
# Zero-Defects in the Automotive Industry Supply Chain: Development of a Framework for an OEM Process Audit Tool

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# Abstract

The automotive industry environment is characterised by high complexity and competitiveness, which drives the companies' to strive for innovation and continuous improvement. In this industry, it is a very common practice to rely on suppliers for the majority of product development. This means that the quality level of Original Equipment Manufacturers (OEMs) is highly influenced by the capability to manage their supply chains in an efficient way. For this task, DAF Trucks N.V. has a Supplier Quality Assurance department that, among other functions, conducts audits to the suppliers to evaluate their performances. As a result, this project was conducted with the main purpose of improving the Process Audit Tool (PAT) used during these audits.

The first objective is to improve the PAT capability of identifying suppliers with a zero-defect performance, by increasing the correlation of the PAT contents with Zero-Defect Manufacturing (ZDM) concepts. The second objective is to improve the PAT effectiveness and adequacy to be used in different audit types, by studying possible solutions to reduce the tool's generalisation.

Prior to the development of a solution suitable to accomplish the defined objectives, a thorough study of the PAT and its utilisation by Supplier Quality Managers (SQMs) was made. This research was conducted using several methodologies like interviews with the SQMs, a quantitative analysis of the PAT performance, an attendance to a supplier audit and an evaluation of the PAT coverage of ZDM principles. Consequently, it was possible to gather a significant amount of information, that allowed to identify the existing problems.

Following this research, a framework was developed. This framework acts as an overall solution to solve the challenges faced with the PAT and achieve both objectives previously mentioned. Firstly, the framework contains all topics considered to be the most relevant to evaluate if the supplier's organisation is achieving a zero-defect performance. Moreover, it also includes topics adequate for other audit objectives, making it adaptable to several audit types. The topics are categorised according to the corresponding purpose, allowing exclusive focus on what needs to be evaluated during an audit. This framework should be implemented in the PAT to complete and, essentially, substitute the existing questions.

On the whole, this master thesis contributed with a solution for future development of a new tool to support the SQMs during audits, better suited to the Supplier Quality Assurance (SQA) department's requirements.

**Keywords**: Automotive Industry; Supply Chain; Quality; Audit; Process Audit Tool; Zero-Defect Manufacturing;

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# Resumo

A indústria automóvel caracteriza-se por um elevado nível de complexidade e competitividade, o que leva as empresas a investirem cada vez mais em inovação e na melhoria contínua dos seus processos. Nesta indústria, é uma prática bastante comum que a maioria dos componentes dos veículos seja produzida por fornecedores. Isto implica que o nível de qualidade das empresas automóveis seja extremamente influenciado pela sua capacidade de gerir de forma eficiente a cadeia de abastecimento. Com este propósito, a DAF Trucks N.V. dispõe de um departamento de *Supplier Quality Assurance* que, entre outras funções, realiza auditorias para avaliar o desempenho dos fornecedores. O presente projeto foi desenvolvido com o principal propósito de melhorar a ferramenta utilizada durante as referidas auditorias.

O primeiro objetivo é aumentar a capacidade da ferramenta de identificar fornecedores cujo processo de produção tenha um nível de defeitos muito reduzido, aumentando a relação entre o conteúdo da ferramenta e os conceitos de *Zero-Defect Manufacturing* (ZDM). O segundo objetivo é melhorar a sua eficácia e possibilidade de utilização em diferentes tipos de auditoria, pesquisando possíveis soluções para reduzir a sua generalização.

Antes do desenvolvimento de uma solução adequada para alcançar os objetivos definidos, foi feito um estudo completo da ferramenta e da forma como esta era usada pelos *Supplier Quality Managers* (SQMs). Para realizar este estudo utilizaram-se várias metodologias, tais como entrevistas com os SQMs, uma análise quantitativa dos resultados obtidos com a ferramenta, a participação numa auditoria e uma avaliação do conteúdo da ferramenta relativamente à abordagem de princípios de ZDM.

Após essa pesquisa, foi desenvolvido um diagrama que funciona como uma solução global para resolver os desafios enfrentados com o uso da ferramenta e atingir os dois objetivos mencionados anteriormente. Primeiramente, estão incluídos no diagrama todos os tópicos considerados como relevantes para avaliar se o fornecedor apresenta uma baixa percentagem de unidades defeituosas na produção e se tem como sua preocupação diminuir cada vez mais esse valor. Além disso, inclui tópicos adequados para auditorias com diferentes objectivos, permitindo um uso diversificado da ferramenta. Os tópicos estão ainda classificados de acordo com a finalidade correspondente, permitindo que, durante uma auditoria, os SQMs se foquem apenas no que é necessário avaliar. O diagrama deve ser implementado na ferramenta para complementer e, em grande parte, substituir as questões existentes.

Em suma, esta dissertação de mestrado contribuiu com uma solução para o desenvolvimento futuro de uma nova ferramenta que suporte os SQMs durante as auditorias, adequada aos requisitos do departamento de *Supplier Quality Assurance* (SQA).

**Palavras-chave**: Indústria Automóvel; Cadeia de Abastecimento; Qualidade; Auditoria; *Zero-Defect Manufacturing*;

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Inês Montenegro

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*"If you want truly to understand something, try to change it."*

Kurt Lewin

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# Contents

# List of Acronyms

| | |
|---|---|
| AIAG | Automotive Industry Action Group |
| APQP | Advanced Product Quality Planning |
| CI | Continuous Improvement |
| CP | Control Plan |
| CTQ | Critical To Quality |
| DFMEA | Design Failure Mode and Effects Analysis |
| DFSS | Design For Six Sigma |
| FMEA | Failure Mode and Effects Analysis |
| IATF | International Automotive Task Force |
| ISO | International Organization for Standardization |
| JUSE | Union of Japanese Scientists and Engineers |
| KPI | Key Performance Indicator |
| MSA | Measurement System Analysis |
| OEE | Overall Equipment Effectiveness |
| OEM | Original Equipment Manufacturer |
| PAT | Process Audit Tool |
| PPAP | Production Part Approval Process |
| PPM | Parts Per Million |
| QMS | Quality Management System |
| SAR | Supplier Audit Request (system) |
| SPC | Statistical Process Control |
| SQA | Supplier Quality Assurance |
| SQM | Supplier Quality Manager |
| SQRM | Supplier Quality Requirements Manual |
| TPM | Total Productive Maintenance |
| TPS | Toyota Production System |
| TQM | Total Quality Management |
| ZDM | Zero-Defect Manufacturing |

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# Chapter 1

# Introduction

## 1.1 Framework and Motivation

A very common practice in the automotive industry is to rely on the outsourcing of components. This means the Original Equipment Manufacturers (OEMs) are delegating more product development responsibilities to their suppliers, who have been taken a much larger role on the industry since the 1990s [1, 2]. With this division of labor, OEMs are now mainly focused on the engine, integration of sub-systems (developed by suppliers according to the OEMs requirements) and marketing of the brand [3]. There are three main reasons that make this such a well-known practice:

- The OEMs can focus on their core competencies.
- It allows the OEMs to reduce unit cost, as suppliers normally develop similar systems for different OEMs.
- Suppliers have the specific knowledge related to the system to be produced, while OEMs may lack expertise and resources.

Due to the noticeable increase in global competition in the automotive industry, there has been a need to constantly improve the companies' performance. As a result of this demand, companies have realized the importance of a supply chain that can deliver products with the desired quality and in compliance with the requested requirements.

Supplier quality management is a continuous process, that allows companies to monitor their supply chain. It starts with the selection of the supplier and the design of the product, continues through the entire production process, and lasts for the duration of the relationship between the company and that particular supplier [4].

The Supplier Quality Assurance (SQA) department of DAF Trucks N.V., where the present work was carried out, conducts several types of audits, depending on the objective to be achieved. To support this process, the Supplier Quality Managers (SQMs) use a Process Audit Tool (PAT), that evaluates the supplier's performance in many different fields. However, the results obtained

with the tool were not always consistent with the quality performance of the supplier. Moreover, there is an annual meeting conducted with all the SQA departments within PACCAR Inc. (the group to which DAF Trucks N.V. belongs to), where the ambiguity of the PAT was confirmed by several SQMs.

Furthermore, it is relevant to mention that in DAF Trucks N.V., certain trucks' parts are frequently upgraded to continuously improve them. More specifically, every three years the engine model is subject to those upgrades, as well as the cabin model, although with a lower frequency. On account of this process, a large number of audits to new suppliers are conducted by the SQA department.

These situations motivate the necessity of studying the aforementioned PAT's problem and the tool contents' correlation with Zero-Defect Manufacturing (ZDM), with the main purpose of improving the Process Audit Tool capability of identifying zero-defect suppliers.

## 1.2 Company Presentation

DAF Trucks N.V. is a Dutch truck manufacturing company, founded in 1928 by Hubert Jozef van Doorne. In October of 1996, DAF was purchased by PACCAR Inc., an American company that is among the largest designers and manufacturers of light, medium and heavy-duty commercial vehicles.

There are numerous locations dedicated to the manufacturing of DAF's products, such as: Eindhoven (Netherlands), Westerlo (Belgium), Leyland (UK), Ponta Grossa (Brasil), Bayswater (Australia) and Dadu (Taiwan). Production of engines, cabs, axles and chassis, as well as final vehicle assembly, are integrated in the various facilities.

PACCAR Purchasing Europe is the purchasing organisation of DAF Trucks N.V., and is part of PACCAR Corporate Purchasing. It is responsible for the delivery of goods and services to production units in Eindhoven and Westerlo (DAF Purchasing) and to Leyland (Leyland Purchasing). The subdivisions of the PACCAR Purchasing Europe are, according to [5]:

- **Product Projects**: Ensures that Purchasing is involved at the start of new product projects;
- **Production Purchasing**: It is the responsibility of this department to purchase components developed by the suppliers, such as engines and gearboxes, with possible adaptations to DAF's preferences. The purchasing of parts developed according to DAF's design and of all raw materials required for in-house processing are also handled by this department;
- **Non-Production Purchasing**: Purchasing of all goods and services that are not directly incorporated in the final products, for instance cabs and spare parts, is dealt by this department;
- **Parts Purchasing**: Its tasks include the supporting of the service obligation that DAF Trucks has towards every DAF truck owner;

- **Supplier Quality Assurance**: Responsible for assuring the quality of the incoming goods flow, which means that the quality of all processes and products delivered by several suppliers is the SQA department's responsibility. This is achieved by guaranteeing that every supplier follows the industry best practices, and that their production processes show continuous improvement regarding quality.

According to [6], in 2019 DAF was in the European Top 3 of largest trucks manufacturers, with a market share of 16.2% in the heavy segment duty. Moreover, it was market leader in 7 countries: Netherlands (31.8%), the UK (29.4%), Poland (22.0%), Hungary (23.8%), Belgium and Luxembourg (19.4%) and Bulgaria (23.6%).

## 1.3 Objectives

As part of the Supplier Quality Managers' responsibility to ensure the quality of the supply chain, supplier audits are performed, and the Process Audit Tool is used to support SQMs on that process. The use of this tool is two-fold: firstly it is used as a self-assessment of the supplier, and secondly it is used by the SQMs to know what questions to ask the supplier, including the critical points that need further attention. This is a global tool, used not only at DAF Trucks N.V., but also within the SQA department of PACCAR's other truck manufacturing brands, like Kenworth and Peterbilt.

The main objective of the present work consisted in the diagnosis of the current challenges faced by DAF Trucks N.V. with the PAT, and in the design of an operating framework for future implementation. To achieve the main purpose of the dissertation, two specific objectives were defined:

**Objective 1:** *To evaluate the correlation of the process audit tool with ZDM, and improve its capability to identify zero-defects suppliers.*

**Objective2:** *To improve the audit tool's effectiveness and its adequacy to be used in a multitude of audit types.*

In order to achieve **Objective 1**, it is necessary to study the characteristics of Zero-Defect Manufacturing and to analyse their current correlation with the existing questions of the audit tool. Considering its global use inside the company, it is also important to study the influence that people have on the results of the audit tool. This is due to the possibility of different people having more than one interpretation of the tool questionnaire. Hence, the following research questions were formulated to accomplish the first objective:

**RQ.1:** *To what extent do scores collected via the audit tool questions correlate to its capability of identifying zero-defect suppliers?*

**RQ.2:** *How can the influence that people have on the audit outcome be reduced?*

The second objective is self-explanatory, therefore, there was no need to formulate research questions for a better comprehension of the targets to be achieved.

## 1.4 Methodology

The primary requirement for selecting a suitable methodology was its ability to support the achievement of the objectives established. These objectives intend to solve challenges experienced by an automotive company, which presupposes that this project is industry-driven. In view of that fact, the methodology followed throughout this research is the *Action Research*. As the name suggests, it consists in research through action in the field. Alternatively to separating the process in two stages, it combines the research work with the practical application of the knowledge obtained by it [7]. According to [8], its main characteristics are:

- Critical: continuously trying to make better changes;
- Reflective: progressive learning by implementing solutions, and making mistakes;
- Accountable: the experience is made public, not only to other participants, but also to other people interested in the work;
- Self-evaluating: changes made are continuously evaluated;
- Multiple Contributors: involves several participants in the process.

It is possible to differentiate four main moments of the *Action Research* process, shown in Fig. 1.1. This is a cyclic process, where each phase is constructed on the basis of the previous phase and the participants seek to learn from the actions taken.

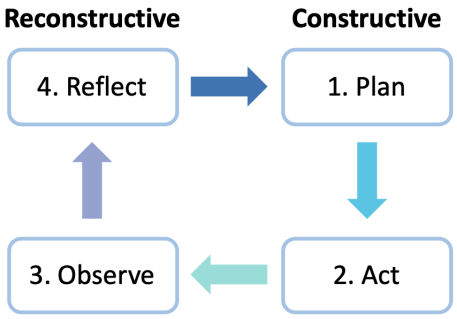


Figure 1.1: Action Research spiral, adapted from [9].

Because the essence of this methodology is to adopt an iterative approach to solve the problem, it proved to be fundamental to the development of this dissertation. Due to its capability of adapting to different situations, it was possible to maintain a constant alignment between the company's requirements and the project scope.

## 1.5 Dissertation Structure

This dissertation is divided in the following five chapters:

- **Introduction**: The first chapter includes the motivation for the dissertation project, a presentation of the institution where it was developed, the methodology followed during the project and its main topics and objectives;
- **Theoretical Review**: A literature review is performed, approaching the main subjects involved in this work: Audits, Quality Management Systems and its application to the Automotive Industry and Zero-Defect Manufacturing;
- **Current Situation Diagnosis and Problem Analysis**: In the third chapter a diagnosis made to the process audit tool is presented. That includes the systematisation of the identified problems, as well as a qualitative and quantitative analysis of the performance of the current tool.
- **Proposed Solution**: Considering the several problems detected, a proposed solution is presented in this chapter. Throughout its sections, the steps taken to develop a future operating framework are also described.
- **Conclusions and Recommendations**: In the last chapter observations about the work developed are made, including the analysis of the results achieved, considering the initially proposed objectives and research questions. Additionally, the main conclusions and recommendations for future work are presented.

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# Chapter 2

# Theoretical Review

This chapter provides the theoretical concepts needed to better understand this research thesis. This information is fundamental to support the decisions made throughout this project. Firstly, it was important to understand the process of auditing and its purpose, as well as the different audit types. For a better understanding of the Process Audit Tool, it was further relevant to study Quality Management Systems and its principles, and some of the Quality Management tools and techniques currently used to improve companies' effectiveness. Lastly, considering the objective of identifying zero-defect suppliers, it was necessary to study the concept of Zero-Defect Manufacturing and the possible approaches to achieve this goal.

## 2.1 Auditing Process and Fundamentals

According to ISO 19011 [10] an audit is a "systematic, independent and documented process for obtaining objective evidence and evaluating it objectively to determine the extent to which the audit criteria are fulfilled". There are several audit methods that can be adopted to conduct an audit. Due to the considerable amount of audit objectives, some audits don't have a defined designation and are named according to their purpose [11]. It is possible to define two simple approaches to designate general types of audits:

- Classification with reference to what the audit intends to assess: product, process or system audits;
- Classification with reference to the relationship between the auditor and the auditee: internal and external audits.

### 2.1.1 Product Audit

A product audit is an evaluation of a particular final product and its qualification for use, according to whether it complies with specifications and customer requirements. Such audits are conducted after the final inspection of the product, with the purpose of improving its quality and increasing

customer satisfaction. Packaging, shipment preparation, product characteristics, product performance, and other customer requirements are some of the aspects that can be audited [11].

### 2.1.2 Process Audit

A process audit is an evaluation of a process to either monitor its efficiency and/or measure its conformity to predetermined instructions or requirements [12]. As stated by D. R. Arter [13] "The process audit examines an activity to verify that the inputs, actions, and outputs are in accordance with defined requirements." During this audit all the resources needed for the process, such as equipment, material and people are examined. Furthermore, several other aspects can be evaluated, as the instructions followed, the environment and the data collected to determine the performance of the process.

If there is a deviation from the process specifications, it is documented and assessed based on the process and/or product risk within the audited organisation [14].

### 2.1.3 System Audit

A system audit is an audit conducted on a company's management system. Quality Management System audits are the most relevant to mention for this dissertation, although there are more management systems inside an organisation. The objective of this audit is to evaluate an existing quality program, by determining its conformance to standards and predetermined requirements [11].

By collecting evidence during the audit, the auditors should be able to identify opportunities for improvement and to issue formal requests for corrective actions when necessary.

### 2.1.4 Internal and External Audits

An audit can be classified as internal or external, taking into consideration the relation between the participants. An internal audit is conducted inside an organisation, by the organisation's own employees. On the contrary, an external audit is conducted in a company by its customers, or by an independent certified company. Fig. 2.1 illustrates the different audit types within internal and external audits.

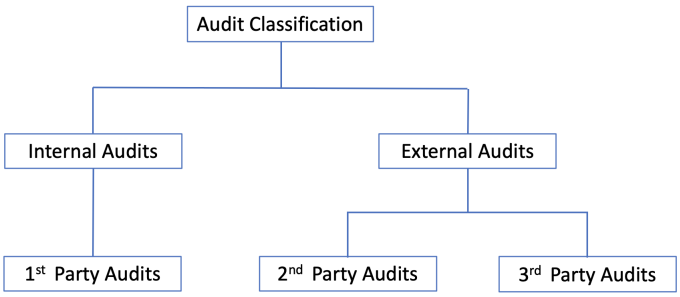


Figure 2.1: Classification of audits [11].

A first-party audit is performed by someone of the company itself to "measure its strengths and weaknesses against its own procedures or methods and/or against external standards adopted by (voluntary) or imposed on (mandatory) the organization." [11]. It is also possible that the company hires an audit organisation to perform the internal audit. This assures impartiality on what needs to be evaluated and a more objective audit result.

A second-party audit is performed by a customer, or a company hired by the customer, to a supplier. It intends to assure the quality of the goods and/or services delivered, and that all customer requirements are being met. For this purpose, the customer can audit the supplier's facilities, resources, personnel, production capabilities, as well as the supplier's management system.

As opposed to the previously mentioned audits, a third-party audit is conducted by a certified body, that is unrelated to the supplier-customer relationship [11]. It occurs when the company wants to have a certificate that proves its conformity to a standard.

## 2.2 Total Quality Management

All the information contained in this section revolves around quality, quality management and how to maintain and improve quality of services, processes and products. Therefore, it is first important to define the meaning of quality.

Quality is a subjective characteristic, and can have different interpretations for different people. Even quality experts give different definitions that complement each other, such as "fitness for use" (Juran, [15]), "conformance to specifications" (Crosby, [16]) and "predictable degree of uniformity" (Deming, [17]). Hence, the definition can diverge according to the context in which the term quality is referred, but it is possible to deduce that it is inherent to the satisfaction of the customer needs.

Total Quality Management (TQM) is an approach to improve an organisation's flexibility and competitiveness and increase customer satisfaction with enhanced quality of products, processes and services delivered [18]. It depends on the commitment of the entire organisation to work towards the same quality goals [19].

There are seven traditional tools that allow the graphical analysis of TQM issues. The tools are simple, but extremely useful in solving critical quality problems: cause-and-effect diagram, Pareto chart, scatter diagram, control chart, flow chart, histogram and check sheet. More recently, the Union of Japanese Scientists and Engineers (JUSE) developed new tools, more innovative and better for communicating information, for the control of quality: affinity diagram, interrelationship diagram, tree diagram, matrix diagram, matrix data analysis, arrow diagram and process decision program chart [20].

### 2.2.1 Quality Management Systems

A Quality Management System (QMS) is a collection of processes and policies that focus on the companies' ability to consistently deliver products and services that meet customer requirements, and to enhance customer satisfaction. Several organisations worldwide implemented the ISO 9001

Quality Management System, to improve business performance and attend customer demand [21]. The ISO 9001, and other related quality management standards, are based on the seven principles of quality management [22]:

1. *Customer Focus:* meet customer requirements and achieve their expectations.
2. *Leadership:* Leaders at all levels should guide people to be committed in achieving the organisation's quality objectives.
3. *Engagement of people:* Competent and empowered people are essential for the organisation's efficiency.
4. *Process approach:* Activities should be managed as interrelated processes, that operate as a coherent system.
5. *Improvement:* Constant improvement of processes is needed, to maintain or enhance current business performance.
6. *Evidence-based decision making:* Decisions are more objective if based on evidence and data analysis.
7. *Relationship management:* The relationships with interested parties, such as suppliers, should be managed in order to optimise their impact on the company's performance.

For the automotive industry there is a specific standard that defines the requirements for a QMS, the IATF 16949, developed by the International Automotive Task Force (IATF). According to the Automotive Industry Action Group (AIAG) [23] this "has become one of the most widely used international standards in the automotive industry, harmonizing the different assessment and certification systems in the global automotive supply chain.". The main goal of this standard is defect prevention and the reduction of variation and waste in the supply chain, alternatively to ISO 9001, that is more customer focused.

### 2.2.2 Continuous Improvement

*Kaizen* is a Japanese philosophy focusing on constant improvement efforts [24] so, when applied to the industry, *Kaizen* refers to the activities that continuously improve all processes and functions and involve all employees. This concept has become known as Continuous Improvement (CI) in the Western writing [25].

There are three main core principles to the *Kaizen* philosophy, according to [25]. The first one describes this methodology as focused on the process. It states that it is fundamental to first have a detailed look into the process, analyse it and improve it. As a consequence, the outcome will be a product of higher quality [26].

The second principle of *Kaizen* is to improve and maintain standards. To achieve better results, it is necessary to combine innovation with the ability of maintaining and enhancing standard performance levels. Tasks that are not standardised are frequently more susceptible to variability

[26]. The Deming's Cycle, or the PDCA (Plan, Do, Check, Act) Cycle (see Fig. 2.2), supports this standard desired behaviours.

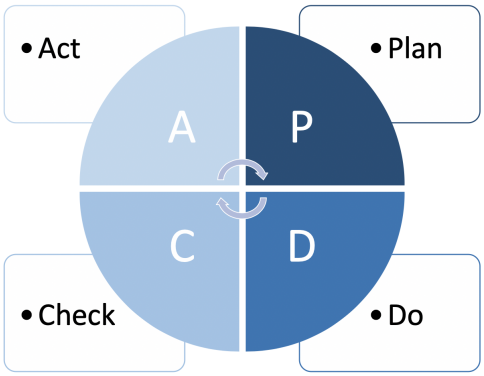


Figure 2.2: PDCA Cycle, adapted from [24].

*Plan* refers to the identification of issues and its root causes, and defining action plans to implement a potential solution. *Do* refers to the implementation of the previously defined plan. *Check* concerns the measurements of the results to verify if the objectives are being achieved. And *Act* refers to the implementation of the solution and its standardisation, to prevent the recurrence of the original problems [27].

The third principle states that *Kaizen* is people-oriented. This means that all people from the organisation should be involved in the improvement activities, from management to shop floor workers [25].

### Lean manufacturing

In the 1950s, Toyota presented the Toyota Production System (TPS). This production system seeks continuous improvement of quality, reducing costs and improving delivery time, through the elimination of waste and activities that do not add value to the product. In the 80s, Toyota started to be recognised worldwide for the quality and variety of products, and for the efficiency of the processes used, becoming the company that created lean manufacturing [28].

There are several tools and techniques that can be implemented by an organisation to improve their processes and achieve lean manufacturing. The most relevant ones for the development of this dissertation project will therefore be described.

**5S:** This designation originated from 5 Japanese words, all started by the letter "S", used to improve workplace practices, allowing a better visual control. Those five words translated to English are: Separate, Set to order, Shine, Standardise and Sustain [29].

***Poka-Yoke:*** *Poka-Yoke* is a Japanese term that means "to make fail safe or mistake-proof". These devices are able to avoid errors by detecting them in advance. They should be implemented in key process operations, to ensure that the product that arrives at the customer is defect free

[26, 28].

**Total Productive Maintenance (TPM):** This is an innovative approach with the purpose of optimising the equipment efficiency by minimising the adjustments needed. It includes the operators in the maintenance of the equipment and helps to prevent breakdowns. Overall Equipment Effectiveness (OEE) is a quantitative metric that provides the percentage of productive working time in a manufacturing process, and it is used by TPM to measure the success of the approach implementation [29, 30].

**Standard Work:** Standard Work is a tool used to document current best practices to reduce variability in working procedures and it should continuously be improved. Standard Work has three elements: Takt time, also designated as the standard manufacturing cycle time to meet customer demand, the work sequence and the standard inventory to keep the process running without interruptions [29].

### 2.2.3 Six Sigma

Six Sigma was developed by Motorola in the 1980s as a quality management methodology for process improvement, and new product and service development, that relies on statistical methods to reduce defects [31]. To achieve Six Sigma, statistically, a process must not produce more than 3.4 defects per million opportunities.

Six Sigma methodology has two approaches. One of them is called DMAIC (D-Define, M-Measure, A-Analyse, I-Improvement, C-Control), which is suitable to use when improving an existing product or process, by following a structured method that helps to avoid jumping to conclusions and ensures an adequate search for an alternative solution to the problem [32]. The second one is DMADV (D-Define, M-Measure, A-Analyse, D-Design, V-Verify), which is suitable when designing a new product and/or implementing a new process, to achieve Six Sigma performance [33].

There are some tools that can be adopted by an organisation to achieve a Six Sigma performance [34]:

- **Measurement System Analysis (MSA):** MSA determines how much the variation of the measurement process, including the test method, measuring instruments, and the entire process of obtaining measurements, contributes to the overall process variability. The analysis is done before the optimisation of a manufacturing process, to understand the accuracy and ability to measure the characteristics of the product that needs to be improved [34].

- **Process Control:** Process control is used in a production process to find deviations from the optimum process outputs and to monitor, control, and eliminate any unexpected process occurrence, to achieve a production level of consistency [34, 35]. There are several techniques used in this endeavor, but the most commonly used is Statistical Process Control (SPC). According to the AIAG [36] there are two phases in SPC: the first phase intends to stabilise

the process by identifying and eliminating the causes of variation, and the second phase has the objective of verifying ongoing process stability by predicting future measurements. A stable, predictable process is said to be in statistical control.

- **Failure Mode and Effects Analysis (FMEA):** FMEA is used to ensure that potential problems are considered and addressed throughout the product and process development. It also studies the consequences of those failures, the ways they can lead to waste or defects. With this methodology each step of the process is systematically examined to determine what could cause damages to the product. Part of the analysis is the risk assessment of potential failures [36].

- **Quality control and capability analysis:** To verify if a Six Sigma level of quality was obtained, there is a need to make a final measure of a process or product, after all corrective actions have been completed. The standard measure of conformance to requirements is the process capability (Cpk). This is the ability of that process to achieve results that satisfy established specifications and statistical limits, based on historical performance. In essence, Cpk indicates how well a process is able to perform and it is a measure customers can require from their suppliers [34].

## 2.3 Zero-Defect Manufacturing

The combination of large production rates of quality products and the need of achieving higher profits, has manufacturing companies constantly facing challenges nowadays. As the demand for quality tends to increase, the industry needs to find new strategies to have the capability of delivering the right product, at the right time, while also being able to reduce production costs. An approach that can be taken into account is Zero-Defect Manufacturing (ZDM), with the objective of eliminating defective parts in production.

It is not possible to enumerate a specific group of methodologies that guarantee a manufacturing process with no defects. It is highly ambitious, or even impossible, to have such a process, due to the dependency on a considerable number of variables, like the type of process and product to be delivered. For that reason, the literature presented on this section is based in research studies and experiments presented on journal articles, publications and technical reports, to provide support to the decisions and outcomes obtained throughout the project.

### 2.3.1 Introduction to Zero-Defect Concept

The concept of Zero-Defect became more acknowledged when Philip B. Crosby incorporated it into his "Absolutes of Quality Management" [37]. According to the author, the third absolute is "The performance standard is Zero Defects".

ZDM intends to eliminate the waste and errors from the manufacturing processes. This approach can be implemented with a product focus, to identify a solution for the problems in the

actual part. It can also be focused on the process where the attention relies on three main aspects [38]:

- Recognising the defects of the manufacturing equipment.
- Data acquisition and processing.
- Process prediction and optimisation.

Additionally, it is possible to apply the ZDM concept to the environment and management of organisations, to increase commitment, overall job satisfaction and individual motivation [39].

Four main stages can be identified, as shown in Fig. 2.3: detect, repair, predict and prevent [40, 41]. When detecting an issue, the parameters and root causes should be saved and mapped with monitoring tools across the shop floor, in a way that the system becomes capable of predicting and preventing the same problem to occur. After detection, a proper repair must be carried, keeping the productivity and production flow.

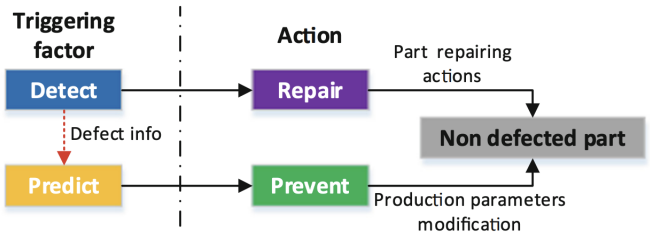


Figure 2.3: Zero-Defect Manufacturing elements, from [40].

With the objective of reducing defects and, consequently, the scrap percentage, there are some recommended actions that could be taken into account [42]. These actions can be divided into the same three focus areas as the ZDM approach:

**Organisation-oriented actions**

One method is planned and preventive maintenance of machines, that aims to avoid unplanned stops, in order to keep the production flow. It allows to reduce the variability of processes and helps to prevent failures caused by fatigue, neglect or related to normal wear. Another important measure is the constant training of operators, as well as their awareness. That triggers a proactive behaviour and gives them the ability of solving problems more easily [39, 42, 43].

**Process-oriented actions**

Dimensional control and visual inspection of raw materials is a method performed to verify if the required specifications are met and the material can be used in the process. This process may include some functionality testing. Furthermore, the process parameters should be monitored to ensure the necessary quality of the product, by using sensors to gather data from the production

equipment. In addition to this measure, dimensional and visual control on the line at important process steps can also be considered to guarantee that Critical to Quality (CTQ) characteristics of the product/process are being controlled, and specifications are being met [42, 43].

**Product-oriented actions**

A practice that is already universally adopted is the analysis of products compliance at the end of the process. These measures are used as a final check, to verify if all the product specifications are met [42].

NXP is a semiconductor manufacturer that practices a zero-defect methodology [44]. Fig. 2.4 shows the quality processes used by this company. This diagram reinforces that, to achieve ZDM, the methodologies specified in this section should be combined with the quality tools mentioned in previous sections of this chapter.

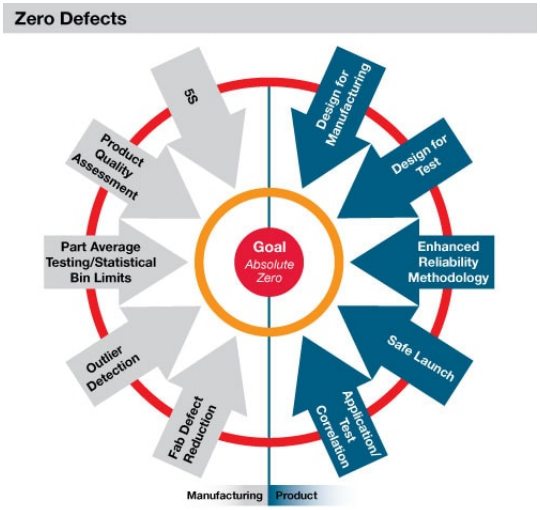


Figure 2.4: NXP zero-defects methodology made up of a balanced set of quality processes, from [44].

Zero-Defect Manufacturing is a promising concept, but not yet a proven solution for manufacturers. It is possible to conclude that data acquisition and monitoring, as well as process prediction & optimisation are crucial to ZDM [45]. With Industry 4.0 becoming a closer reality, allowing manufacturing enterprises to be interconnected and making useful analysis of all the data gathered, ZDM may find a base for its establishment.

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# Chapter 3

# Current Situation Diagnosis and Problem Analysis

This project focuses on the improvement of the Process Audit Tool (PAT) used in the SQA department to assist the audits. However, auditing suppliers is not the only task executed. Hence, a brief explanation of the work done by Supplier Quality Managers is presented in this chapter.

Identifying possible improvements for the PAT necessarily involved making a diagnosis of the current operating model. That included interviews and meetings with the stakeholders, a study of the tool and its contents and the attendance to a supplier audit. Through these activities, it was also possible to determine the existing problems.

Using the methodology mentioned in section 1.4, the development of this pragmatic project consisted in taking practical actions, followed by an analysis and reflection about the results obtained. This means that the predefined strategy was not always strictly followed but, instead, it was adapted and improved according to the progress of the project and the needs of the company. By taking this approach, some of the problems initially identified were corroborated by the steps taken to achieve a solution.

## 3.1 Supplier Quality Assurance Department

The SQA department has a mission statement to follow. It affirms that the SQMs are "a highly motivated team of SQ professionals, coaching the DAF supply base to a zero defect culture and a world class quality performance". The work performed by SQMs lays in the five main pillars shown in Fig. 3.1. The first three pillars are considered to be preventive actions to avoid the occurrence of mistakes. On the other hand, the last two pillars are reactive actions towards suppliers' performance issues.

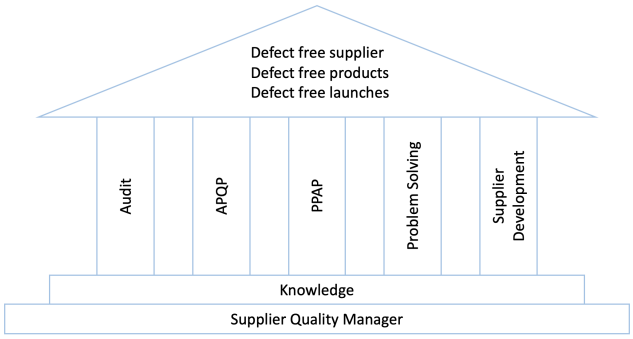


Figure 3.1: Essential working processes of the SQA department.

**1.Audit:** Audits are normally conducted by one or two SQMs, and they have the duration of one day, although it is possible to be a two-day audit, if necessary. There are several reasons why an audit may need to be conducted, such as:

- To verify if a supplier can produce high risk products;
- To evaluate the release of an existing site for a new commodity. This means the supplier intends to produce a new part in the existing manufacturing line;
- To evaluate the release of a new supplier site, which means the supplier is changing the production of a certain part to a new location;
- To evaluate the release of a new supplier, which occurs when DAF Trucks N.V. wants to substitute a supplier that is delivering a certain part;
- To evaluate performance issues, in order to identify systemic problems for supplier development. This audit type also evaluates the supplier's Quality Management System;
- To evaluate the release of a new or modified production process at an existing supplier;
- To support suppliers to achieve a zero-defect performance;
- To support the development of suppliers that are not IATF certified;
- To perform an annual audit update;
- To perform a Software Audit.

Before conducting the audit, there is a preparation made by the SQM and the process audit tool is sent to the supplier as a self-assessment. That way, the SQM knows beforehand the topics that could be of higher risk and need additional attention.

**2.APQP:** Advanced Product Quality Planning (APQP) is a structured process, defined by the AIAG as a way of reducing the complexity of product quality planning for customers and suppliers. It operates as a standard way for automotive companies to easily communicate requirements to

their suppliers [46]. With APQP, Supplier Quality Managers aim to consistently translate DAF's design requirements into process and part specifications.

AIAG has defined five main phases for this process: program planning and definition, product design and development, process design and development, product and process validation and lastly, feedback, assessment and corrective action. A lot of topics are monitored throughout this process, like design robustness, production process design or process capability.

**3.PPAP:** In addition, it is the responsibility of the SQA department to verify if a product developed by a supplier is ready for serial production. Production Part Approval Process (PPAP) is the industry standard, also defined by the AIAG, to perform this verification. This procedure guarantees that engineering design and product specification requirements are met, and products can be produced consistently meeting these requirements. This approval process may be applied to new parts, new production tools, new supplier location or a changed process [47].

For both these processes, APQP and PPAP, the supplier needs to fill in the templates provided by DAF Trucks N.V. with the required specifications regarding the production process and product. The supplier also needs to provide the design related documents and analysis performed to product and process. This information is then constantly reviewed by the SQMs to guarantee all requirements are correctly taken into account and followed. If this is accomplished, then the SQMs can approve the production of the parts.

**4.Problem Solving** and **5.Supplier Development:** Lastly, it is also part of SQMs functions to do problem-solving and supplier development. When a problem is identified, the Supplier Quality Managers use a six sigma approach and issue a Request for Corrective Action (RCA) to the supplier. This procedure has the objective of identifying the root cause of the problem and finding a resolution to prevent the defect recurrence. The performance of a supplier is measured by their PPM, calculated by:

$$PPM(n) = \frac{\text{Nº of rejected parts delivered by supplier}}{\text{Total nº of parts delivered by supplier}} \times 1000000 \tag{3.1}$$

where $n$ is the number of months, normally one, three or twelve, for which the PPM is calculated. The higher the value of the PPM, the lower the performance of the supplier. For the 25 suppliers with the poorest results, DAF has a structured development program. The program combines audits and problem solving tools to identify and solve systemic issues, that are causing defects to be produced and shipped to the customer.

## 3.2 Current Process Audit Tool

As mentioned in section 3.1, the Process Audit Tool is sent to the supplier to be filled in before the audit actually occurs. When the tool is sent back to the SQM, it provides, in advance, a perception regarding the quality of the supplier's organisation. It is also used by the SQM during the audit, to make the necessary corrections on the answers given by the supplier and to take notes regarding the findings of the audit.

This tool is built in MS Excel and has a main menu, as shown in Fig. 3.2, with the possible categories to evaluate the supplier, which are the blue coloured buttons.

The grey buttons lead to sheets where data can be collected and graphical results of the audit are shown. As the name suggests, the *Summary Sheet* contains a summary of all the audit information. It includes the supplier name, location and global information, the name of the PACCAR SQMs involved in the audit, and the audit date and rating. In addition, there is also a field that allows the SQM to write the necessary comments about the findings of the audit. The complete *Summary Sheet* from the tool can be consulted in Fig. A.1, in Apendix A.

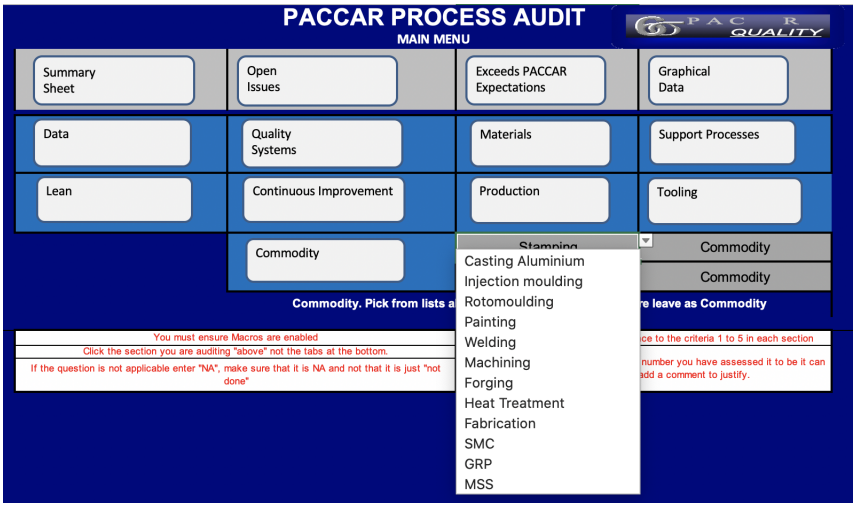


Figure 3.2: Process Audit Tool main menu.

The *Data* button opens a sheet with a set of questions related to the topic *Data*, as shown in Fig. 3.3. The same applies to the remaining buttons, that are associated with sheets including questions related to *Quality Systems*, *Materials*, *Support Processes*, *Lean*, *Continuous Improvement*, *Production* and *Tooling*.

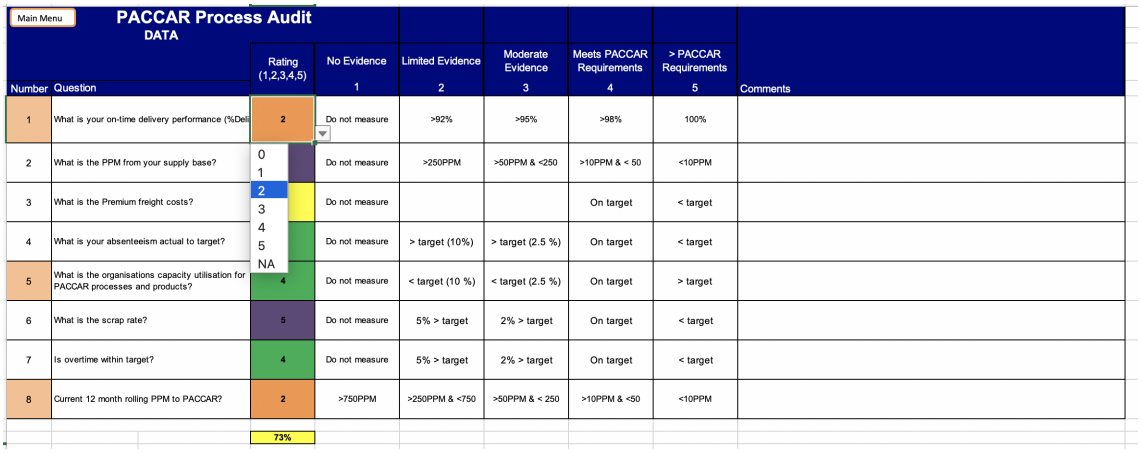


Figure 3.3: PAT Data questions, arbitrarily evaluated with a score from 1 to 5.

The questionnaire can be evaluated with a score between 1 and 5. The lowest score evidences the supplier's lack of capability to perform what is asked. The highest score translates into the supplier's competence to successfully exceed PACCAR's expectations, by efficiently accomplishing what is asked and having a substantial amount of evidence to prove it. Moreover, a question can be scored with "NA", providing the topic addressed is not applicable to the audited supplier. The questions have been classified arbitrarily as an example, as shown in Fig. 3.3. After having all the scores defined, the supplier gets a final evaluation from 0% to 100% per category.

In the main menu, there is also a *Commodity* button, followed by four grey rectangles. In each of these rectangles there is a list with the options of different commodities that can be selected (see Fig. 3.2), referring to specific manufacturing processes, as Casting Aluminium or Injection Moulding. If a commodity is chosen, this button then leads to a sheet with questions related to the specific processes. In Fig. 3.4 it is possible to see this sheet, where the two commodities mentioned were selected in the main menu as an example.

Main Menu

**PACCAR Process Audit**
**Casting Aluminium**

| | | Question | Where to look for evidence | Score |
|---|---|---|---|---|
| Commodity | Casting Aluminium | Are there recipe cards for the different alloyed metals manufactured? | | 0 |
| Commodity | Casting Aluminium | Are the temperatures of the melt ovens monitored? How often? | | 0 |
| Commodity | Casting Aluminium | How is hydrogen content measured and/or controlled? | | 0 |
| Commodity | Casting Aluminium | How is silicon modification achieved (in A356 alloy)? | | 0 |
| Commodity | Casting Aluminium | Does the supplier have a written procedure to ensure that material properties are to required specification? | | 0 |
| Commodity | Casting Aluminium | Are the test bars retained for traceability back to the production run? | | 0 |
| Commodity | Injection moulding | Are raw materials/components stored properly to protect against environmental contamination? | | 0 |
| Commodity | Injection moulding | Is there a procedure in place to control raw materials/components prior to start of moulding? | | 0 |
| Commodity | Injection moulding | Is there an incoming material assessment procedure, covering onsite testing or acceptance of supplier testing, with criteria (i.e., melt flow, specific gravity). | | 0 |
| Commodity | Injection moulding | Is there an incoming components assessment procedure, covering onsite testing or acceptance of supplier testing, with criteria (if applicable). | | 0 |
| Commodity | Injection moulding | Is there a stock rotation system in place for First in/First out (FIFO) and shelf-life | | 0 |
| Commodity | Injection moulding | Is the storage environment temperature controlled | | 0 |

Figure 3.4: PAT Commodity sheet.

Furthermore, the sheet *Open Issues* is where all the questions scored with a 1, 2 or 3 are grouped. That is designed for the SQM to easily identify the major problems, and to make the necessary comments. It is also possible to mention the actions that should be followed by the supplier to solve the issues found. The *Exceeds PACCAR Expectations*, as opposed to the previous section, is the sheet where the questions scored with a 5 are gathered.

Finally there is a *Graphical Data* sheet, where all the results from the audit are gathered and presented in a graphic (see Fig. 3.5).

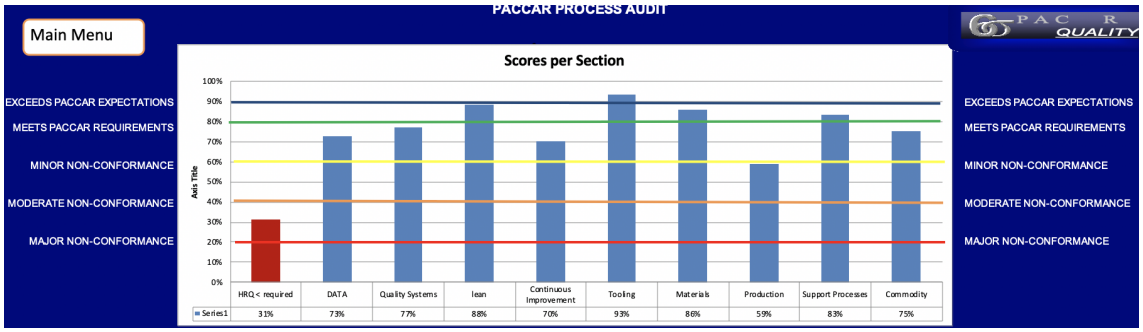


Figure 3.5: Results obtained from the arbitrary filling of the tool, presented on a graphic from PAT *Graphical Data* sheet.

These results are presented per category and in percentage, from 0% to 100%. The first column of the graphic shows the percentage of high risk questions (the ones highlighted in orange in the first column of each category sheet. It is possible to see an example in Fig. 3.3, where questions number 1, 5 and 8 are high risk ones), that were classified with a 1 or 2, and did not achieve a high enough score to meet minimum requirements. This information is presented with a higher level of detail in a second graphic, where the number of questions answered per category is showed, emphasizing the high risk ones. A complete view of this sheet is showed in Fig. A.2, in Appendix A.

The *Graphical Data* also contains a table that provides the number of questions categorised by the correspondent scores, divided per topics. Next to this table, there is another one containing a summary of the percentages obtained per each category. By calculating the average of these results, a final audit score is obtained. This final result also appears on the *Summary Sheet*.

## 3.3 Problem Identification and Critical Analysis

### 3.3.1 Interviews with Intervening Parties

The first step taken to understand the current model of the process audit tool and the challenges associated with it, was to conduct structured interviews with the SQMs of the department. Essentially, through these interviews it was intended to listen to the users of the Process Audit Tool, to adequately understand the way audits are conducted, how the PAT was used by different people and identify what were the main problems found when using the tool. Moreover, in any project that involves change, listening to its stakeholders is a fundamental activity to ensure that the recommendation of the future model is based not only on theoretical research, but also on improvement aspects that they can identify.

During these interviews, each of the Supplier Quality Managers was asked to first explain the steps taken to perform an audit and when the tool was used during that process. Subsequently, they were asked to describe what topics are evaluated during an audit of a supplier, by giving examples of questions asked, and if those topics were addressed in the tool or not. Finally, all

interviewed SQMs were asked to suggest opportunities for improving the Process Audit Tool and to specify, according to their view, the reasons why they considered the current model was not efficient enough.

Adding to these interviews, organised with just one SQM per interview, it was also conducted a meeting with three SQMs simultaneously. This meeting was organised due to the fact that the SQMs had participated in an IATF training a few months before this project started. During the training, one of the tasks consisted of brainstorming about the current state of the PAT and what could be done to improve it. Therefore, considering the correlation between the subject of the training and the project to be carried out, this was a fundamental interview.

From the interviews held, it was possible to take some important topics that pointed out a few problems and opportunities for improvement:

- The topic "Leadership" is missing from the questions in the PAT;
- The topic "Quality Culture" is missing from the questions in the PAT;
- The topic "Tier 2 Management" is missing from the questions in the PAT;
- The description of the questions' scores, from 1 to 5, are not always defined, making it difficult to select between two consecutive scores;
- The amount of questions is too many, not allowing to review all of them in a one-day audit;
- When possible, make the link between IATF clauses and the questions, to provide the SQM a more solid justification when a non-conformity is found;

It is worth noting that all the interviews held were documented in individual minutes, which objectively systematised all information, allowing a clearer view of the Process Audit Tool usage and respective issues described. Examples of the referred minutes can be found in Appendix B. These minutes contain the information collected from one individual interview with a Supplier Quality Manager and the meeting regarding the IATF training. This last mentioned interview, most likely represents the one that contributed the most to evidencing some of the existing problems.

#### 3.3.1.1 Change Management

By making regular presentations of the project progress, it was possible to ensure the full involvement of the several SQA departments within PACCAR Inc.. Those presentations acted as brainstorming sessions, which initially contributed to corroborate the existing issues and, during the course of the project, with suggestions to achieve a solution.

This activity was fundamental within the scope of change management which, although often overlooked, is crucial to ensure that the changes made in the process and associated activities are followed by the respective adaptation and awareness of its stakeholders [48]. With this purpose, it was essential to guarantee a clear communication to the complete SQA department, providing everyone the opportunity to pose questions, observations and suggestions.

### 3.3.2 Quantitative Analysis of PAT Performance in Supplier Classification

The scoring of the tool was mentioned as a point of improvement a considerable amount of times, as it did not transmit objectively the risk the supplier represents to the company. Although the final result in the tool is presented as a percentage, it is associated with a specific classification:

- Result < 60% - High Risk Suppliers.
- Result >= 60% and < 80% - Medium Risk Suppliers.
- Result >= 80% - Low Risk Suppliers.

Subsequent to an audit being conducted, the final version of the Process Audit Tool must be submitted into the Supplier Audit Request (SAR) system, with the necessary comments regarding the audit findings and the final result. This system is used to keep track of the state of the audits, from the moment they are requested until the result is archived. In that system, suppliers are classified according to their level of risk.

To analyse the consistency between the outcomes of the tool in percentage and the classifications concerning the risk level of the suppliers, some PAT files were chosen from the system. The SAR system has a total of 793 entries, although a significant number of them do not refer to already concluded audits. Therefore, it was necessary to ensure the files selected were archived, guaranteeing the audits were completed and a PAT file was attached. Another requisite was ensuring the audits had a final classification assigned, like High Risk Supplier, Medium Risk Supplier or Low Risk Supplier. It was also important to guarantee the file corresponded to the version of the tool that is being studied (this model is relatively recent, being used for less than two years).

The amount of High Risk suppliers was considerably lower than the other two categories, existing only 39 entries of High Risk suppliers, when compared with 99 of Medium Risk and 406 of Low Risk ones. To ensure the same sample size between the three groups of documents to be analysed, it was first chosen the PAT files from the High Risk suppliers' list. The low number of entries, combined with the aforementioned restrictions, only allowed to review 12 files from this list.

These files were uploaded to SAR system during a period of time that starts in October 2018 until February 2020. When selecting the 12 documents from the other categories, it was also considered this time frame, including the specific months, because the amount of experience with the Process Audit Tool could be a factor interfering in the scores given and consequent result.

From the 36 files collected, all the final percentages obtained with the Process Audit Tool were gathered, and grouped according to the level of risk the supplier had been classified with. This information was visualised in a boxplot, as shown in Fig. 3.6, obtained with Minitab[1].

[1]Minitab is a statistical software, that allows data visualisation and analysis.

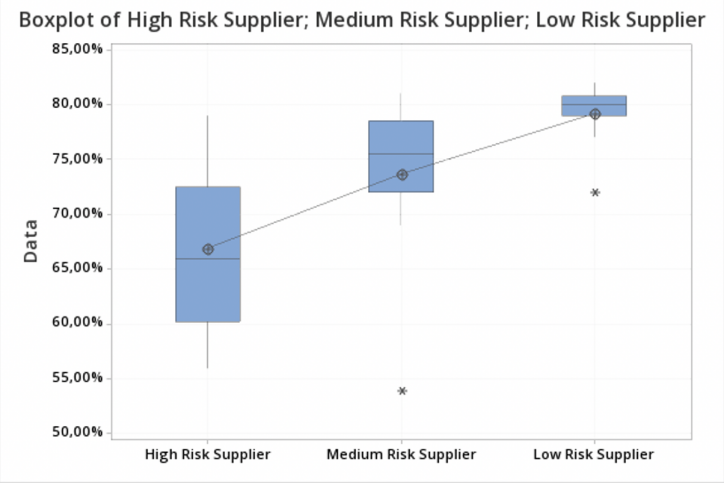


Figure 3.6: Boxplot containing the audit results from the SAR system.

From the graphic, it is noticeable the nonconformity between the classifications and the corresponding percentage ranges, predominantly for High Risk Suppliers. Regarding this category, the majority of values is between 60% and 72%, and the highest score given is 79%, which is extremely close to a Low Risk one. For Medium Risk Suppliers, the majority of values is between 72% and 79%, while for Low Risk ones most of the values are accumulated between 79% and 80%.

However, for these last two categories there are still inaccurate evaluations made, which can be demonstrated in Table 3.1. In this table, the percentage of audit outcomes that correctly meet the corresponding criteria is calculated.

| Audit Outcome | Evaluation Criteria | % of Correct Classification |
|---|---|---|
| High Risk | < 60% | 25,0% |
| Medium Risk | >= 60% and < 80% | 75,0% |
| Low Risk | >= 80% | 66,7% |

Table 3.1: Percentage of classifications that were accurately made according to the criteria.

Some possible conclusions were taken from this analysis, the first one being that the PAT has the lowest accuracy when evaluating High Risk Suppliers. This means that the questions in the tool are not capable of making an objective assessment of the supplier's problems identified by the SQMs, in order to provide a clear distinction between the different classifications according to the level of risk the supplier represents. Moreover, it was implicit that there is a frequent need for the SQMs to disregard the fixed relation between the PAT results and the supplier's risk level, and provide a classification based on their opinion. This reliability on SQM's points of view originates a lot of variability in the supplier's classification after the audits.

By doing this analysis a question was raised regarding the production processes (referred as

commodities in the PAT), and how they could or not influence the audit result, due to the fact that in some audits the manufacturing processes are specifically evaluated, but in some they are not. Hence, from the 36 PAT files it was also gathered the results from each category, including the commodities. For the 16 suppliers that had their process evaluated, the final audit results were calculated with and without the commodity score. Then, the delta between both results was also calculated. These results are shown in the graphic below, in Fig. 3.7.

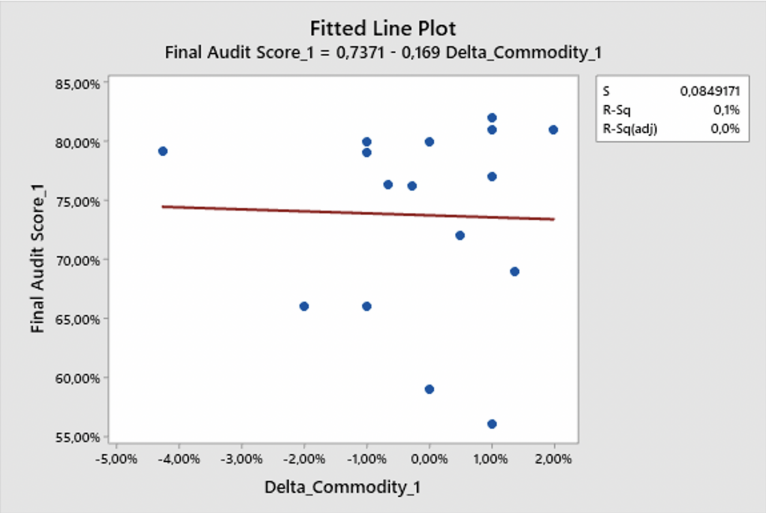


Figure 3.7: Correlation between commodity scores and final audit result.

From the linear regression calculated in this graphic, that is almost constant, and the equation that correlates the final audit score with the deltas, it can be concluded that the scores of the commodities do not have a significant influence on the final result. This is due to the fact that the process audited has normally a score similar to the other categories of the PAT. In consideration of the aforesaid, it is reasonable to assume that if an organisation is quality driven, so is the manufacturing process they have.

### 3.3.3 Supplier Audit Observation

The observation of supplier audits and use of the tool during those audits was a fundamental way to understand how the PAT works. Consequently, the initial strategy included the attendance to a considerable number of audits, not only to observe when and how the tool was used, but also to verify if different SQMs used a similar approach while auditing a supplier. Due to reasons external to DAF Trucks N.V. and its suppliers, it was only possible to observe in person one audit being conducted. Two online audits were also observed. In spite of the fact that this process was new to DAF Trucks N.V., it was possible to recognise some similarities between both audit types regarding the steps to follow.

The attended audit had a duration of two days. During the audit preparation, the SQM established an agenda, in agreement with the supplier, which is presented in Fig. 3.8. The sections of the agenda were followed, although some adjustments needed to be made.

**Date:** 26 February 2020

**Responsible:** Team 3 SQM

**Agenda:** 26 February

| Time | Action |
|---|---|
| 11:00 | Arrival |
| 11:00-12:30 | Introduction, management kick-off, audit approach and company presentation |
| 12:30-13:00 | Lunch |
| 13:00-14:30 | General plant tour |
| 14:30-17:00 | Short presentation(~15min) by the organisation responsible per main audit topic (Data, Quality systems, Materials, Support Processes, Lean, Continuous Improvement, Production, Tooling).<br>Please highlight the items which have a 1, 2 or 5 score. |

27 February

| Time | Action |
|---|---|
| 08:00-11:00 | Specific topic plant tour (areas depend on presentations and general plant tour) |
| 11:00-12:00 | Interview to Quality Manager |
| 12:00-12:30 | Lunch |
| 12:30-13:00 | preparation for summary |
| 13:00-14:00 | Management summary |

Figure 3.8: Supplier audit agenda.

During this audit, two main phases were identified:

- The line-walks, where the SQM walks trough the supplier's organisation production line. This gives the SQM an opportunity to see the process, machines and equipment, speak with the operators and understand the company's level of organisation.
- The interviews, conducted in an office, where the Supplier Quality Manager examines the PAT answers, together with the relevant employees of the supplier's organisation (the Quality Manager, the main responsible for maintenance, among others).

The line-walks are identified as "plant tour" in the agenda, which implies that the remaining time is occupied by interviews. Although this was a two-day audit, and the great majority of time was spent inside an office, the tool's questions were not fully addressed during the meetings conducted. In the PAT, the SQM marked the topics that were not reviewed as "NR", making a total of 42 questions with this classification, which represents almost 50% of the questionnaire. Considering that one day is the most common duration for an audit, it was reasonable to assume that the PAT questionnaire is too extensive to be completely checked.

During the online audits, the line-walk through the supplier organisation was replaced by photographs and videos of the several manufacturing processes, complemented with explanations from the supplier. The PAT questions were discussed during the remaining time. From these audits it was also perceptible that there was not enough time to review all the Process Audit Tool's questions with the supplier.

Despite the fact that some of the PAT's questions were classified in accordance with what was observed during the line-walk, the information gathered in the interviews was enough to answer the majority of questions. This demonstrates the tool is not suitable to support the SQM during

the evaluation of the suppliers' production lines, and clarifies the reason for the dependency on the SQM's opinion when classifying a supplier, as mentioned in section 3.3.2.

### 3.3.4 Tool Content Correlation with ZDM

Considering that one of the defined objectives is to improve the Process Audit Tool capability of identifying zero-defect suppliers, it was important to first determine the current correlation of the tool with the concept of ZDM.

A PPM value between 1 and 10, indicates an extremely close to zero-defect performance. Therefore, it was initially intended to make a quantitative analysis of the suppliers with the highest PPM values. These results would then be compared to the ones obtained with the PAT, from an audit performed to the corresponding suppliers. The objective was to study the consistency between both outcomes, due to the relation between zero-defects and a supplier's PPM. However, that study did not give reliable results, possibly because of two reasons:

- The audits were conducted a long time before the PPM results could give information to take meaningful conclusions. During that time, it is possible that some variables in the supplier organisation have changed, for example the manufacturing process may have experienced modifications, becoming the reason for the PPM value obtained. These variables cannot be controlled, nor could they be predicted by the audit, which means that, if there is inconsistency between outcomes, it was not due to the PAT.
- The audit was carried out precisely as a result of the company's bad performance.

Consequently, another approach to determine this correlation was considered. A diagram was developed, as showed in Fig. 3.9, based in the literature research presented on Chapter 2, the interviews conducted to the SQMs and the brainstormings from the initial presentations of the project. As a result of this diagram, the framework that depicts in Fig. 3.10 was designed. This framework contains the topics considered to be essential in evaluating an organisation's capability of achieving zero-defects.

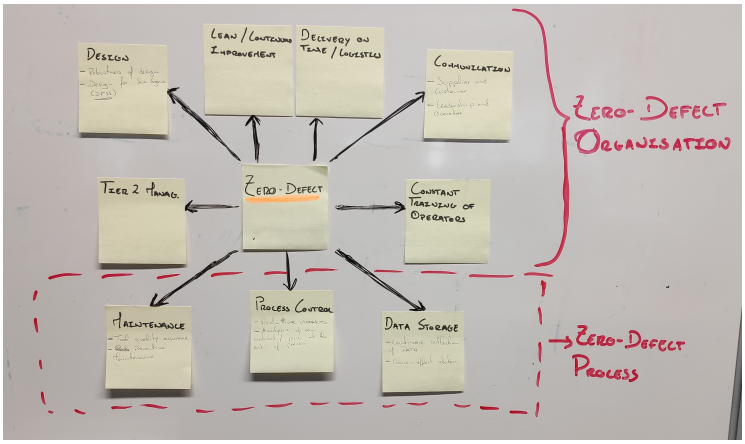


Figure 3.9: Diagram containing zero-defect topics.


Figure 3.10: First framework developed, containing zero-defect topics.

This framework constitutes the starting point for the development of the solution proposed in Chapter 4. For a better comprehension of the framework, a brief explanation of the subjects addressed is presented:

- **Tier 2 Management:** Assesses the organisation's capability of managing its suppliers: from their selection, to their performance and development;
- **Logistics:** Evaluates the supplier maturity regarding logistics, for example if they have clear storage locations and how organised and effective is their packaging process.
- **Design:** Refers to Design for Six Sigma (DFSS), which is a Six Sigma methodology used in process or product design. The objective of DFSS is to "design it right the first time". For that, some Six Sigma tools can be used, as DFMEA (Design Failure Mode and Effects Analysis), design review, reliability testing, error-proofing, among others [49].
- **Lean/Continuous Improvement:** Evaluates the organisation's endorsement of lean tools and Continuous Improvement mentality, from the management to the shop floor.
- **Management & Communication:** Determines the level of communication inside the organisation, between the leadership and the operators, as well as between the supplier and the customer.

- **Constant Training of Operators:** Assures the operators are continuously trained to effectively perform their work functions.
- **Data Storage & Analysis:** Evaluates the data collection of the supplier, from equipment, processes and products, and if there is an efficient analysis of that data to obtain cause and effect relationships.
- **Process Control:** Evaluates the standardization level of the process, its man-dependency, if real time measurements are performed and if a constant control of quality is made.
- **Maintenance:** Verification if preventive maintenance plans are considered and applied, not only to the machines but to the entire equipment.

After the development of this framework, it was necessary to investigate the relation between these topics and the PAT. This was accomplished with a table that contained the question numbers in the first column and all the existing categories in the PAT in the first row (see Fig. 3.11). Inside this table, each question was given a score.

| Questions\Section: | Data | Quality Systems | Continuous Improvement | Lean | Tooling | Materials | Production | Support Processes |
|---|---|---|---|---|---|---|---|---|
| 1. | 2 | 5 | 5 | 2 | 5 | 1 | 3 | 3 |
| 2. | 2 | 2 | 2 | 2 | 5 | 4 | 1 | 1 |
| 3. | 4 | 5 | 4 | 4 | 3 | 1 | 1 | 1 |
| 4. | 4 | 5 | 1 | 4 | 1 | 4 | 5 | 4 |
| 5. | 4 | 5 | 3 | 3 | 3 | 3 | 2 | 4 |
| 6. | 1 | 5 | 5 | NA | 2 | 2 | 2 | 1 |
| 7. | 3 | 5 | NA | NA | 4 | 4 | 1 | 3 |
| 8. | 1 | 3 | NA | NA | 1 | 2 | 1 | 3 |
| 9. | NA | 5 | NA | NA | 5 | 2 | 3 | 5 |
| 10. | NA | 1 | NA | NA | NA | 4 | 1 | 3 |
| 11. | NA | 5 | NA | NA | NA | 2 | 1 | 1 |
| 12. | NA | 4 | NA | NA | NA | 1 | 2 | 3 |
| 13. | NA | 2 | NA | NA | NA | 2 | 5 | 5 |
| 14. | NA | 3 | NA | NA | NA | 4 | 2 | NA |
| 15. | NA | 5 | NA | NA | NA | 2 | 2 | NA |
| 16. | NA | 1 | NA | NA | NA | 5 | 3 | NA |
| 17. | NA | 3 | NA | NA | NA | 5 | NA | NA |
| 18. | NA | 1 | NA | NA | NA | NA | NA | NA |
| 19 | NA | 3 | NA | NA | NA | NA | NA | NA |
| 20. | NA | 2 | NA | NA | NA | NA | NA | NA |

Figure 3.11: Correlation between PAT questions and the framework topics.

Initially, only three scores were defined. However, during the execution of this activity, these scores proved not to be sufficient to classify the questionnaire, because some questions could not be classified strictly as related or not related to zero-defect topics. Although associated with the framework, some of the questions were simply a duplication of what should have already been evaluated if the supplier was IATF certified. Others were not directly related to the topics, but could represent an indirect contribution to identify zero-defect suppliers. For this reason, five scores were defined with the following meanings:

1. The question is directly related to a topic of zero-defect process.

2. The question is directly related to a topic of zero-defect organisation.

3. The question is not relevant to evaluate an IATF certified supplier, since it should be mandatory that the supplier satisfies this requisite already (it is important to highlight that only a very small percentage of the suppliers are not in possession of this certificate).

4. The question is indirectly related to one of the zero-defect topics by addressing a subject that, despite not directly related, has influence on the zero-defect performance of the supplier.

5. The question is unrelated with any topic of the designed framework.

The results obtained with this assessment are presented in Table 3.2:

| Score | Nº of Questions |
|---|---|
| 1 | 21 |
| 2 | 20 |
| 3 | 18 |
| 4 | 15 |
| 5 | 20 |

Table 3.2: Results obtained by linking PAT questions with the zero-defect framework topics.

The PAT has a total of 94 questions, and only 41 of them were evaluated with a score of 1 or 2, which translates into, approximately, 50% of the complete questionnaire. In addition to this point, these questions did not cover all the framework's topics.

Furthermore, 18 questions were scored with a 3, not being relevant to the majority of suppliers. Lastly, 20 questions were evaluated with a 5 suggesting that, around 20% of them were not related to zero-defects at all.

This indicates that half of the PAT's questionnaire is influencing the final audit result, despite the fact that these questions don't contribute to the tool's capability of determining if the supplier is moving towards the zero-defect concept.

## 3.4 Summary

As a result of the previously mentioned activities, it was possible to analyse the current situation and identify the main problems of the tool. A lot of issues were pointed out from the interviews with the SQMs therefore, it was necessary to make a distinction between the ones that could effectively contribute to the improvement objectives of this project, and the ones that did not. As such, a systematisation of the main problems is presented below:

- With the initial interviews, it was possible to identify some relevant topics missing from the questionnaire, as "Quality Culture" and "Leadership". This was further corroborated with the framework presented in Fig. 3.10;
- There is inconsistency between the final audit percentage and the supplier's classification regarding the level of risk represented. This is due to the inefficiency of the questions to reflect the SQMs' opinions.
- The Process Audit Tool is too extensive to be completely reviewed in a one-day audit.
- The Process Audit Tool questionnaire does not support SQMs during the line-walk phase of the audits, contributing to an increased discrepancy in the audit outcome.
- The current capability of the PAT to identify zero-defect suppliers is limited. This is a result of the insufficient coverage of zero-defect relevant topics simultaneously with the impact that questions unrelated to zero-defects have in the final audit result.

# Chapter 4

# Proposed Solution

After the diagnosis phase of the Process Audit Tool's current situation, through the systematisation of its problems and identification of possible improvement opportunities, the future operating framework was designed.

All the steps taken to address and solve the problems previously identified will be explained throughout this chapter, as well as the proposed final solution.

## 4.1 Framework Development

The framework presented in section 3.3.4 was the starting point for the development of this project. It was acknowledged that, to improve the PAT, its contents would have to be changed, ensuring that the correlation with the concept of ZDM would be increased.

There is a clear deficiency in the amount of empirical research work related to investigate possible zero-defect strategies, and its relation with suppliers' performances in the automotive industry. As a result of this situation, it was necessary to link the research work with the experience of the SQMs on evaluating suppliers' organisations. For this purpose, a team of SQMs was assigned to support on the development of this project. This team consisted in six SQMs from several SQA departments of PACCAR's truck manufacturing brands:

- One SQM from Peterbilt, located in Texas, USA.
- One SQM from Leyland Trucks, located in Leyland, UK.
- One SQM from DAF Trucks CZ, located in Czech Republic.
- Three SQMs from DAF Trucks N.V., located in Eindhoven, Netherlands.

The work done with the team consisted, mostly, of weekly brainstorming sessions. These sessions were used to present the updates of the project and define the next steps to follow, always ensuring it was covering the company's requirements. These meetings did not have a similar structure, as they depended on the weekly progress achieved. Nevertheless, they were documented

in minutes for a better comprehension of the information gathered, as the two examples provided in Appendix C.

In section 2.3.1, it was mentioned that zero-defect actions could have three directions: organisation-oriented, process-oriented and product-oriented. The first framework presented did not contain the third approach mentioned, which had to be included. Furthermore, it was essential to determine if these three approaches were sufficient to cover all the audit's objectives. To have this association, it was first defined the main questions SQMs needed to be able to answer with the PAT when auditing a supplier, before further development of the framework. Those questions are:

1. Is the supplier capable of making the product without defects?
2. Is the supplier capable to support project/design?
3. Is the supplier's organisation capable of sustaining zero defects?
4. Is the supplier meeting standards and customer requirements?

These four questions translated into the four topics represented in Fig. 4.1.

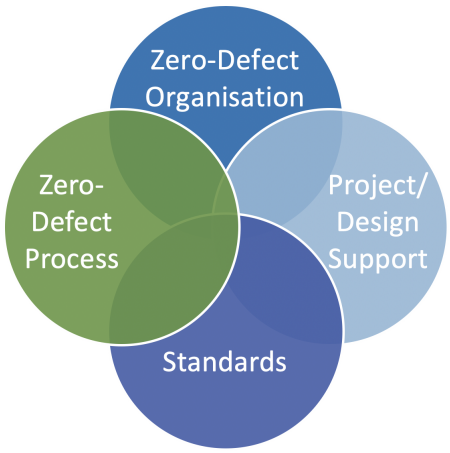


Figure 4.1: Four fundamental audit objectives.

The first question, although containing the word "product", refers to the capability of the supplier to produce the parts without defects. This is not directly related to the product itself, but to the process-oriented approach. Hence, the topic inside the green circle was defined and concerns the necessity of the supplier's manufacturing process to be efficient enough to have a zero-defect production.

The second question addresses the technical capability of the supplier to support PACCAR's projects and part design, and is represented in the light blue circle. The topics related to this question affect directly the quality of the product, making this objective related to the product-oriented approach.

The third question is portrayed in the dark blue circle and addresses the organisation-oriented approach. It includes the organisation's quality practices and its employees' mentality to continually improve, which supports the sustainability of the two previous points.

The last question works mainly as support to the other three objectives. Despite the fact that this is not referred in the ZDM methodologies discussed in section 2.3.1, to achieve the first three objectives the supplier also needs to have implemented the automotive industry's standards and the requirements defined by PACCAR. Additionally, this topic is of high importance for the suppliers that are not IATF certified, to evaluate their level of maturity regarding this aspect (although these suppliers represent a very low percentage in the entire supply chain). This question is illustrated in the purple circle.

The combination of these four objectives of the PAT with the first framework presented in Fig. 3.10, resulted in the following update, shown in Fig. 4.2.

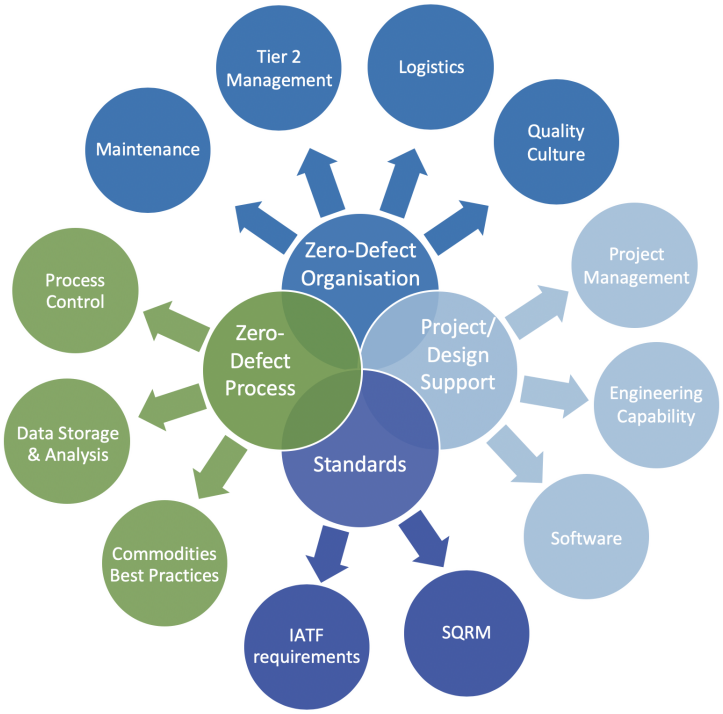


Figure 4.2: Second update to the zero-defect framework.

There are some clear changes between this framework and the previous version. The most perceptible one concerns the number of central divisions that, instead of two, now consists of four topics.

In the circle *Zero-Defect Process* the topics *Process Control* and *Data Storage & Analysis* were carried over, but there was a new topic added that was missing from the former framework. It was explained in section 3.2 that the Process Audit Tool has a group of questions for the specific production processes that can be audited. These questions are important to determine if a supplier is following the best practices towards the commodity, to reduce the number of defects as much as possible. Hence, the topic *Commodities Best Practices* was included.

For the *Zero-Defect Organisation* circle, the *Logistics* and *Tier 2 Management* topics remain similar. *Maintenance* was also an existing topic, but was previously related to the process instead. This was changed because it is the supplier's organisation responsibility to assure an ef-

fective maintenance and preservation of equipment and it was presented in section 2.3.1 as an organisation-oriented approach. Furthermore, *Lean/Continuous Improvement*, *Management & Communication* and *Constant Training of Operators* were considered to be part of a company's quality culture. Therefore, they were summarised into the topic *Quality Culture*.

Considering that the two remaining circles are both new to the framework, an explanation of the topics linked to each one is given below.

There are two topics regarding *Standards*:

- IATF Requirements: Indicates the automotive industry standard that defines the requirements for a Quality Management System, the IATF 16949, mentioned in section 2.2.1.
- SQRM: Refers to PACCAR's Supplier Quality Requirements Manual (SQRM), that defines customer-specific requirements for organisations supplying production parts or assemblies to PACCAR.

For *Project/Design Support* three topics were defined:

- Project Management: Evaluates the supplier's project management process effectiveness, which includes their process for risk management.
- Engineering Capability: Evaluates the capability of the process to meet the Critical To Quality (CTQ) characteristics of the product. This topic is also related to *Design* mentioned in section 3.3.4, which concerns the supplier's utilisation of DFSS and the level of translation of the CTQs to the Design FMEAs.
- Software: At DAF Trucks N.V. many of the software systems are developed by various suppliers. As a result, it is essential to assure the capability of the process used to develop the software and also the product quality of the software embedded in these systems.

## 4.2 Framework Definitive Version

Following the development of the framework, it was important to correlate it with the questions of the PAT, to establish how it would be integrated in the tool. Otherwise stated, it was required to determine the number of questions in the PAT that would be preserved, what were those questions and to what topics were they linked.

For this process, an MS Excel file was created including all the sections and corresponding questions of the tool, as shown in the first and second columns in Fig. 4.3. In the following columns, the assessment made by four team members is presented. Due to the fact that some questions included information related to more than one framework topic, it was possible to link them to a maximum of three categories. Additionally, there was an option to classify the questions as related to "another category", which means that the questions addressed a topic that was not represented in the framework. This association was made by the entire team to obtain less biased results.

| Audit tool section | Audit tool questions | Inês Categories | | | SQM1 Categories | | | SQM2 Categories | | | SQM3 Categories | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Data | What is your on-time delivery performance (%Delivery reliability OE)? | Logistics | Supplier Quality Requirements Manual | | Logistics | | | Logistics | | | Logistics | Supplier Quality Requirements Manual | IATF Requirements |
| Data | What is the PPM from your supply base? | Tier 2 Management | Supplier Quality Requirements Manual | | Tier 2 Management | | | Tier 2 Management | | | Tier 2 Management | Data Storage & Analytics | Supplier Quality Requirements Manual |
| Data | What is the Premium freight costs? | Logistics | | | Logistics | | | Logistics | Question could be more objective | | Process Control | Quality Culture | Tier 2 Management |
| Data | What is your absenteeism actual to target? | Quality Culture | | | Quality Culture | | | Quality Culture | | | Quality Culture | Fits another category | Data Storage & Analytics |
| Data | What is the organisations capacity utilisation for PACCAR processes and products? | Process Control | | | Process Control | | | Question could be more objective | | | Quality Culture | Data Storage & Analytics | |
| Data | What is the scrap rate? | Process Control | Data Storage & Analytics | | Process Control | | | Quality Culture | | | Process Control | Maintenance | Data Storage & Analytics |
| Data | Is overtime within target? | Quality Culture | | | Fits another category | | | Quality Culture | | | Quality Culture | Data Storage & Analytics | |
| Data | Current 12 month rolling PPM to PACCAR? | Supplier Quality Requirements Manual | | | Process Control | | | IATF Requirements | | | Process Control | Quality Culture | Tier 2 Management |
| Quality Systems | Is there a formal quality system? | IATF Requirements | Question could be more objective | | IATF Requirements | | | IATF Requirements | | | IATF Requirements | Supplier Quality Requirements Manual | Quality Culture |
| Quality Systems | Is there an approved supplier list and are most suppliers are IATF16949, if not are the sub tiers at least ISO9001:2015 ? | IATF Requirements | | | Tier 2 Management | IATF Requirements | | IATF Requirements | | | Tier 2 Management | Supplier Quality Requirements Manual | IATF Requirements |
| Quality Systems | Is the certification body of the ISO suppliers an accredited third party? (for list see www.iaf.nu - then click on iaf members and signatories) | IATF Requirements | | | IATF Requirements | | | Fits another category | | | IATF Requirements | Supplier Quality Requirements Manual | |
| Quality Systems | (Mexico), AEO (Europe) or C-TPAT (Customs-Trade Partners against Terrorist)? (N/A for Europe) | Fits another category | | | Fits another category | | | Fits another category | | | Fits another category | | |
| Quality Systems | kept secure from product being added to a shipment in a threatening situation? (N/A for Europe) | Fits another category | | | Fits another category | | | Fits another category | | | Fits another category | | |
| Quality Systems | Is the ISO14001 certification up to date? | IATF Requirements | | | IATF Requirements | | | Question could be more objective | | | Supplier Quality Requirements Manual | | |
| Quality Systems | Is the PACCAR 1 page RCA document used for responding to non-conforming product? | Supplier Quality Requirements Manual | | | Supplier Quality Requirements Manual | | | Supplier Quality Requirements Manual | | | Process Control | Supplier Quality Requirements Manual | |
| Quality Systems | Does the organisations have an internal audit system and non-conformances are being addressed in a timely manner to a structured plan with specific timing? | IATF Requirements | | | Quality Culture | IATF Requirements | | IATF Requirements | | | Process Control | Quality Culture | |

Figure 4.3: PAT's questionnaire relation with framework topics.

By establishing this correlation two main conclusions were drawn:

- The PAT covers an extensive amount of topics and not all of them are relevant for the several audit objectives. Hence, when reviewing all of them in an audit, the tool becomes too general. This may contribute to the tool's insufficient capability of accurately evaluating a supplier.
- The framework is still missing some relevant points to cover all the audit objectives.

Although these conclusions may seem contradictory, they are not. The observations imply that the tool may include all the necessary subjects, provided that there is an association between them and the corresponding audit objective. This intends to avoid an overload of different topics during an audit, as some of them are not relevant for the evaluation to be made.

Considering the identification of the missing topics on the framework, another approach was taken to complete it. In the weekly brainstorming sessions, the four main questions defined in the previous section were thoroughly discussed. As a result, each main question was complemented with the necessary topics. It is important to mention that this was an iterative process, during which a lot of small modifications were made to the tool. It was also by regularly acknowledge that improvements needed to be made, that a favourable solution was achieved. Taking this into account, a new and final version of the framework was developed, as illustrated in Fig. 4.4.


Figure 4.4: Final version of the designed framework.

Analogous to the previous update made to the framework, it is possible to see some differences and some similarities between this and the previous version depicted in Fig. 4.2. Firstly, the four middle topics were maintained, considering that this update was also based in the four main questions predefined. In the topic *Standards*, a new subsection was added. The *PACCAR Standards*

refer to the PACCAR's requirements concerning the specific product to be produced. This means that, on the contrary to the SQRM, these specifications are different from supplier to supplier. *Software* was eliminated from the framework, because it was considered to be an independent audit type and its questions will be individually added to the tool. This is due to the fact that a Software audit is very specific and the majority of the topics on the framework are not relevant for this audit type. For each of the remaining categories in the framework were also defined sub-topics, in order to facilitate the comprehension of their purpose. Hence, a more detailed explanation will be given, regarding what each topic aims to review and evaluate during an audit.

***Zero-Defect Process***

- Process Design: Intends to evaluate the supplier's risk-based level of thinking regarding the process, and the efficiency of the documents that should address this risk. This can be described as the capacity of translating specifications into production controls. CTQs are defined and monitored and there is a link between PFMEAs, Control Plans[1] (CPs) and work instructions. Therefore, the CPs ought to be developed from PFMEAs, and the work instructions and CPs should be consistent.

- Incoming Parts: This topic refers to the verification of incoming goods, to monitor if they are received without damages, in production adequate packaging material and with standardised labelling. Furthermore, this topic aims to review if CTQs of incoming parts are measured to check its compliance with requirements, and if they have an approved PPAP (concept explained in section 3.1). For this verification, the sample size should be adequate to identify defined risks.

- Tooling: Evaluates the state of the tools, to guarantee they are acceptable for producing the product. This means the tools need to be regularly controlled, calibrated and maintained (ensure the tools are part of the predictive and preventive maintenance plans of the organisation).

- Equipment: Evaluates the autonomy of the equipment and the level of its technical controls. The process should be able to meet product specifications, and the part's characteristics should be controlled, for example by measurement jigs. The process controls should be automated as much as possible (or be *poka-yokes*). Additionally, SPC (mentioned in section 2.2.3) should be used to collect data and continually improve the process. It also assesses the capability of measurement equipment, like gauges.

- Rework & Repair: Assesses the supplier's capability of separating parts with and without defects and if the process of rework and repair is properly controlled. This implicates that parts should have full traceability when they go through this process.

[1] A Control Plan is defined by the IATF as a documentation of product and process characteristics, tests, process controls and measurement systems included in the production phase.

- Skill Level of Operators: This topic refers to the organisation's work and inspection instructions that should be explicit, as well as the level of flexibility in operators' functions (if needed, one operator should be able to work in more than one workstation). The supplier should have a fixed rate of skilled operators corresponding to, at least, 70%.

***Zero-Defect Organisation***

- Quality Culture: Evaluates the management of Continuous Improvement (CI) on the shop floor, by assessing the level of operators responsibilities. These should include their involvement in problem-solving by showing contributions to error proofing, providing improvement ideas and maintaining 5S standards (mentioned in section 2.2.3). Furthermore, daily production meetings should be carried out to ensure full involvement and awareness of operators.
- Data Analysis: The supplier should use SPC to monitor and control process parameters, ensuring the process operates efficiently. It should also document deviations on process and product parameters and define follow up actions for those deviations. Furthermore, it is important to store measurement and inspection data for parts with and without defects, and to define and measure Key Performance Indicators (KPIs).
- Leadership: This topic aims to guarantee that management has quality targets defined, like rework & repair, % of scrap, PPM to customer, among others. These targets are met and continually adjusted. Moreover, CI is part of management's responsibilities and is constantly included in the performance review.
- Maintenance: Evaluates general organisation's maintenance plans, which should include the workshops, equipment and tools. It also verifies the compliance with principles of Total Productive Maintenance, the existence of maintenance KPIs and the availability of proven skilled maintenance people.
- Continuous Improvement: This topic reviews if CI projects are implemented, managed and sustained. Moreover, it evaluates the level of involvement inside the organisation regarding these projects.
- Operator Training: Evaluates how and with what frequency are the operators trained to perform their functions. Skill matrices should be available across all areas of the organisation.
- Tier 2 Management: This topic refers to the supplier's capability of measuring its suppliers' performances and of developing its supply base to continually improve its quality.
- Logistics: Evaluates the level of warehouse and part identification, and if the warehouse layout includes a clear and correct marking of the storage locations. Furthermore, it assesses the quality level of packaging materials and packaging standards, as well as if there is a barcode system implemented into the complete packaging and storage system that allows full data collection and traceability.

***Project/Design Support***

- General Requirements: Refers to the supplier's project management process and change management system effectiveness. It also evaluates the supplier's organisation capability of meeting PACCAR's production volume requirements on time.

- Product Design: This topic is important when the supplier is responsible for product design. It addresses the same contents mentioned in the *Engineering Capability* topic of the framework's previous version, presented in section 4.1.

- Process Design: Relevant topic when the supplier is responsible for process design. It evaluates the supplier's capability of giving good feasibility input, through feasibility studies for design, that objectively identify strengths and weaknesses of the process.

- Tool Design: This topic is relevant for suppliers that are responsible for tool design and assesses if the tools are correctly designed according to specifications and adapted to the available machines in the organisation.

- Tier 2 Management: The supplier should identify and monitor its own critical suppliers. Moreover, there should be an SQA function in place to stimulate CI of the supply chain and support low performing suppliers to improve.

Subsequently to the complete framework's development, the four main audit objectives defined were linked with the audit types presented in section 3.1. This was fundamental to ensure that the scope of topics evaluated during an audit included only the ones related to the purpose of that audit.

| | | **Audit Objectives** | | | |
|---|---|---|---|---|---|
| | | Zero-Defect Process | Zero-Defect Organisation | Project/Design Support | Standards |
| **Audit Types** | Verify the supplier can produce high risk products | | | X | |
| | Release an existing site for a new commodity | X | | X | |
| | Release a new supplier site | X | | | |
| | Release a new supplier | X | X | | X |
| | Performance issues | X | X | | |
| | New/changed process at existing supplier | X | | | |
| | Annual Audit Update | | X | | X |
| | Support suppliers to achieve zero-defects | X | X | | |
| | Development of suppliers not IATF certified | X | X | | X |

Figure 4.5: Link between audit types and the four main audit objectives defined.

### 4.2.1 Implementation of the Framework

All the relevant topics necessary to audit the zero-defect performance of a supplier are objectively defined in the final version of the framework, presented in the previous section. This framework, when implemented, will allow the SQMs to select an appropriate scope of topics according to the purpose of the audit. Although the implementation phase is not part of this dissertation's scope, the duration of this project allowed to start that process. Hence, an explanation of how this is being conducted will be provided in this section.

In order to collect all the necessary information for the development of a new PAT, an MS Excel file was created, as shown in Fig. 4.6. It is important to note that the second and third image are the horizontal extension of the first image. An overall view of this sheet is displayed in Appendix D.

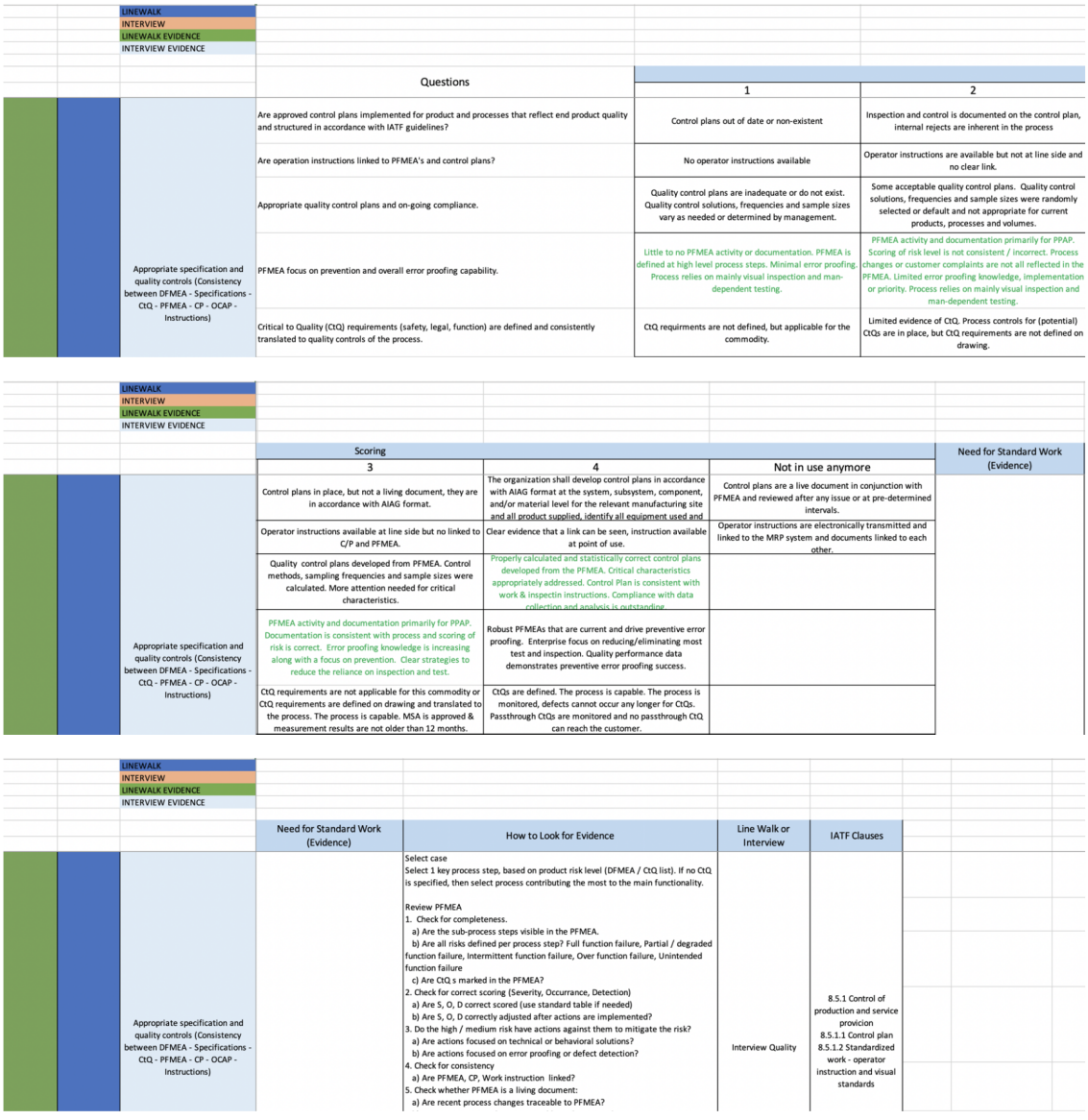


Figure 4.6: MS Excel file containing all gathered information.

The first column contains the four main questions defined in section 4.1 and the second one contains all the categories defined in the framework's final version. It is possible to confirm this with the Fig. D.3. Moreover, the third column includes the detailed sub-topics that give a comprehensive explanation of each framework's category. These columns have different colours according to the classification that can be seen in the first four rows of the file. These classifications intend to categorise the topics as "Interview", "Line-Walk", "Interview Evidence" and "Line-Walk Evidence". This process has two objectives:

- The first objective is to increase the level of standard work between different SQMs, by defining in which phase of the audit the topic should be addressed.
- The second objective is to specify which categories need the SQMs to look for a substantial amount of evidence, to verify the answer provided by the supplier. This means that the topics coloured with "Interview Evidence" and "Line-Walk Evidence" will have a section with detailed instruction, explaining the steps to follow for an appropriate method to look for evidence. This will also contribute to standardise the audits and to provide better support to SQMs with a lower level of experience.

This classification of the framework allowed to confirm that the topics related to *Zero-Defect Process* will support the SQMs during the evaluation of the suppliers' production lines.

The following columns named "Questions" and "Scoring" contain all the questions of the Process Audit Tool, and the corresponding descriptions of the scores, linked to the topics they could be related to. It is relevant to note that in these columns there are also questions compiled from other tools owned by PACCAR. These tools aim to assist during audits but do not have the same amount of use by SQMs as the PAT. Additionally, there is a specific column to write the instructions on how to look for evidence and one with the IATF clauses that cover some of the detailed sub-topics.

With all this information gathered, several brainstorming sessions will now be organised per each SQA team of DAF Trucks, which includes SQMs working in Brazil, The Netherlands, UK and Czech Republic. The purpose of these sessions is to determine what questions of the previous model of the PAT will be preserved or not, to complete the scores of the questions and to fill the column with the steps to find the relevant evidence.

The first sub-topic was concluded during the first session, as an example to what was intended to achieve. It is possible to see this example in Fig. 4.7, where the second image is the horizontal extension of the first image. This model is similar to the one showed in Fig. 4.6, but the information is now complete and well organised, and the previous questions from the PAT were eliminated.

| Framework_L1 | Framework_L2 | Framework_L3 | Question | Scale_1 | Scale_2 | Scale_3 |
|---|---|---|---|---|---|---|
| Defect free process | Process design | Appropriate specification and quality controls (Consistency between DFMEA - Specifications - CtQ - PFMEA - CP - OCAP - Instructions) | Appropriate quality control plans and on-going compliance. | Quality control plans are inadequate or do not exist. Quality control solutions, frequencies and sample sizes vary as needed or determined by management. | Some acceptable quality control plans. Quality control solutions, frequencies and sample sizes were randomly selected or default and not appropriate for current products, processes and volumes. | Quality control plans developed from PFMEA. Control methods, sampling frequencies and sample sizes were calculated. More attention needed for critical characteristics. |
| | | | PFMEA focus on prevention and overall error proofing capability. | Little to no PFMEA activity or documentation. PFMEA is defined at high level process steps. Minimal error proofing. Process relies on mainly visual inspection and man-dependent testing. | PFMEA activity and documentation primarily for PPAP. Scoring of risk level is not consistent / incorrect. Process changes or customer complaints are not all reflected in the PFMEA. Limited error proofing knowledge, implementation or priority. Process relies on mainly visual inspection and man-dependent testing. | PFMEA activity and documentation primarily for PPAP. Documentation is consistent with process and scoring of risk is correct. Error proofing knowledge is increasing along with a focus on prevention. Clear strategies to reduce the reliance on inspection and test. |
| | | | Critical to Quality (CtQ) requirements (safety, legal, function) are defined and consistently translated to quality controls of the process. | CtQ requirments are not defined, but applicable for the commodity. | Limited evidence of CtQ. Process controls for (potential) CtQs are in place, but CtQ requirements are not defined on drawing. | CtQ requirements are not applicable for this commodity or CtQ requirements are defined on drawing and translated to the process. The process is capable. MSA is approved & measurement results are not older than 12 months. |

| Scale_4 | How to look for evidence | Linewalk | Interview | IATF Reference |
|---|---|---|---|---|
| Properly calculated and statistically correct control plans developed from the PFMEA. Critical characteristics appropriately addressed. Control Plan is consistent with work & inspectin instructions. Compliance with data collection and analysis is outstanding. | Select case<br>Select 1 key process step, based on product risk level (DFMEA / CtQ list). If no CtQ is specified, then select process contributing the most to the main functionality.<br><br>Review PFMEA<br>1. Check for completeness.<br>a) Are the sub-process steps visible in the PFMEA.<br>b) Are all risks defined per process step? Full function failure, Partial / degraded function failure, Intermittent function failure, Over function failure, Unintended function failure<br>c) Are CtQ s marked in the PFMEA?<br>2. Check for correct scoring (Severity, Occurrance, Detection)<br>a) Are S, O, D correct scored (use standard table if needed)<br>b) Are S, O, D correctly adjusted after actions are implemented?<br>3. Do the high / medium risk have actions against them to mitigate the risk?<br>a) Are actions focused on technical or behavioral solutions?<br>b) Are actions focused on error proofing or defect detection?<br>4. Check for consistency<br>a) Are PFMEA, CP, Work instruction linked?<br>5. Check whether PFMEA is a living document:<br>a) Are recent process changes traceable to PFMEA?<br>b) Are customer complaintes traceable in the PFMEA? | Linewalk | Interview Quality | 8.5.1 Control of production and service provicion<br>8.5.1.1 Control plan<br>8.5.1.2 Standardized work - operator instruction and visual standards |
| Robust PFMEAs that are current and drive preventive error proofing. Enterprise focus on reducing/eliminating most test and inspection. Quality performance data demonstrates preventive error proofing success. | | N/A | Interview Quality | |
| CtQs are defined. The process is capable. The process is monitored, defects cannot occur any longer for CtQs. Passthrough CtQs are monitored and no passthrough CtQ can reach the customer. | In case of a non-conformity, redo the previous step for 2 other process steps. In case a single deviation is found a minor non-conformity is found, in case more than 1 issue is found a major non-conformity is found.<br><br>In case PFMEA only exists as PPAP document - PFMEA is incomplete, not updated, not used as tool by the organization - risk thinking of the organization is considered a systemic issue - set all scores in this section to the minimum level. | Linewalk | Interview Quality | |

Figure 4.7: Information regarding the first sub-topic completed.

## 4.3 Synthesis

In this chapter, the steps taken to achieve a solution for the identified problems in Chapter 3 were described. The proposed framework was developed to help mitigate these problems.

Firstly, all the relevant topics that were missing from the PAT were covered. It was also accomplished the improved effectiveness desired, considering it includes not only the relevant topics to audit a supplier's capability of achieving a zero-defect performance, but also several other topics important for the remaining audit types.

The objective division of categories will allow the SQM to select only the necessary topics to perform the required evaluation of a supplier, which will make the tool smaller and easier to review in a one-day audit. Furthermore, there a considerable amount of topics that can be reviewed during the line-walk phase, improving the tool's capability to reflect the SQMs' opinion.

Lastly, the division of topics into "Line-Walks" and "Interviews" combined with the detailed instructions to look for evidence during an audit, despite not being directly inserted in the framework, will reduce the ambiguity in the final audit result.

# Chapter 5

# Conclusions and Recommendations

This chapter presents the results and reached conclusions of the research questions developed in Chapter 1. Moreover, the conclusions withdrawn from the development of this project, as well as suggestions for future development are hereby presented.

## 5.1 Conclusions

**RQ.1:** *To what extent do scores collected via the audit tool questions correlate to its capability of identifying zero-defect suppliers?*

To answer this question it was established a relation between the PAT's questions and the defined zero-defect topics. It was possible to understand that a lot of the questions were not relevant to determine the supplier's capability of having a zero-defect performance. Despite this fact, these questions were influencing the final results obtained with the tool after an audit. Therefore, the conclusion reached was that the scores collected via the PAT questions were reflecting the tool's poor capability of identifying a zero-defect supplier, because the questions were not effective enough to accomplish this objective.

This was improved with the designed framework, considering its deeper level of focus on zero-defect's subjects. Although the large number of topics in the framework, the possibility to use it according to the audit's objective enhances the scores' capability of providing a more objective supplier classification. The audit result will be calculated considering only the relevant topics for the audit.

**RQ.2:** *How can the influence that people have on the audit outcome be reduced?*

This problem was studied with two approaches: the analysis presented in section 3.3.2 and the attended audit. Both these methods allowed to understand that the supplier's classification depended on the SQMs' opinions. The framework provided contributes to a score estimation that translates accurately the supplier's level of risk, to eliminate the need of having people's influence in the audit result. Moreover, the development of a detailed section with instructions to look for

evidence will increase the level of standard work between different SQMs, reducing the variability on the audit outcome and making the auditing process less subjective.

This project consisted in developing a framework that could be applied to the Process Audit Tool used in the Supplier Quality Assurance department at DAF Trucks N.V. and at PACCAR's other truck manufacturing brands. This solution was obtained by identifying the existing problems of the PAT and studying the appropriate way of overcoming the issues found.

Using different methodologies, five main problems were identified. The first problem was detected with the several interviews conducted with the Supplier Quality Managers, which indicated that the PAT was missing some relevant topics to evaluate supplier's performances. The second problem was identified through the analysis presented in section 3.3.2. It was regarding the existing variability in supplier classification due to the questions' insufficient capability to translate the SQMs' opinions into the final score. Furthermore, the third and fourth problems were established with the observation of an audit. The main conclusions were that the questionnaire of the PAT was too extensive to be reviewed in a one-day audit and it did not assist the SQM during the line-walk phase. Finally, the fifth problem was related to the amount of questions influencing the audit result, despite not being correlated to zero-defect topics. This issue was presented in section 3.3.4 with the evaluation of the PAT's questionnaire.

With the thorough study of the questionnaire and throughout the process of developing a solution, it was clear that the tool was covering too many aspects during an audit. Regardless of the objective of the audit, all the questions needed to be evaluated and the entire questionnaire contributed to the final score. This made the tool too generic and often incapable of accurately evaluating suppliers, which emphasised the necessity of having the several topics linked to the audit objectives.

The framework and its implementation presented on section 4.2.1 intend to solve all the identified problems. Firstly, it was assured that all the relevant topics, including the ones established as being missed, were included in the framework. Secondly, despite the extensive scope of the framework, all the topics were linked to the four main audit objectives and were further linked to the specific audit types mentioned in section 3.1, in order to reduce the number of questions assessed per audit. These questions are also divided according to whether they are reviewed during an interview or a line-walk. This increases the level of standard work and it provides the SQM more support during the assessment of the supplier's production line. Lastly, the combination of the above-mentioned characteristics of the framework will also generate a more accurate audit result that is more aligned with the audit objective, as well as the SQM's assessment.

On the whole, this thesis presents a designed framework that contains all the relevant topics to evaluate a supplier's performance, and its potential integration as a solution to the identified problems.

## 5.2 Recommendations

Considering that the optimisation of any process or activity should be a continuous cycle, some perspectives of future work that could be implemented are presented as follows:

- Although the implementation phase is not part of the scope or objectives of this work, it would have been interesting to monitor the use of the tool by the SQMs and measure the effectiveness of the improvements implemented. This could be done by assisting a considerable number of audits to evaluate the work standardisation and conducting a similar analysis to the one performed in Section 3.3.2.

- The topics of the PAT could have different impacts in the final audit score, to make it even more accurate. The topics that have a section with instructions to look for evidence should be considered as the more significant ones to evaluate a supplier. Hence, their influence in the final result could be increased.

- The use of this tool with MS Excel presents some challenges, especially when sent to the supplier to obtain the self-assessment, due to the use of Macros. It would be beneficial to implement the framework developed in a tool that allowed a much more effective way of presenting the results and an increased user-friendliness.

- In the interest of continuously improving the Process Audit Tool, and considering the relevance of brainstorming for this purpose, it is suggested that regular meetings are conducted, for example annually, to make a periodic analysis of the situation. These meetings would have the objective of measuring the level of satisfaction with the model used and understand if there were opportunities to implement upgrades. It is also important to evaluate the pertinence of these upgrades before implementing them, to guarantee that the focus on the audit objectives is preserved if questions are added to the PAT.

- Every SQM with a lower or non-existent level of experience in auditing a supplier should perform this activity with a more experienced SQM. This would allow the SQM to be trained with the necessary skills to have the correct approach when performing audits, which would also be reflected in a more effective use of the PAT.

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# Appendix A

# Process Audit Tool Sheets

This appendix presents the *Summary Sheet* and Graphical Data sheet of the PAT.

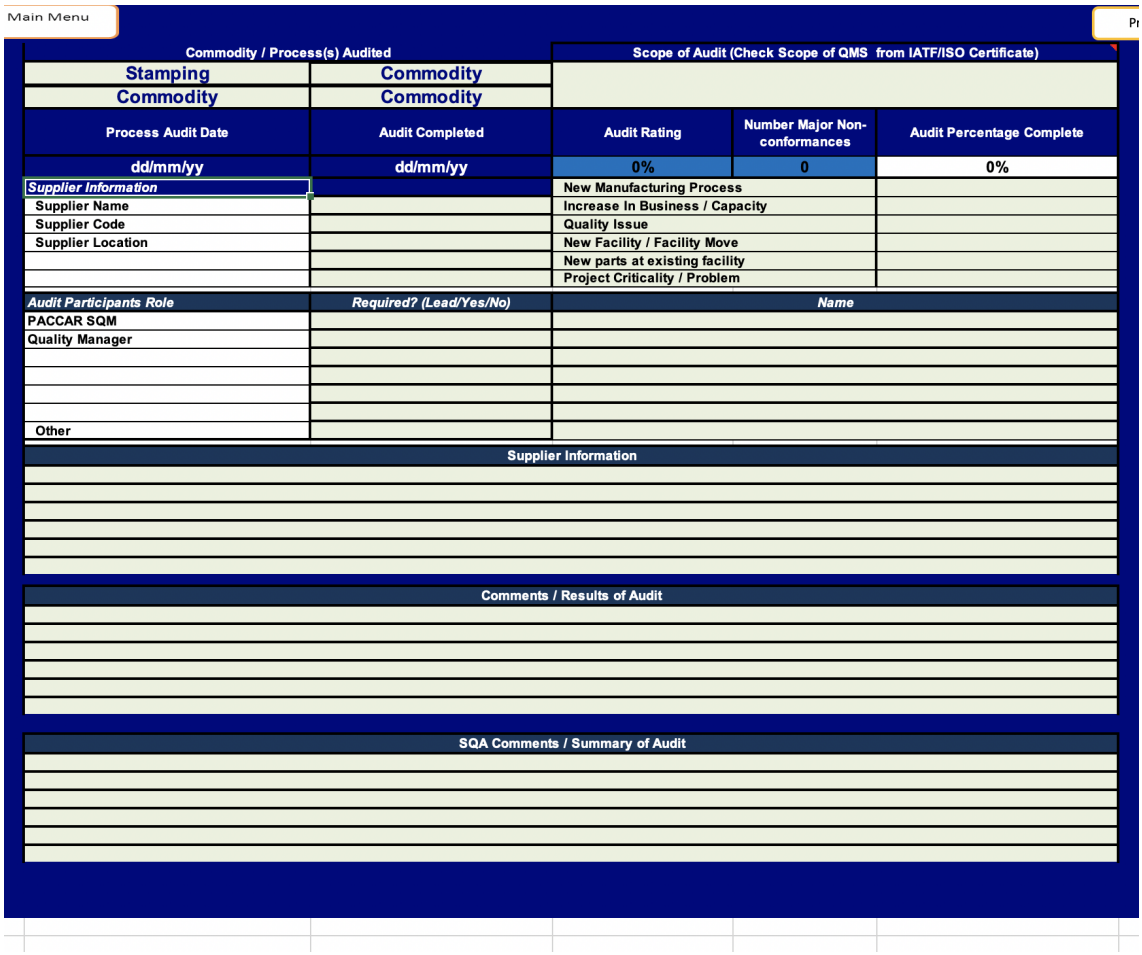


Figure A.1: PAT Summary Sheet.

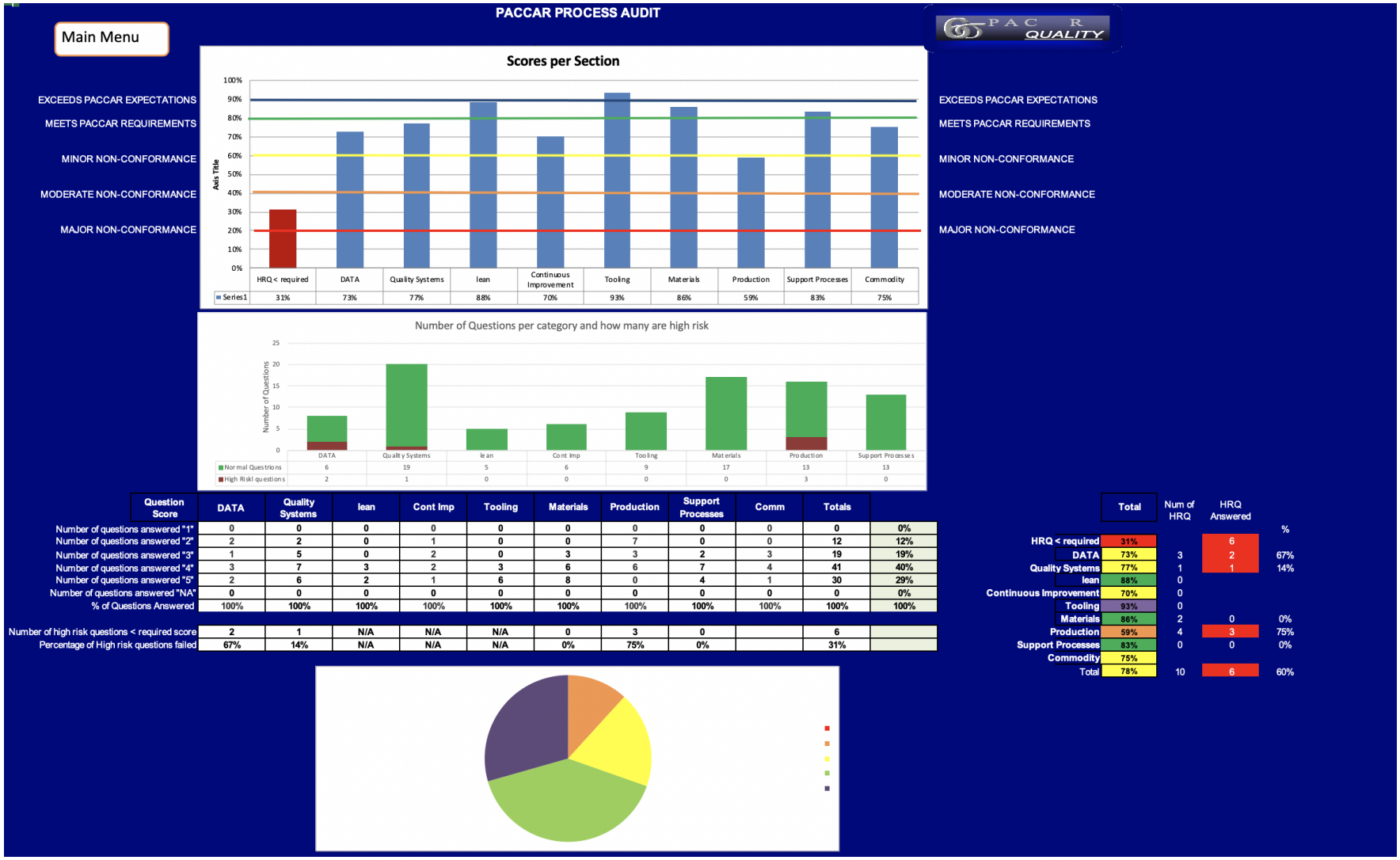


Figure A.2: PAT *Graphical Data* complete sheet.

# Appendix B

# Examples of Interview and Meeting Minutes Held With SQMs

# Interview 1



**Beginning Time:** 2:30PM

**End Time:** 3:30PM

**Place:** DAF Trucks N.V. Offices

**Participants:** SQM from Team 2

## Agenda:

- Comprehension of the steps taken to conduct an audit, and when is the tool used in this process;
- Topics addressed and questions asked when auditing a supplier;
- Existing problems within the tool.

## Notes:

**Audit steps**

- Send a notification to perform the audit;
- Send the process audit tool to the supplier for a self-assessment (the supplier has, normally, 3 weeks to fill the tool);
- Review the questions scored with 1, 2 or 3 (topics that will need higher attention during the audit);
- Plan a visit to the supplier organisation;
- During the visit, there is a plant tour through the manufacturing line and interviews with the quality manager and other relevant employees (where the tool is reviewed and scores are changed when needed).

**Topics and Questions**

- Did you have any recent audits carried out by other customers? What were the results of that audit?; (not in the tool)
- How is the information that DAF shares on supplier standards managed;
- How many changes have you done in the last month and how many were reported to customers?; (not in the tool)
- Check FMEAs;
- Mindset of the company management towards continuous improvement;
- Understand if managers accept the audit findings and cooperate to become a zero-defect supplier;
- Investigate if poka-yokes are used;
- Employees' empowerment.

**Issues and Improvements**

- Ambiguity of questions (it is sometimes possible to give more than one answer to a question);
- Description of some scores is missing.

# IATF Meeting



**Beginning Time:** 1:00PM

**End Time:** 2:30PM

**Place:** DAF Trucks N.V. Offices

**Participants:** 3 SQMs from IATF Training

## Agenda:

Information about the brainstorm that took place at the IATF training, took by some of the SQMs.

## Notes:

- IATF upgrades;
- Process Audit Tool is very general;
- Description of some scores is missing;
- List of improvement points according to the scores obtained in the questions could be added. This list should be able to answer the following question: What does the supplier needs to do to be able to reach the next level?;
- Automotive core tools to be added, only a few questions on the topic(PPAP, APQP, FMEA, among others);
- Link IATF clauses to some of the questions, tfor a better justification on why the non-conformity was pointed out;
- New main menu could be done, with matrix according to the types of supplier (new/existing) and then the type of product (new/existing) and add special topics/special types of audits;
- Leadership/Quality culture to be included. Some question examples: How often do you review KPIs/APQP?; Is there a Continuous Improvement/Lean/Six Sigma project being implemented? How are the quality KPIs organized? Are they available for everyone? How many improvement ideas did the supplier have this year? How many of those were actually implemented?;
- How suppliers manage their projects (see VDA 6.3);
- Categorise the scoring to understand if it is a high-risk supplier for DAF. That could be done according to the questions being high risk or not; major/minor non-conformities
- Some scores need adjustment and the software sheet scores do not work properly;

- Evaluate the importance of the categories according to each type of audit;
- First and second graphic of the graphical data need attention (it is possible to have a major nonconformity even if the % is above 20%. Additionally it should be specific the scores of the high-risk questions because they are still high risk even if they are scored 3/4/5);
- Translate risk into cost, being able to inform the purchasing of the risks;
- Understand the context of the supplier, his location, country politics, etc – to be able to evaluate according to these parameters;
- 📌 How do suppliers manage their sub suppliers (Tier2 Management)?.

Items of major relevance were marked with a pin.

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# Appendix C

# Examples of Meetings' Minutes of the Process Audit Tool Team

# Process Audit Tool

Wednesday, April 1, 2020 3:36 PM

**Meeting Date:** 4/1/2020 2:00 PM
**Location:** Microsoft Teams Meeting
**Link to Outlook Item:** *click here*
**Invitation Message**
**Participants**

- Ines Sequeira Braga Montenegro (University of Porto) (Meeting Organizer)
- Philip Aspinwall (Accepted in Outlook)
- Michiel Schonewille (Accepted in Outlook)
- Aprameya Muralidhar (Accepted in Outlook)
- Ruud Swanink
- Martin Jilek (Declined in Outlook)

## Notes

- 4 Main Audit Questions:
  - Supplier capability of making the product
  - Supplier capability of meeting zero defects
  - Supplier capability of supporting project/design
  - Supplier capability of meeting the standards/costumer requirements

- Framework needs to be changed - add a 4th circle for "Standards"
- The objective is to look for evidence of effectiveness per subcategory, e.g. tier 2 management, of the framework

### Actions for next meeting

- Excel file linking the questions and the objectives until Monday (April 6th)
- Review last three audit agendas from SQMs as a way of gathering info about audit's steps (April 6th)

Next steps

- Define key questions per framework circle

# Process Audit Tool

Thursday, 9 April 2020 17:25

**Meeting Date:** 09/04/2020 11:00
**Location:** Microsoft Teams Meeting
**Link to Outlook Item:** *click here*
**Invitation Message**
**Participants**

- Ines Sequeira Braga Montenegro (University of Porto) (Meeting Organizer)
- Aprameya Muralidhar (Accepted in Outlook)
- Michiel Schonewille (Accepted in Outlook)
- Martin Jilek (Accepted in Outlook)
- Ruud Swanink
- Philip Aspinwall (Accepted in Outlook)

## Notes

- Questions were allocated to each framework objective, after reviewing all excel files filled in
- Started brainstorming: Review each question and check if it belongs or not to the framework objective previously assigned

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | What is the scrap rate? | | 18 | | Result Metric | indicator about health of organisation | |
| 3 | Are performance tests verified to engineering requirements and recorded, i.e. pressure test, continuity test etc.? | | | | Process control | | |
| 4 | Are the work and inspection stations suitable for the operation? (space, environment, lighting etc.) | | | | Work environment | | |
| 5 | Are test and error proofing equipment validated before start of production? | | | | PC | | |
| 6 | After tooling maintenance is the product output verified? (to clarify, this is not just normal cleaning, it is extraordinary requirements or scheduled maintenance, strip down etc.) | | | | PC | | |
| 7 | How is quality of incoming parts validated? | | | | PC | | |
| 8 | Is there a clear process for non-conforming parts | | | | IATF | SQRM | put together in 1 |
| 9 | How are non-conforming materials/parts identified and controlled? (segregation / quarantine) | **Process Control** | | | IATF | SQRM | question |
| 10 | Does the supplier have raw material traceability on receiving goods | | | | IATF | SQRM | requirement for |
| 11 | Does the supplier have raw material traceability on finished goods? | | | | IATF | SQRM | data analytics |
| 12 | Does the supplier have a capacity/resource plan to address build rate increases/decreases in short- and long-term? | | | | IATF | SQRM(20%) | |
| 13 | Are capability studies performed for Critical/Significant Characteristics, targets as per SQRM? | | | | PC | | |
| 14 | How are the key process parameters controlled and analysed to take actions in case of deviation? | | | | PC | | |
| 15 | Are the authorities and responsibilities defined and present for the start and stop of production? | | | | PC | | |
| 16 | How does the supplier control/change process parameters? | | | | PC | | |
| 17 | How do you ensure all operations in the process flow are completed? | | | | PC | | |
| 18 | Are shift handovers conducted in a controlled manner? | | | | PC | | |
| 19 | Is your product / service re-certified after maintenance activities which can affect the product quality? | | | | same as quest | this is better question | |
| 20 | Are all required tools, gages, equipment controlled, calibrated and maintained? - process control | | | | | | |
| 21 | | | | | | | |

**Next Steps**

- Continue the brainstorming initiated

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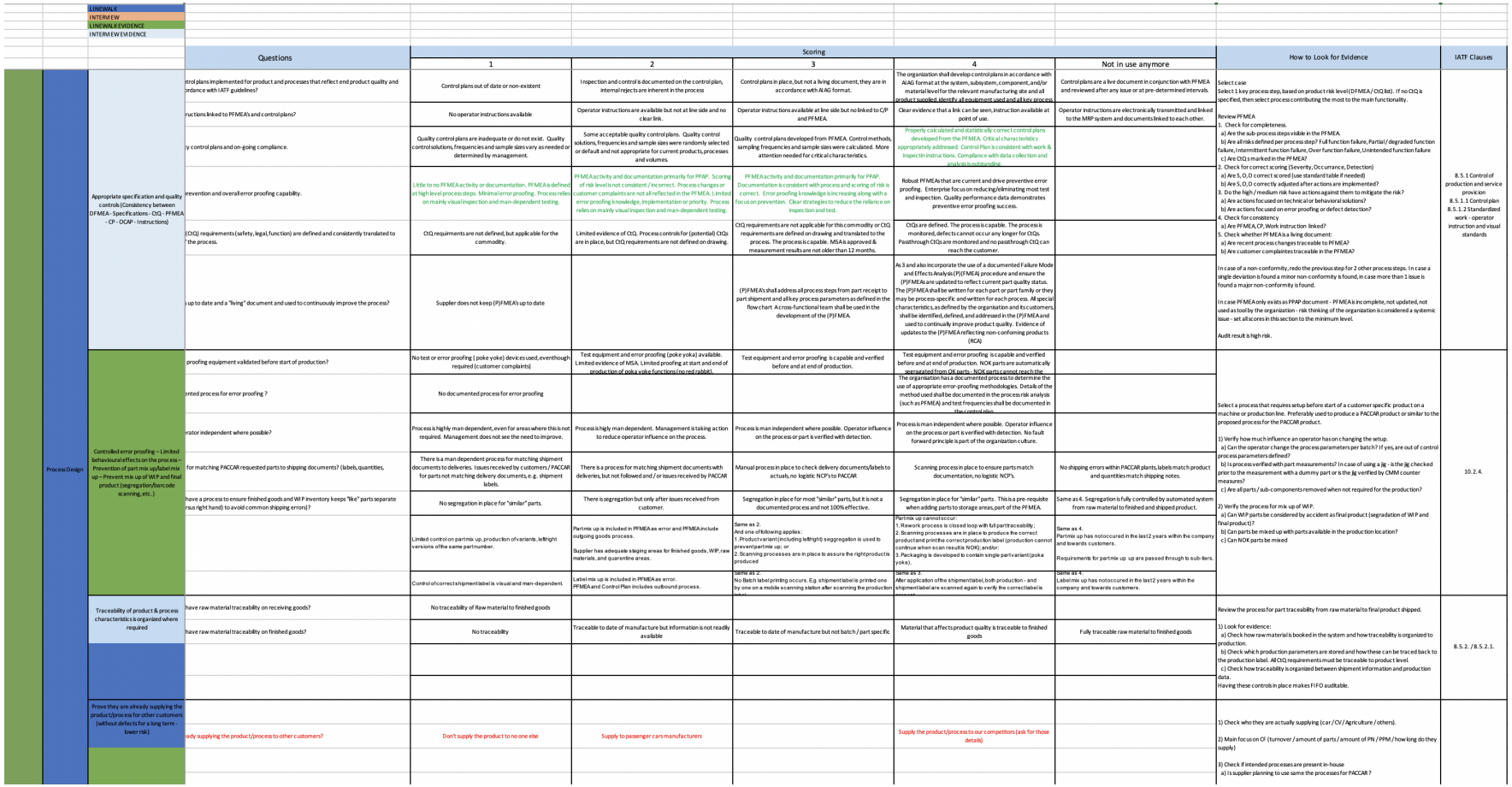
# Appendix D

# Implementation of the Framework

This appendix presents a general vision of the combination of the framework with the remaining important information, for future creation of a new Process Audit Tool.



LINEWALK
INTERVIEW
LINEWALK EVIDENCE
INTERVIEW EVIDENCE

| | | Questions | Scoring 1 | 2 | 3 | 4 | Not in use anymore | How to Look for Evidence | IATF Clauses |
|---|---|---|---|---|---|---|---|---|---|
| | Process Design | Appropriate specification and quality controls (Consistency between DFMEA - Specifications - CtQ - PFMEA - CP - OCAP - Instructions) | trol plans implemented for product and processes that reflect end product quality and rdance with IATF guidelines? | Control plans out of date or non-existent | Inspection and control is documented on the control plan, internal rejects are inherent in the process | Control plans in place, but not a living document, they are in accordance with AIAG format. | The organization shall develop control plans in accordance with AIAG format at the system, subsystem, component, and/or material level for the relevant manufacturing site and all product supplied. Identify all equipment used and all key process | Control plans are a live document in conjunction with PFMEA and reviewed after any issue or at pre-determined intervals. | Select case<br>Select 1 key process step, based on product risk level (DFMEA / CtQ list). If no CtQ is specified, then select process contributing the most to the main functionality.<br><br>Review PFMEA<br>1. Check for completeness.<br>a) Are the sub-process steps visible in the PFMEA.<br>b) Are all risks defined per process step? Full function failure, Partial / degraded function failure, Intermittent function failure, Over function failure, Unintended function failure<br>c) Are CtQ's marked in the PFMEA?<br>2. Check for correct scoring (Severity, Occurrance, Detection)<br>a) Are S, O, D correct scored (use standard table if needed)<br>b) Are S, O, D correctly adjusted after actions are implemented?<br>3. Do the high / medium risk have actions against them to mitigate the risk?<br>a) Are actions focused on technical or behavioral solutions?<br>b) Are actions focused on error proofing or defect detection?<br>4. Check for consistency<br>a) Are PFMEA, CP, Work instruction linked?<br>5. Check whether PFMEA is a living document:<br>a) Are recent process changes traceable to PFMEA?<br>b) Are customer complaintes traceable in the PFMEA?<br><br>In case of a non-conformity, redo the previous step for 2 other process steps. In case a single deviation is found a minor non-conformity is found, in case more than 1 issue is found a major non-conformity is found.<br><br>In case PFMEA only exists as PPAP document - PFMEA is incomplete, not updated, not used as tool by the organiation - risk thinking of the organiation is considered a systemic issue - set all scores in this section to the minimum level.<br><br>Audit result is high risk. | 8.5.1 Control of production and service provision<br>8.5.1.1 Control plan<br>8.5.1.2 Standardized work - operator instruction and visual standards |
| | | | ructions linked to PFMEA's and control plans? | No operator instructions available | Operator instructions are available but not at line side and no clear link. | Operator instructions available at line side but no linked to C/P and PFMEA. | Clear evidence that a link can be seen, instruction available at point of use. | Operator instructions are electronically transmitted and linked to the MRP system and documents linked to each other. | |
| | | | y control plans and on-going compliance. | Quality control plans are inadequate or do not exist. Quality control solutions, frequencies and sample sizes vary as needed or determined by management. | Some acceptable quality control plans. Quality control solutions, frequencies and sample sizes were randomly selected or default and not appropriate for current products, processes and volumes. | Quality control plans developed from PFMEA. Control methods, sampling frequencies and sample sizes were calculated. More attention needed for critical characteristics. | Properly calculated and statistically correct control plans developed from the PFMEA. Critical characteristics appropriately addressed. Control Plan is consistent with work & inspectin instructions. Compliance with data collection and analysis is outstanding. | | |
| | | | revention and overall error proofing capability. | Little to no PFMEA activity or documentation. PFMEA is defined at high level process steps. Minimal error proofing. Process relies on mainly visual inspection and man-dependent testing. | PFMEA activity and documentation primarily for PPAP. Scoring of risk levels not consistent / incorrect. Process changes or customer complaints are not all reflected in the PFMEA. Limited error proofing knowledge, implementation or priority. Process relies on mainly visual inspection and man-dependent testing. | PFMEA activity and documentation primarily for PPAP. Documentation is consistent with process and scoring of risk is correct. Error proofing knowledge is increasing along with a focus on prevention. Clear strategies to reduce the reliance on inspection and test. | Robust PFMEAs that are current and drive preventive error proofing. Enterprise focus on reducing/eliminating most test and inspection. Quality performance data demonstrates preventive error proofing success. | | |
| | | | (CtQ) requirements (safety, legal, function) are defined and consistently translated to the process. | CtQ requirments are not defined, but applicable for the commodity. | Limited evidence of CtQ. Process controls for (potential) CtQs are in place, but CtQ requirements are not defined on drawing. | CtQ requirements are not applicable for this commodity or CtQ requirements are defined on drawing and translated to the process. The process is capable. MSA is approved & measurement results are not older than 12 months. | CtQs are defined. The process is capable. The process is monitored, defects cannot occur any longer for CtQs. Passthrough CtQs are monitored and no passthrough CtQ can reach the customer. | | |
| | | | up to date and a "living" document and used to continuously improve the process? | Supplier does not keep (P)FMEA's up to date | | (P)FMEA's shall address all process steps from part receipt to part shipment and all key process parameters as defined in the flow chart Across-functional team shall be used in the development of the (P)FMEA. | As 3 and also incorporate the use of a documented Failure Mode and Effects Analysis (P)FMEA) procedure and ensure the (P)FMEAs are updated to reflect current part quality status. The (P)FMEA shall be written for each part or part family or they may be process-specific and written for each process. All special characteristics, as defined by the organisation and its customers, shall be identified, defined, and addressed in the (P)FMEA and used to continually improve product quality. Evidence of updates to the (P)FMEA reflecting non-conforming products (RCA) | | |
| | | Controlled error proofing – Limited behavioural effects on the process – Prevention of part mix up/labels mix up – Prevent mix up of WIP and final product (segregation/barcode scanning, etc. ) | proofing equipment validated before start of production? | No test or error proofing ( poke yoke) devices used, eventhough required (customer complaints) | Test equipment and error proofing (poke yoke) available. Limited evidence of MSA. Limited proofing at start and end of production of poka yoke functions (no red rabbit) | Test equipment and error proofing is capable and verified before and at end of production. | Test equipment and error proofing is capable and verified before and at end of production. NOK parts are automatically segregated from OK parts - NOK parts cannot reach the | | Select a process that requires setup before start of a customer specific product on a machine or production line. Preferably used to produce a PACCAR product or similar to the proposed process for the PACCAR product.<br><br>1) Verify how much influence an operator has on changing the setup.<br>a) Can the operator change the process parameters per batch? If yes, are out of control process parameters defined?<br>b) Is process verified with part measurements? In case of using a jig - is the jig checked prior to the measurement with a dummy part or is the jig verified by CMM counter measures?<br>c) Are all parts / sub-components removed when not required for the production?<br><br>2) Verify the process for mix up of WIP.<br>a) Can WIP parts be considered by accident as final product (segradation of WIP and final product)?<br>b) Can parts be mixed up with parts available in the production location?<br>c) Can NOK parts be mixed | 10.2.4. |
| | | | nted process for error proofing ? | No documented process for error proofing | | | The organisation has a documented process to determine the use of appropriate error-proofing methodologies. Details of the method used shall be documented in the process risk analysis (such as PFMEA) and test frequencies shall be documented in the control plan | | |
| | | | rator independent where possible? | Process is highly man dependent, even for areas where this is not required. Management does not see the need to improve. | Process is higly man dependent. Management is taking action to reduce operator influence on the process. | Process is man independent where possible. Operator influence on the process or part is verified with detection. | Process is man independent where possible. Operator influence on the process or part is verified with detection. No fault forward principle is part of the organisation culture. | | |
| | | | for matching PACCAR requested parts to shipping documents? (labels, quantities, | There is a man dependent process for matching shipment documents to deliveries. Issues recieved by customers / PACCAR for parts not matching delivery documents, e.g. shipment labels. | There is a process for matching shipment documents with deliveries, but not followed and / or issues received by PACCAR | Manual process in place to check delivery documents/labels to actuals, no logistic NCP's to PACCAR | Scanning process in place to ensure parts match documentation, no logistic NCP's. | No shipping errors within PACCAR plants, labels match product and quantities match shipping notes. | |
| | | | have a process to ensure finished goods and WIP inventory keeps "like" parts separate rsus right hand) to avoid common shipping errors)? | No segregation in place for "similar" parts. | There is segregation but only after issues received from customer. | Segregation in place for most "similar" parts, but it is not a documented process and not 100% effective. | Segregation in place for "similar" parts. This is a pre-requisite when adding parts to storage areas, part of the PFMEA. | Same as 4. Segregation is fully controlled by automated system from raw material to finished and shipped product. | |
| | | | | Limited control on partmix up, production of variants, leftright versions of the same partnumber. | Partmix up is included in PFMEA as error and PFMEA include outgoing goods process.<br><br>Supplier has adequate staging areas for finished goods, WIP, raw materials, and quarentine areas. | Same as 2.<br>And one of following applies:<br>1. Product variant (including leftright) segregation is used to prevent partmix up; or<br>2. Scanning processes are in place to assure the right product is produced | Partmix up cannot occur:<br>1. Rework process is closed loop with full parttraceability;<br>2. Scanning processes are in place to produce the correct product and print the correct production label (production cannot continue when scan results in NOK); and/or:<br>3. Packaging is developed to contain single partvariant (poka yoke). | Same as 4.<br>Partmix up has notoccured in the last2 years within the company and towards customers.<br><br>Requirements for partmix up are passed through to sub-tiers. | |
| | | | | Control of correct shipment label is visual and man-dependent. | Label mix up is included in PFMEA as error.<br>PFMEA and Control Plan includes outbound process. | Same as 2.<br>No Batch label printing occurs. Eg. shipment label is printed one by one on a mobile scanning station after scanning the production | Same as 3.<br>After application of the shipment label, both production - and shipment label are scanned again to verify the correct label is | Same as 4.<br>Label mix up has notoccured in the last2 years within the company and towards customers. | |
| | | Traceability of product & process characteristics is organized where required | have raw material traceability on receiving goods? | No traceability of Raw material to finished goods | | | | | Review the process for part traceability from raw material to final product shipped.<br><br>1) Look for evidence:<br>a) Check how raw material is booked in the system and how traceability is organized to production.<br>b) Check which production parameters are stored and how these can be traced back to the production label. All CtQ requirements must be traceable to product level.<br>c) Check how traceability is organized between shipment information and production data.<br>Having these controls in place makes FIFO auditable. | 8.5.2. / 8.5.2.1. |
| | | | have raw material traceability on finished goods? | No traceability | Traceable to date of manufacture but information is not readily available | Traceable to date of manufacture but not batch / part specific | Material that affects product quality is traceable to finished goods | Fully traceable raw material to finished goods | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | Prove they are already supplying the product/process for other customers (without defects for a long term - lower risk) | | | | | | | 1) Check who they are actually supplying (car / CV / Agriculture / others).<br><br>2) Main focus on CF (turnover / amount of parts / amount of PN / PPM / how long do they supply)<br><br>3) Check if intended processes are present in-house<br>a) Is supplier planning to use same the processes for PACCAR ? | |
| | | | ady supplying the product/process to other customers? | Don't supply the product to no one else | Supply to passenger cars manufacturers | | Supply the product/process to our competitors (ask for those details) | | |
| | | | | | | | | | |
| | | | | | | | | | |

Figure D.1: MS Excel file containing all relevant information for PAT.

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|---|---|---|---|---|---|---|---|---|---|---|
| | | LINEWALK | | | | | | | | |
| | | INTERVIEW | | | | | | | | |
| | | LINEWALK EVIDENCE | | | | | | | | |
| | | INTERVIEW EVIDENCE | | | | | | | | |
| | | | Questions | Scoring | | | | | How to Look for Evidence | IATF Clauses |
| | | | | 1 | 2 | 3 | 4 | Not in use anymore | | |
| Is the supplier capable of making the product without defects? | | Prove they are already supplying the product/process for other customers (without defects for a long term - lower risk) | | | | | | | 1) Check who they are actually supplying (car / CV / Agriculture / others).<br>2) Main focus on CF (turnover / amount of parts / amount of PN / PPM / how long do they supply)<br>3) Check if intended processes are present in-house<br>a) Is supplier planning to use same the processes for PACCAR ? | |
| | | | ady supplying the product/process to other customers? | Don't supply the product to no one else | Supply to passenger cars manufacturers | | Supply the product/process to our competitors (ask for those details) | | | |
| | | OCAP including containment process in case defect product is produced, e.g. drill brakes down | | | | | | | | |
| | | | proach used when defect products are produced? | Doesn't use structured approach to problem-solving | | 8D | | Equal tool to PACCAR RCA template | | |
| | | | se the tool? | No proper use of AD reports (e.g. they are not closing some steps) | | | | They complete all the steps | | |
| | Equipment | High autonomy with technical controls (process can meet product specification/tolerances) - operator cannot overrule controls | rocess parameters controlled and analysed to take actions in case of deviation? | SPC not used as a method to ensure processes are in control | SPC recorded for PPAP only | SPC is used to ensure processes are setup correctly, but not continuous | SPC is part of the production process and actions documented for deviations for all key process parameters. | | 1) Verify if the supplier uses SPC<br>a) Check which system is used (online SPC, x-chart, others)<br>b) How SPC data is used..<br>2) Interview on how the supplier manages his task.<br>3) Deepdive on how the supplier manages the parameters.<br>a) Who is allowed to change parameters?<br>b) How the parameters are protected (password / key)?<br>c) Are the parameters permanently availble to be changed (key is always in)?<br>d) How does the supplier manage the parameters and how does he monitor the changes? | |
| | | | and responsabilities defined and present for the start and stop of production? | Not defined | Not documented but word of mouth no clear responsibilities | Authorities and responsibilities are defined but not adhered too. | Authorities and responsibilities are defined and known and visible by all relevant personnel and adhered too. | | | |
| | | | | Process and End of Line controls consists out of visual checks and/or are man-dependent. | Majority drawing characteristics, influenced by process, are controlled by checking jigs, measurement jigs or process controls (build in quality). | Same as 2.<br>All drawing characteristics, influenced by process, are controlled by e.g. checking jigs, measurement jigs or process controls (build in quality). | Same as 3.<br>Process controls are automated (where possible) and operator cannot overrule decision when partis NOK. | Same as 4.<br>Production process is ready for automated adjustment of production line parameters (industry 4.0). | | |
| | | | oler control/change process parameters? | No control | Process documented but not adhered too. | Only certain people allowed to change process parameters, not documented | There is a documented WI/process to ensure changes are implemented in a controlled manner. Verified back-up methods of process control are available when issues occur. | | | |
| | | Production process meets commodity best practice "excellent" level | ific questions | | | | | | | |
| | | Capability of measurement equipment, jigs and poka-yoke solution – MSA meets requirements – detection is technical where possible. | lies performed for Critical/Significant Characteristics, targets as per SQRM? | No evidence of capability studies. | Capability study completed for PPAP only, no long term capability studies | Capability and MSA studies available for all Critical/Significant characteristics and not all meeting the SQRM/drawing requirements. | Capability and MSA studies are completed for all new processes, paying special attention to Critical/Significant characteristics that they are meeting the SQRM/drawing requirements.<br>Adherence to the following<br>a) measurement techniques;<br>b) sampling plans;<br>c) acceptance criteria;<br>d) records of actual measurement values and/or test results for variable data;<br>e) reaction plans and escalation process when acceptance | | | 7.1.5.1.1. |
| | | | proofing equipment validated before start of production? | No test or error proofing ( poke yoke) devices used. | Test equipment available but no error proofing | Test and Poke Yoke devices used but no clarification if they are working correctly, no verification. | All Poke Yoke devices are checked with good and bad products at start of shift or proven frequency. | | | |
| | | | ne stoppage strategy, implementation and compliance. | No trigger limits implemented. Line stoppage is rarely allowed but is at the discretion of management. | No trigger limits implemented. Operators may be allowed to stop the line in rare instances if quality defects are excessive. No clear limits when to do so, no documentation of stoppages. | Trigger limits on critical processes, but levels may be questionable. Operators are to stop production when the trigger limit has been met. Action is required to identify the root cause and correct it. | Statistically correct trigger limits on critical processes. Trigger limits are recalculated as quality improves. Operators are empowered to stop production based on trigger and immediate action is required. | | | |
| | Tooling | Tool is able to meet product specifications | tenance is the product output verified? (to clarify, this is not just normal cleaning, it is uirements or scheduled maintenance, strip down, etc) | No verification takes place | Tool verified but not product | Parts are attribute tested on a checking fixture | Clear evidence that product is fully verified after maintenance activities, follows documented procedure. | Automated system in place to ensure verification of product and tool takes place after maintenance | | |
| | | Tool state is acceptable for producing the product (not exceeding shot life, not having overdue maintenance / open maintenance activities) | your preventive maintenance plans? | No preventative maintenance activities for tooling, fix as fail | Not all tools on maintenance plan schedules not followed | Tools are maintained as part of the preventative maintenance programme but not based on data. | Tools are maintained as part of the preventative maintenance programme, based on historical data | All tools have a comprehensive spares system and all aspect of maintenance can be performed in house based on predictive maintenance. | | |
| | | | ls, gages, equipment controlled, calibrated and maintained? | No calibration process in place and equipment are not controlled, maintained | Calibration process in place but does not contain all equipment, etc. | Calibration system in place, but some of them overdue. | Documented calibration system in place all up to date. | | | |
| | | | handle PACCAR tools | | | | | | | |
| | | Parts have 100% PPAP | PQP) / safe launch plan (PPAP) available for supplied products? | No plans available, issues at SOP | No plans available but no issues at SOP, PPAP not ready and no SLP | Plan available but not effective problems with PPAP | Evidence of no rejects at SOP and documented quality plans available, fully approved PPAP at VW. | All new parts are planned using APQP and full PPAP's available at CV, no reject's since introduction | 1. Check the supplier's APQP procedure to see how 100% PPAP at Customer's CV/VW/SOP is guaranteed (Target should be 100% PPAP at Customer VV)<br>a) Check instances from past project and/or running business to verify if parts have PPAP (on time).<br>b) Check if there is a Safe Launch Plan procedure defined to ensure parts without PPAP are not used after SOP. | 8.6.4. / 8.3.4.4. |
| | | | tion have a process in place to comply with on time PPAP submission? | No process to track on time PPAP submission | Process in place but PPAP's are late and of poor quality | PPAP's submitted on time with issues | Process in place PPAP's submitted on time with no issues | 4= supplier is proactive with addressing road blocks to full approval | | |

Figure D.2: Extension of the MS Excel file containing all relevant information for PAT.

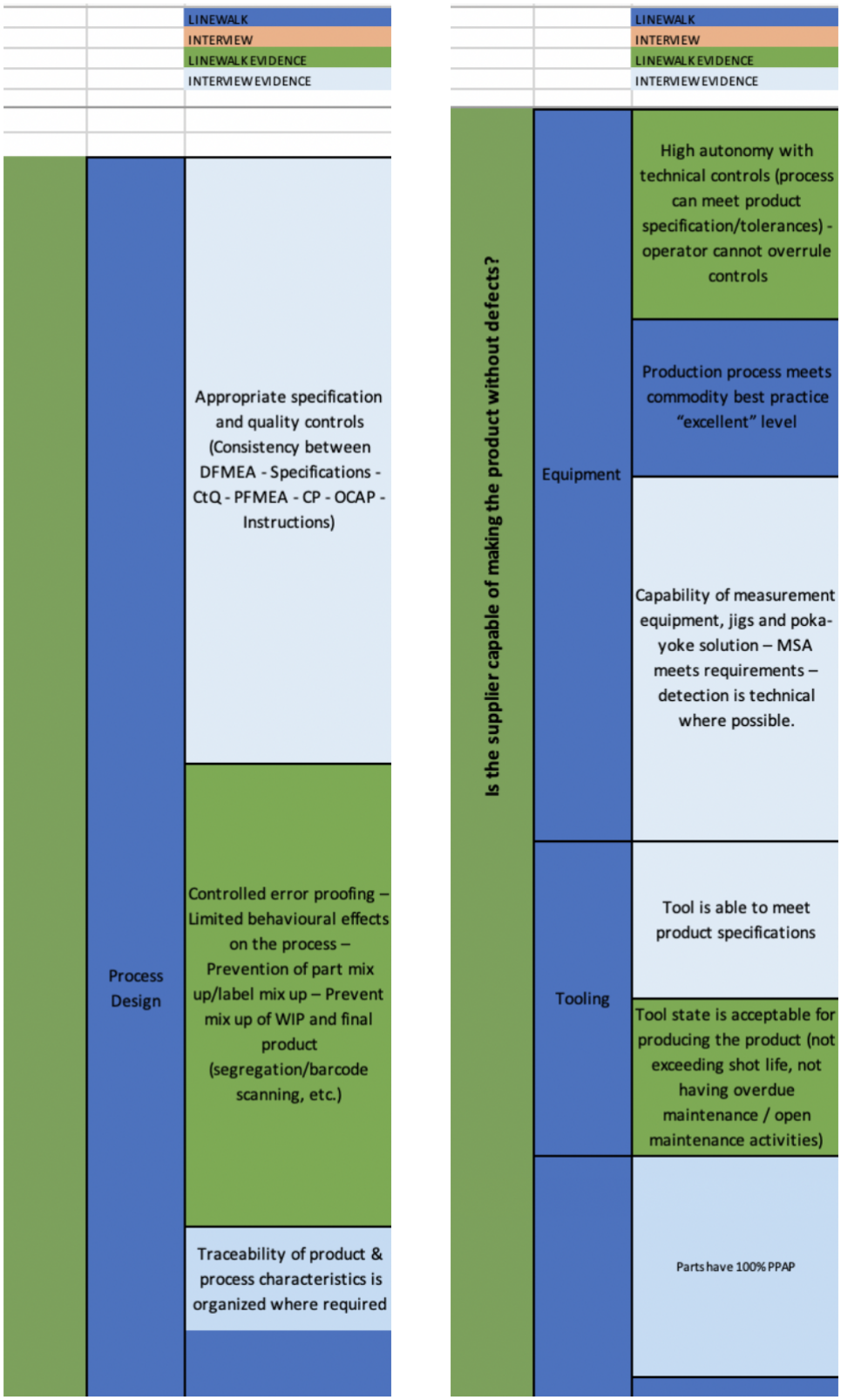


Figure D.3: Amplification of the first three columns of the previous MS Excel file presented.