, after approving the tool assembly. The operator only has put his signature on the delivery list to complete the documentation.

What is the input necessary to complete the task? Is the input received by the Performer adequate? Is it accurate delivered at the right time?

How are multiple or competing priorities clarified? What guidance exists for the Performer?

Competing priorities are not clarified on paper, although there is a verbal agreement. Beyond the preparation of tool assemblies, the presetting department also delivers protective equipment and tools for production. For non-urgent matters, the presetting department has two standard opening hours wherein materials can be picked up by employees from production. The rest of the day the presetting operators should officially focus on the preparation of ordered tool assemblies. However, the standard presetting process is sometimes disrupted because production needs a new tool assembly on the spot because a tool assembly broke down. Depending on the urgency, the operator then stops with his normal work, and first prepares this tool assembly to continue production. The worker is then disrupted in his work. The guidance is that the operator only stops with his normal work if there is an urgent problem that stops production, nevertheless, the judgement of the urgency done by the operator himself and the manager from production that is setting out the request.

What resources are provided to complete the job (people, equipment, tools, time, forms, information, space, money)? Are these resources available when required? Are they sufficient for the tasks?

The coordinator explained that the presetting department has sufficient time and people to fulfill the presetting process for composite machining. Besides, the machines and equipment are appropriate for the task of presetting. In particular, the presetting department is provided with high quality presetting machinery and equipment. All operators agreed that they have the best machines and equipment at hand for presetting.

However, there are some issues concerning the tool holders: sometimes the presetting operator cannot prepare/deliver the desired tool assembly because the right tool holder is not available/present (in stock) at the presetting department. In other words, there sometimes is a shortage of tool holders (or tool holder components). Operators 3 and 4 and the coordinator said this in the interview. This is due to the fact that the number of tool holders in circulation is low and because the machining department does not always send the tool assemblies immediately back. In fact, tool assemblies are sometimes ordered, but stay long at the machining department, because they are not used or the machining operator wants to keep some extra tool assemblies at the machine (he is building extra stock, by ordering more assemblies than needed).

Moreover, the tool holders are not always sufficient for the task (achieving the TDM tolerances). With good shrink holders the expectations (TDM tolerances) can easily be attained. However, with good collet chuck holders the desired measurements still cannot always be achieved, because a collet chuck holder is physically/technically not suitable to obtain a very accurate tool assembly, as required by TDM. In other words, the current TDM tolerances are not matching the physical capabilities of a collet chuck holder. To put differently, collet chuck holders are not capable to always meet the current TDM tolerances. Furthermore, the state of the collet chucks is not great. Operators 1 and 2 explained this during the interview. Approximately 70% of all collet chucks are old (deformed and worn out) and therefore insufficient for achieving the requirements. In fact, these old collet chucks are not accurate and reliable and should not be used anymore. However, these collet chucks are still used in practice because there are not enough new and good collets available at the presetting department. In other words, there is a shortage of good collet chucks. All operators replied that they rather use new collet chucks if these are available at the presetting departments, but that it often happens that they are forced to use old/worn out collets because all good/new collets are already sent to production. Operator 1, 2 and 4 explained that the tolerances of TDM can hardly be met with old and worn out collets. Operator 2 also replied that the use of old collet chucks provokes knocking on the tool assembly.

It was claimed by operator 1 that the high amount of poor collet chucks emerged from inadequate tightening of collet chuck holders in the past. Before the torque wrench was introduced (one year ago) the nut was just manually tightened, enabling too strong tightening (deforming collets). Furthermore, the torque wrench is still not always used, thus, collet chuck are still deformed nowadays. Another cause of worn out collet chucks is that operators sometimes use the wrong collet chuck in an tool assembly, because the right collet chuck is out of stock. For instance, a cutting tool of 4.1 should be placed in a collet chuck of 4.5, however, in case this collet is not available, the operator can alternatively pick a collet chuck of 4.0 and push the cutting tool in this collet, even though he knows this is not good because the collet gets deformed/damaged. This was mentioned by operators 2 and 3.

Moreover, operators 1, 2 and 3 replied that there also exist a shortage in good tightening nuts for collet chucks holders. There are currently two type of nuts in circulation: a new type and an old type of nut. The operators explained that the new type tightening nut clamps the collet chuck better than the old type, because the collet is better positioned in the nut, resulting in a better (more accurate) tool assembly. Currently, 50% of the nuts in circulation are from the new type. All operators said they prefer to use the new type of nut, however, the new nuts are sometimes out of stock. Consequently, old nuts are also used.

The state of shrink fit holders is much better. There are generally no problems with shrink holders based on the state of the tool holders. Shrink fit holders are sooner replaced than collet chuck holders when they are not accurate anymore. However, it occasionally happens that a shrink holder is heated too much, but is not replaced and kept for use.

How supportive is the physical setting?

What aspects of the physical environment impede performance?

The coordinator believes that the physical setting is supportive, although there is little room at the presetting department. Operator 3 explained that there is little space at the presetting department, and that this is sometimes bothersome during presetting. Operator 1 and 2 explained that the workplace is dirty/dusty because used tool assemblies are currently cleaned at the presetting department, since the machining department sends them back dirty. After cleaning (blowing with compressed air), composite powder/dust whirls around, polluting the machinery and equipment at the presetting department. This is unfavorable for a good presetting process. Operator 2 believes that the presetting department should be situated in a clean secluded room, where the temperature and humidity are controlled.

Questions to analyze the Performer component:

How capable is the Performer to meet performance expectations?

What are the prerequisite knowledge and skills for job success?

The coordinator explained that the prerequisite knowledge and skills for presetting are not specified. It is not established/documented what knowledge and skills are required for job success. Therefore, it cannot factually be assessed if a new or current operator is capable to meet the performance expectations. Consequently, there are no starting/entrance requirements regarding skills and knowledge for a new presetting operator. For the coordinator, the most important characteristic for a presetting operator is that he can work precisely. Operator 2 and 3 also explained that a crucial characteristic is that the person works accurately.

The operator should know how the measuring machine works. Furthermore, he should have knowledge about how the shrinking, mounting and measuring process has to be performed. Lastly, the operator has to have skills in assembling and measuring tool assemblies.

How well are the knowledge and skill requirements understood?

How well do the Performer's knowledge and skills match those required?

What is being done to fill any gaps?

Besides, a new presetting operator is not trained before he starts working at the presetting department, so he has to learn on the job. New presetting operators are trained on the job by an experienced operator. The content of training is not specified. The taught behavior depends on the individual operator that trains the new operator.

How have these requirements changed since the job was originally designed?

What aspects of knowledge and skills are required infrequently?

How well does the Performer understand why the performance is expected?

What preferred communication styles are best suited to this job?

What benefits might other preferred communication styles bring to performance?

What are the physical, emotional, or intellectual requirements for this job?

What personal limitations to success might exist? (Test for specific information on physical, emotional, or intellectual difficulties and avoid labelling.)

What evidence exists for concerns of this nature on other occasions when this Performer completed the job?

What is the evidence for any temporary problems in these areas?

What special circumstances might be causing a temporary problem?

Overall, how well suited is this person to the job?

According to the coordinator, every operator at the presetting department is suited to the job, but this claim is not based on the assessment of prescribed competences/criteria for a presetting operator. The coordinator evaluates the operators based on their experience. All operators have multiple years of experience at the presetting department. In addition, all operators have knowledge about the measuring machine as well as the assembly and measure process. Thus, based on this it is assumed/concluded that the operators have the required knowledge and skills for presetting.

<u>Questions to analyze Consequences:</u>

How well do the Consequences encourage expected Performance?

What happens to the Performer when the action or behavior is completed?

When the operator delivers every tool assembly conforming TDM, without knocking on the tool assembly the consequence for him is that he loses a lot of time (because he has to reassemble and replace the tool assembly various times, while there is still a possibility that he ultimately cannot deliver the tool assembly according to the requirements (since it is difficult to achieve the requirements). These are negative consequences for the presetting operator. When the operator loses much time on getting it right he cannot complete all ordered tool assemblies before the end of the day. The coordinator then complains that he has not delivered the tool assemblies on time (the expectation is that all assemblies are completed by the end of the day, the coordinator checks this). The same holds for choosing not to deliver a tool assembly because it is not conforming TDM, production (the manager of machining) then complains that they need the tool assembly for production. Operators 3 and 4 replied they have to deliver/release the tool assemblies anyway (no matter in what state), because otherwise production is interrupted. A positive consequence of sticking to TDM is that the operator cannot be seen as responsible for problems in production, because he has released it according to the requirements. However, the operator is not rewarded for delivering the tool assemblies conforming TDM. For some reason, there is no positive reaction from composite machining (or production management) that encourages the operator to work conforming to the TDM tolerances. The coordinator does not stimulate the operators to stick to the tolerances of TDM without knocking.

The positive consequence of using the torque wrench is that the cutting tool is appropriately clamped and that the operator knows that he does not deform or damage the collet. The negative consequence is that the operator has to perform an extra activity that costs him some more time. Sometimes the operator has to wait on a colleague, before the torque wrench is available, so this extra costs time.

What Consequences are in place, planned or not?

What Consequences support alternative Responses, rather than expected performance?

A positive consequence of knocking on the tool assembly is that the operator can save time and thus work faster (prepare more per hour) while the tool assembly meets the TDM requirements (if knocking works). In addition, the operator does not have to reassemble the tool assembly, which is also an annoying task for him. Furthermore, the operator can deliver all tool assemblies before end of the day such that the coordinator is satisfied, thus this is positive consequence for him. The tool assemblies are meeting the tolerances, so he has met the requirements for production (TDM). There are currently no negative consequences related to knocking because this does not lead to negative feedback from production. All operators replied that they have never heard anything from production about problems caused by knocking.

For ignoring the tolerances, the consequences are very similar to knocking: the positive consequence is that the operator can save time, work faster, and thus finish his work (the ordered assemblies) before the end of the day. There are no negative consequences because the operator is not punished for ignoring the tolerances. Furthermore, this behavior does not lead to more complains from production, so the operator is not discouraged about this. All operators replied that they have never had any complaints from production about releasing tool assemblies not meeting the tolerances of TDM.

The positive consequence of not using the torque wrench is that time can be saved. The negative consequence of not using the torque wrench is that the tool assembly might not be adequately clamped and causes damage to the product at production (machining). In the past, there have been complaints from machining that the tool assemblies caused defect products because they were not tightened appropriately. However, there have been only a few incidents, so the operators do not often get complaints from production if they do not use the torque wrench.

How does this specific Performer feel about these results of performance? Encouraged or discouraged?

The operators are satisfied with the current performance, even though they admit that they should not knock on the tool assembly. However, all operators replied that they have no other choice than performing like this (including knocking and ignoring), because they have to deliver the tool assemblies anyway because production needs them. Furthermore, because knocking an ignoring the tolerances rarely leads to complaints/problems at production they think they are doing a good job (encouraged). The operators are currently delivering the tool assemblies before the end of the day, they feel encouraged about that, because the coordinator and production manager find this important.

How significant are the Consequences to this Performer?

The consequences are significant for the operators. Complaints by the coordinator or manager from production are harmful for the operator, because after multiple complaints they could lose their job (the coordinator and production manager can ultimately fire people, if they are not satisfied).

How can the Consequences be made more personal?

How appropriate are the Consequences, given the Performer's preferred communication style?

How quickly do these events occur after the Response?

If the tool assemblies are not finished before the end of the day or not prepared at all, the complaints (consequences) occur quickly, mostly within a day. However, complaints about problems at production can arise somewhat later, it can take a day up to several weeks before a tool assembly is used at machining, so if there is something wrong with a tool assembly due to a presetting, the consequences (complaints) happen not always immediately.

How consistent are these Consequences over time for the same Response?

The consequences are consistent for the same response. The consequences are usually the same, only for not using the torque wrench it might differ because this rarely leads to complaints from production.

What consequences can the Performer anticipate, based on previous performance?

What is the impact on the organization? Positive or negative?

The alternative responses have a negative impact on the organization. See the analysis of the response component for more details about this point.

How consistent are the Consequences to the Performer with organization results?

How do the Consequences influence performance?

On balance, how supportive are the Consequences of the desired performance?

The consequences for desired performance are not supportive, the current consequences provoke alternative behavior more than the desired behavior. Since the negative consequences outweigh the positive consequences for the desired performance, the operators are discouraged to stick to TDM without knocking. Because of multiple positive consequences, the operators are encouraged to knock on the tool assembly or ignore the TDM tolerances. For the use of the torque wrench the consequences are more supportive, however, since the operators are not discouraged to not use the torque wrench, they are still sometimes not using it.

<u>Questions to analyze feedback:</u>

How appropriate is the Feedback and how well is it used to influence performance?

What information is received about performance?

What information is given about results and about actions or behaviors?

How closely is the information related to the organization Consequences?

By measuring the tool assembly after assembling, the presetting operators receive feedback about their performance. The length and diameter are precisely measured; the machine provides measuring values with an accuracy of a thousandth of a millimeter. With the graphical zoom display on the measuring machine, the operator can observe whether the cutting tool is standing skew in the holder, or is dusty. In addition, the cutting surfaces of cutting tools can be observed, to check whether a cutting tool is adequately sharpened. The operator can also check whether the tool assemblies is correctly measured by the measuring machine (if the machine measured the exterior correctly). Hence, the operators receive adequate direct feedback about their performance. Moreover, this information is used to influence performance, because operators sometimes (depending on the scenario) modify/change tool assemblies based on this data (e.g. reassembling and knocking).

Moreover, the operators indirectly get feedback about their performance by complaints from production (machining). If there are defects at machining resulting from a tool assembly, an official NC (non-conformance) report is established and the coordinator is contacted about the issue/problem. The coordinator then investigates which presetting operator has prepared the concerned tool assembly (this data is monitored in a handbook), and discusses the defect/problem with the operator. The impact on production (the consequence for the organization) is explained to the operator and if it was the operators fault, he is held responsible. In other words, the operator receives feedback about his performance. NC's at machining are also explained to the other operators (by the coordinator).

Furthermore, the operators receive feedback about their working pace. The coordinator checks whether the order lists are completed before the end of the day. If the operators have not completed the order lists on time, he gives feedback to the operators that they should work quicker.

How completely are performance requirements covered? Is information on measures associated with all aspects of performance communicated?

The performance requirements are not completely covered. Feedback is provided about the working pace/delivery time and mistakes, however, there is currently no information provided about the proportion of tool assemblies conforming TDM. It is not calculated how much tool assemblies are meeting the tolerances. The presetting operators are not coached based on the accuracy/quality of the prepared tool assemblies. Furthermore, the coordinator does not give feedback to influence the performance of the presetting operators. No feedback is given to prevent knocking, ignoring tolerances or not using the torque wrench.

How well does the Feedback cover information on aspects of performance to be maintained on those to be modified?

How is the delivery of Feedback tailored to fit the Performer's preferred communication style?

How often is feedback given or available?

The feedback from the measuring machine is always available after assembling. The feedback from production only applies when there are NC reports at production.

How quickly is the information communicated after performance?

The information of the measuring machine is quickly available, since the tool assemblies are directly measured after assembling. The feedback from production is received later, since this information is communicated after machining, if there are NC's. It lasts several weeks or even months before a tool assembly is used at machining, so this feedback is received lately after performance.

How specific and accurate is the information?

The current feedback is accurate and specific. The measuring machine provides detailed information about the physical tool assembly. When there is an NC report, the problem/issue is clear.

How has the accuracy of the Feedback been confirmed with the Performer?

How easily and consistently can the information be interpreted?

What steps have been taken to ensure the coach and the Performer have the same interpretation of the Feedback?

How has the Performer's agreement with the feedback been tested?

How well can information significant to performance be separated from all other available information?

How well does the Feedback cover progress tracked over time?

There is currently no feedback given to track progress over time.

What is source of performance information? What should be the source?

The sources are currently the machining department (for NC reports), the measuring machine and the coordinator. The coordinator should be the main source, coaching the presetting operators based on their behavior and KPI's about the output (tool assemblies per hour and end accuracy). In addition, the coordinator should provide feedback/coach the presetting operators to use the torque wrench and obey the tolerances.

How constructive is the delivery of Feedback?

How well does the Feedback combine sound analysis and effective coaching? (Does the Feedback include information on performance? Is the the Feedback delivered in a supportive manner?)

What actions has the Performer agreed to take based on the Feedback? How was agreement reached?

10.5 Appendix E: Time measurements performance system analysis

Measurement	Type	Operator	Rework time (hh:mm:ss)
1	Collet	1	00:04:53
2	Collet	1	00:03:24
3	Collet	1	00:00:00
4	Collet	1	00:07:15
5	Collet	1	00:05:39
6	Collet	1	00:00:00
7	Collet	1	00:02:57
8	Collet	1	00:10:01
9	Collet	1	00:00:00
10	Collet	1	00:00:00
11	Collet	2	00:05:44
12	Collet	2	00:01:23
13	Collet	2	00:00:00
14	Collet	2	00:03:30
15	Collet	2	00:03:15
16	Collet	2	00:00:00
17	Collet	2	00:02:52
18	Collet	2	00:00:00
19	Collet	2	00:01:39
20	Collet	2	00:00:46
21	Shrink	1	00:00:00
22	Shrink	1	00:00:00
23	Shrink	1	00:00:00
24	Shrink	1	00:00:00
25	Shrink	1	00:01:09
26	Shrink	1	00:00:00
27	Shrink	1	00:00:00
28	Shrink	1	00:00:32
29	Shrink	1	00:00:00
30	Shrink	1	00:00:00
31	Shrink	2	00:00:00
32	Shrink	2	00:00:00
33	Shrink	2	00:02:51
34	Shrink	2	00:00:00
35	Shrink	2	00:00:00
36	Shrink	2	00:00:00
37	Shrink	2	00:00:00
38	Shrink	2	00:00:00
39	Shrink	2	00:00:00
40	Shrink	2	00:00:00

Average rework time collet chuck holder (hh:mm:ss)	00:02:40
Average rework time shrink fit holder (hh:mm:ss)	00:00:14
Percentage of conforming tool assemblies collet chuck holder	35%
Percentage of conforming tool assemblies shrink fit holders	85%

10.6 Appendix F: Dataset cost comparison collet chuck/shrink fit holder

Costs replacing collets and clamping nuts		
Non-recurring costs	**€**	**20.600**
Price new collets	€	15.200
Price new nuts	€	5.400
Recurring costs (annual)	**€**	**2.192**
Replacement of collets/nuts	€	2.192

Costs completely switching to shrink fit holders		
Non recurring costs	**€**	**173.500**
Price new shrink fit holders	€	66.000
Price new shrinking machine	€	70.000
Workhours to change CNC programs/TDM/order new tools	€	37.500
Recurring costs (annual)	**€**	**187.920**
Additional costs cutting tools (specials)	€	187.920

10.7 Appendix G: Dataset cost/benefit calculation redesign

Costs Redesign (78%)		
Non-recurring costs	**€**	**29.088**
Price new collets	€	11.856
Price new nuts	€	4.212
Workhours to adjust TDM tolerances	€	7.020
Workhours to develop education program	€	6.000
Recurring costs (annual)	**€**	**1.710**
Replacement of collets/nuts	€	1.710

Benefit per year (cost savings 78%)	€	12.168

Years	**Cost/benefit ratio (78%)**	
0	€	-29.088
1	€	-18.630
2	€	-8.172
3	€	2.287
4	€	12.745

5	€	23.203
6	€	33.661
7	€	44.120
8	€	54.578
9	€	65.036
10	€	75.494

10.8 Appendix H: Validation measurements good presetting process

Measurement	Diameter (mm)	Length (mm)
1	4,194	136,197
2	4,204	136,422
3	4,202	135,261
4	4,202	135,575
5	4,198	135,436
6	4,206	135,465
7	4,210	136,130
8	4,212	136,523
9	4,192	135,872
10	4,204	135,735
11	4,214	134,240
12	4,212	135,852
13	4,196	136,114
14	4,192	135,968
15	4,210	135,840
16	4,204	135,822
17	4,200	136,070
18	4,212	136,179
19	4,198	135,912
20	4,202	135,130
21	4,198	135,484
22	4,210	134,924
23	4,206	135,283
24	4,198	135,435
25	4,210	134,895
26	4,194	135,132
27	4,200	135,971
28	4,202	135,880
29	4,196	135,458
30	4,188	135,665
31	4,204	135,378
32	4,198	134,556
33	4,192	135,167
34	4,198	134,635
35	4,198	134,652
36	4,194	134,279

10.9 Appendix I: Validation measurements poor presetting process

Measurement	Diameter (mm)	Length (mm)
1	4,224	136,589
2	4,198	135,330
3	4,222	135,662
4	4,206	134,639
5	4,216	136,009
6	4,196	135,192
7	4,204	136,004
8	4,228	136,180
9	4,212	136,231
10	4,200	135,719
11	4,192	136,732
12	4,198	136,161
13	4,240	135,644
14	4,216	135,637
15	4,192	135,508

10.10 Appendix J: Gage R&R study

Part	Operator	Replication	Length (mm)	Diameter (mm)
1	A	1	121.093	7.968
2	A	1	121.065	7.942
3	A	1	121.108	7.966
1	B	1	121.094	7.972
2	B	1	121.065	7.942
3	B	1	121.109	7.964
1	A	2	121.094	7.968
2	A	2	121.065	7.942
3	A	2	121.109	7.966
1	B	2	121.094	7.972
2	B	2	121.065	7.944
3	B	2	121.110	7.964
1	A	3	121.094	7.970
2	A	3	121.065	7.942
3	A	3	121.109	7.962
1	B	3	121.094	7.972
2	B	3	121.065	7.942
3	B	3	121.110	7.964
1	A	4	121.094	7.968
2	A	4	121.066	7.942

3	A	4	121.110	7.962
1	B	4	121.092	7.972
2	B	4	121.064	7.942
3	B	4	121.108	7.964
1	A	5	121.095	7.970
2	A	5	121.065	7.942
3	A	5	121.109	7.962
1	B	5	121.092	7.972
2	B	5	121.064	7.944
3	B	5	121.108	7.964
1	A	6	121.093	7.970
2	A	6	121.064	7.942
3	A	6	121.108	7.964
1	B	6	121.094	7.970
2	B	6	121.064	7.940
3	B	6	121.109	7.962
1	A	7	121.093	7.972
2	A	7	121.065	7.942
3	A	7	121.109	7.964
1	B	7	121.094	7.970
2	B	7	121.064	7.940
3	B	7	121.108	7.962
1	A	8	121.094	7.970
2	A	8	121.065	7.942
3	A	8	121.109	7.964
1	B	8	121.093	7.970
2	B	8	121.064	7.940
3	B	8	121.109	7.962
1	A	9	121.095	7.970
2	A	9	121.065	7.940
3	A	9	121.109	7.962
1	B	9	121.093	7.970
2	B	9	121.064	7.940
3	B	9	121.109	7.962

Gage R&R Study - ANOVA Method

```
Gage R&R for Diameter

Gage name:       Zoller 1
Date of study:   21-03-2019
Reported by:     K. Reuvers
Tolerance:
```

Misc: Shrink fit holder 9 replications

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	2	0.0080413	0.0040207	743.548	0.001
Operator	1	0.0000012	0.0000012	0.219	0.686
Part * Operator	2	0.0000108	0.0000054	3.244	0.048
Repeatability	48	0.0000800	0.0000017		
Total	53	0.0081333			

α to remove interaction term = 0.05

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0000021	0.92
Repeatability	0.0000017	0.74
Reproducibility	0.0000004	0.18
Operator	0.0000000	0.00
Operator*Part	0.0000004	0.18
Part-To-Part	0.0002231	99.08
Total Variation	0.0002252	100.00

Process tolerance = 0.038

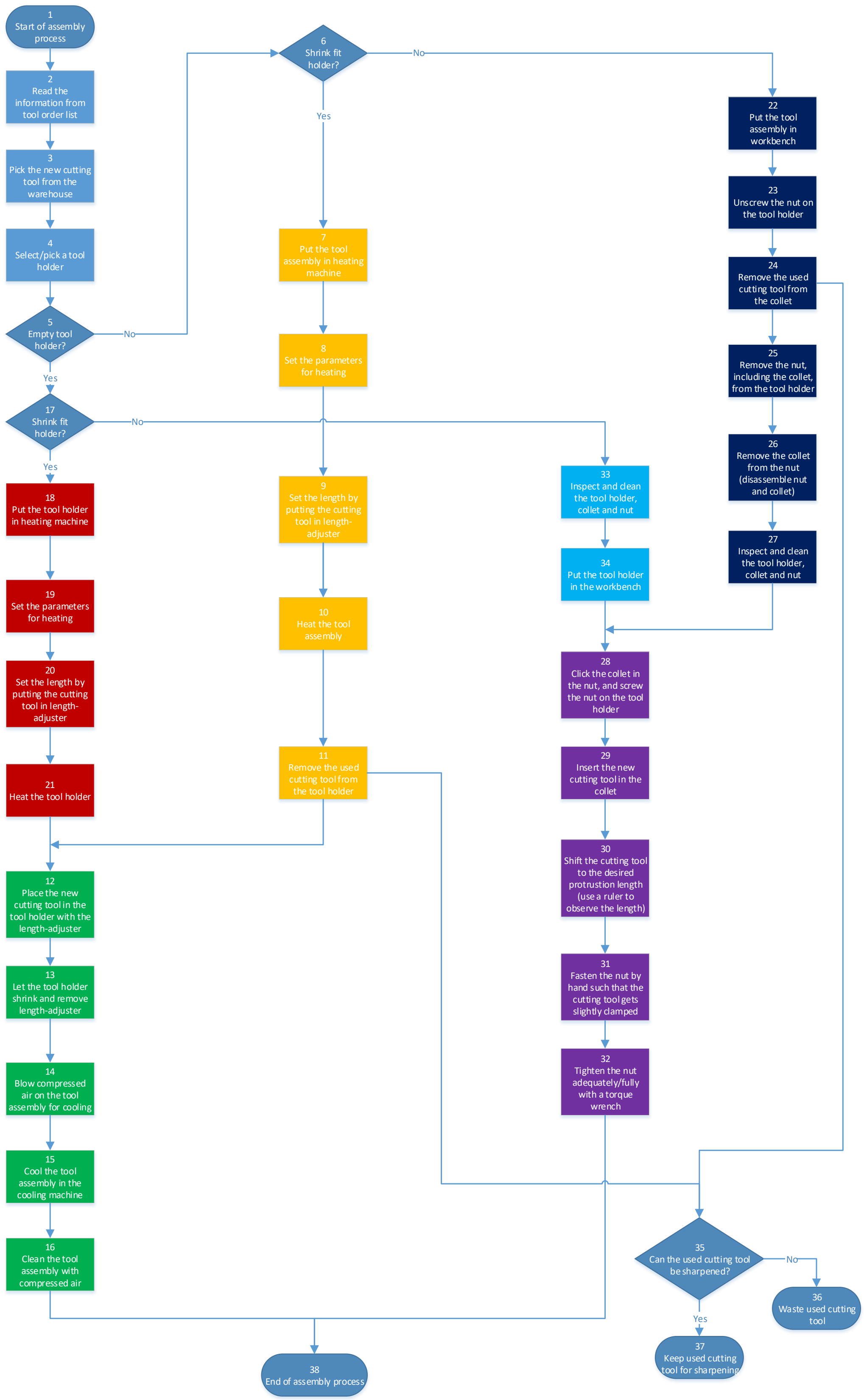
Source	StdDev (SD)	Study Var (5.15 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0014430	0.0074315	9.62	19.56
Repeatability	0.0012910	0.0066486	8.60	17.50
Reproducibility	0.0006447	0.0033202	4.30	8.74
Operator	0.0000000	0.0000000	0.00	0.00
Operator*Part	0.0006447	0.0033202	4.30	8.74
Part-To-Part	0.0149355	0.0769180	99.54	202.42
Total Variation	0.0150051	0.0772761	100.00	203.36

Number of Distinct Categories = 14

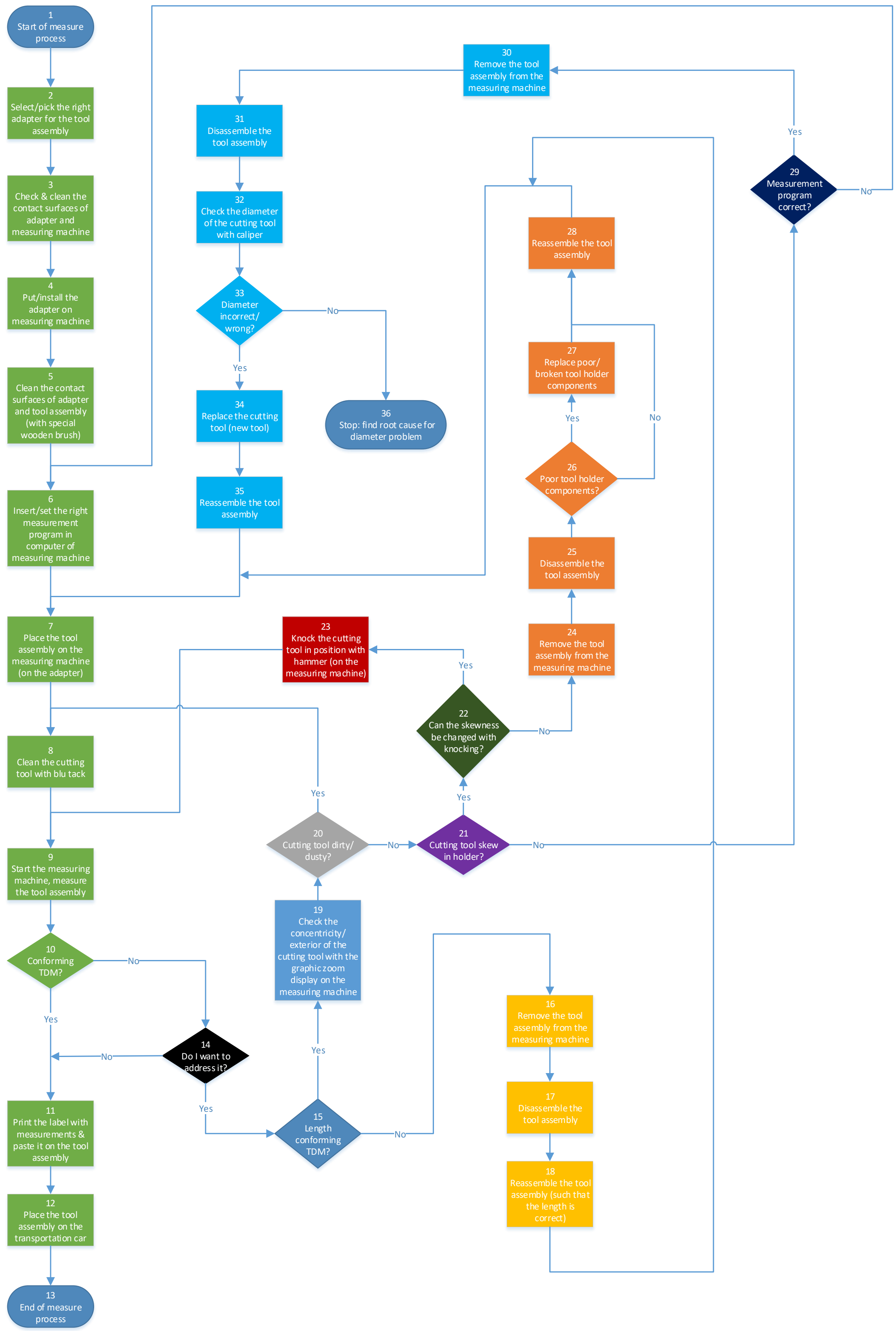
10.11 Appendix K: Dataset for validation of implication on machining

Assembly #	Diameter (mm)
1	4,206
2	4,200
3	4,198
4	4,232
5	4,198
6	4,186
7	4,214
8	4,218
9	4,208
10	4,196

10.12 Appendix L: Enlarged flowchart assembly process



10.13 Appendix M: Enlarged flowchart current measure process



10.14 Appendix N: Enlarged flowchart new measure process