# ŠKODA AUTO VYSOKÁ ŠKOLA o.p.s.

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# Quality assurance within Intelligent Vehicle Measurement Process 2030 in ŠKODA AUTO a.s.

## Bachelor Thesis

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# REGISTRATION FOR BACHELOR THESIS

Candidate: **Matúš Toráč**

Study programme: Business Administration

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Thesis title: **Quality assurance within Intelligent Vehicle Measurement Process 2030 in ŠKODA AUTO a.s.**

Aim: The main aim of the bachelor thesis is to describe and characterize the measurement methods used in the automotive industry, to approach the iVMP 2030 measurement strategy and the commitments arising from its adoption. To analyse the current state of vehicle measurements and to propose the implementation of the strategy to the Measurement process.

Content areas:

1. Introduction to Quality Management, Metrology and Measurement methods utilized in the automotive industry.
2. Introduction and description of iVMP 2030 strategy, goals and commitments of the strategy.
3. Analysis of the current state at ŠKODA AUTO a.s. in regards to Metrology.
4. Proposal of iVMP 2030 strategy implementation in ŠKODA AUTO a.s.

Length of thesis: 25 – 30 stran

Recommended literature:

1. LINDSAY, W M. *Managing for quality and performance excellence.* 10th ed. Cengage Learning, 2017. 701 p. ISBN 978-1-305-66254-4.
2. *Quality assurance : applying methodologies for launching new products, services, and customer satisfaction / D.H. Stamatis.* Boca raton: Taylor & Francis Group, 2016. ISBN 9781498728706.
3. NENADÁL, J. *Management kvality pro 21. století.* 1st ed. Management Press, 2018. 366 p. ISBN 978-80-7261-561-2.
4. *Introduction to Quality and Reliability Engineering.* Springer Berlin Heidelberg, 2015. Springer Series in Reliability Engineering. ISBN 9783662472156.

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I would like to thank doc. Ing. et Ing. Martin Folta, Ph.D., EUR ING. for his professional and kind supervision of my thesis providing me with beneficial advice, necessary information and proficient experience in the academic sphere and field of quality assurance.

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# Contents

## List of abbreviations and symbols

| | |
|---|---|
| APQP | Advanced Product Quality Planning |
| A-SUVe | Electric Sport Utility Vehicle of A segment |
| BEV | Battery Electric Vehicle |
| DMAIC | Define, Measure, Analyse, Improve, Control – optimization process |
| EOF | End-Of-Line quality inspection |
| FMEA | Failure Mode & Effects Analysis |
| IATF | The International Automotive Task Force |
| ISO | International Organization for Standards |
| iVMP | Intelligent Vehicle Measurement Process |
| LCL | Lower Control Limit |
| MBA | Master of Business Administration |
| MSA | Measurement System Analysis |
| PDCA | Plan, Do, Check, Act – Deming's cycle |
| PMD | Promess Measurement Device |
| PPAP | Product Parts Approval Process |
| Q-management | Quality management |
| SOP | Start of Production |
| SPC | Statistical Process Control |
| SWOT | Strengths, Weaknesses, Opportunity, Threats analysis |
| UCL | Upper Control Limit |
| VFF | Vorserien-Fraigabe-Fahrzeuge |

## Introduction

The chosen subject for this final thesis is Quality assurance within Intelligent Vehicle Measurement Process 2030 in ŠKODA AUTO a.s. that is highly relevant to the current industry 4.0 transformation in the automotive industry.

The main objective of this thesis is to describe and characterize the measurement methods, strategies and tools used in the automotive industry and further approach the Intelligent Vehicle Measurement Process strategy and the commitments arising from adoption of the strategy, to analyse the current state of vehicle measurements and to propose the implementation within a chosen project of the strategy to the measurement process

The author is motivated to describe this topic due to awareness of a necessary shift to a more effective and efficient means of measurements within ŠKODA AUTO a.s. and the motivation to compete at the ŠKODA AUTO Laurin & Klement competition of university students.

The thesis is further divided into a theoretical part where Quality management as such is discussed. The main objective of the theoretical part is to lead focus on quality as a concept for a better understanding within the broad public. In this sense terms such as quality and management are described along with three main concepts of Quality management along with basic quality management principals.

Following, the aim of the theoretical part is to elaborate more on metrology as a scientific field and two basic subfields of metrology. Metrology of systems and practical metrology, including MSA and PPQP strategies, are described.

Further the focus is narrowed down to the automotive industry and quality measurement methods and tools utilized within the industry. The objective is to describe the importance of Product Part Approval Process and tool such as Failure Mode & Effects Analysis, Statistical Process Control and The Lean methodology and  Six Sigma strategy resulting in Lean Six Sigma.

In the second, practical part of the study, the author focuses on the newly emerging measurement strategy in ŠKODA AUTO a.s. – The Intelligent Vehicle Measuremnt Strategy 2030, leaving the public with all essential knowlage considering this strategy. The core of the strategy including three ground pillars of iVMP 2030 are described.

The following chapters are devoted to a conduction of an analysis of the current state regarding the utilization of metrology in ŠKODA AUTO a.s. Author characterises a quality department of ŠKODA AUTO a.s. that focuses on measurements execution.

Nevertheless, the Intelligent Vehicle Measurement Process 2030 strategy is suggested regarding the utilization of optical measurement means. The goal and core of the final part is devoted to the transformation from touch-based measurements to optical measurements and possible implementation to the assembly ass end-of-line inspection and scenarios if the method will not be implemented.

Quality management is nowadays a highly desirable aspect of modern manufacturing. In an extremely competitive and saturated environment, manufactures can beat the competition only by supplying products or a services of excellent quality.

# 1 Quality management

As stated by Nendál (Nenadál, 2018), the term quality is the most influential aspect of our daily life. It has always played a key role in the decision-making process when choosing a product or a service. Quality explains how producers should manufacture their products. For a better understanding of quality, it is essential to consider its historical development and first appearance in the antic Greece.

Aristoteles once said, *“Quality is not an act, it is a habit.”* His famous quote is considerate as the first description of the concept of quality. Many others followed this philosophy. Henry Ford once said, *“Quality means doing it right when no one is looking.”* From these two instances it is noticeable that quality is a set of actions to achieve a desirable state.

Moreover, quality and its depth is influenced by the customer and his expectations and needs. Considering ISO 9000 family of standards (iso.org, 2015), one of the elementary certificates assuring state of the art quality in modern manufacturing, the term Quality is defined as “*the degree to which a set of inherent characteristics of an object fulfils requirements.”.*

According to Stamitas (Stamatis, 2016) when deciding if a product meets a certain level of quality, two basic quality characteristics are considered:

1. **Quantitative** – measurable signs (dimensions, weight, power output, etc.)
2. **Qualitative** – non-measurable signs (taste, smell, approach of personal, etc.)

Every company in the world has its specific goals that are measurable, achievable, relevant and time bound. According to Jennifer Herrity (Herrity, 2019) management combines the coordination and administration of certain task to achieve these goals. To achieve a common goal, leaders in charge - managers must specifically set targets, organize and motivate their teams with a set of soft skills such as leadership, analytic thinking, organizational skills and many more. Only under these conditions a goal could be successfully achieved.

On the authority of Lindsay (LINDSAY, 2017), quality management represents the penetration between quality and management. It uses managerial skills to ensure a continual satisfaction of customers’ expectations and needs, in other words quality.

Nevertheless, it has become the decision-making factor when distinguishing a functional conforming product or a part and a faulty product, a so called non-conformity.

Springer Berlin Heidelberg (Springer Berlin Heidelberg, 2015) states that not only modern companies that need to achieve top level quality and customer satisfaction, yet all organization that have the ambition to enter the production industry and would like to be successful in the competitive market have to considered three basic concepts of Quality management listed below:

1. ISO 9000 Standards
2. Industry (corporate) Standards
3. TQM – Total Quality Management

According to ISO standards (iso.org, 2015) the ISO family standards set criteria for quality management and its systems in many different fields such as requirements - EN ISO 9001: 2019, sustainable success - ISO 9004:2019, EN ISO 14001: 2019 for environment or auditing – EN ISO 19011:2019.

Source: (iso.org, 2015)

***Figure 1 ISO Standards logo***

Further ISO 9000 family standards (iso.org, 2015) are used in over 170 countries and have universal use among all industry fields and could be used as guidelines for a further quality achieving. These standards are considerate as minimum requirements that must be fulfilled. The best-known standard is the ISO 9001 by which organizations must be audited and certified. It consists of all Quality management principals, further described in the thesis, such as customer focus, employee involvement process and systematic approach, continuous improvement etc.

On the authority of IATF (IATF, 2016) industry standards are more specific than generic ISO 9000 standards and are valid within a specific industry field like automotive, pharmacy, agriculture, construction, financial sphere even military and education. These standards are more demanding than basic ISO 9000 standards and must be followed and fulfilled by all entities operating within the certain industry field. Meeting the requirements of IATF 16 949 is an absolute necessity for all organizations operating within the automotive industry.

Continued by IATF (IATF, 2016), the IATF 16 949 standard was created by the International Automotive Task Force. The main goal of this standard is a continuous improvement of the quality capability within the supply chain. In this sense the product quality could be ensured and certified at the highest level possible.

Howard Newton once stated, "*People forget how fast you did a job, but they never forget how well you did it*". In this sense it is necessary to consider the Total Quality Management approach in production facilities and supply of services.

According to Adam Baron on Investopedia (Baron, 2022) TQM is originally a Japanese approach to quality emerging first in 1970s and 1980s. TQM as a concept brought the automotive industry to the state where it is now. Although nowadays TQM is perceived more as a management philosophy, due to no standardization via industry standards, the ground pillars of TQM are largely spread among many production facilities.

## 1.1 Quality management principals

According to Stamitas (Stamatis, 2016) quality management is based on basic principles, customer focus, leadership and management, employee involvement, process approach, system approach to management, continuous improvement, decisions based on facts and mutually beneficial relationship with suppliers.

Many authors state a different number of basic principles of TQM, yet on the authority of (Nenadál J. , 2018) the thesis is going to focus on the eight following principals of TQM:

1. Customer focus
2. Leadership & Total employee involvement
3. Process approach
4. Integrated system
5. Systematic approach
6. Continuous improvement
7. Decisions based on facts
8. Mutual beneficial relationships with suppliers

Considering Josh Kaufman (Kaufman, 2012) when applying customer focus approach, the key is to correctly define the customer of a certain organization, since the final customer does not necessarily have to be the only customer. This could be achieved by a deep systematic examination of customer needs and requirements which are implemented into the product or service an organization offers.

Kaufman continues (Kaufman, 2012), not only the requirements, yet customer goals achieved via systematic communication with the customer supported by the management must be in accordance with the manufacturer. The combination of systematic communication and common goals leads to effective and efficient fulfillment of customer needs, a great level customer satisfaction and strong relationship between the organization and the customer.

As claimed by Jocko Wilkin (Wilkin & Babin, 2017) one of the goals of an organization is not only customer satisfaction, yet stakeholder satisfaction too. In this regard it is essential to define a stakeholder-oriented mission, vision and policy within the organization. This leads to a complete understanding of the common company mission and huge increase in effective employee involvement and motivation.

In the light of Jocko Wilkins (Wilkin & Babin, 2017), for a great leader it is important to believe and completely understand the common mission. Only in this sense he is able to hand over the mission to his subordinate team members, so that they completely understand the common goal and believe that the following action will lead to success and result in mutual benefits for the organization, its employees and its stakeholders.

On the report of Lidsay (LINDSAY, 2017), the focus of TQM is lead to the horizontal process interconnection rather than the vertical division of processes. The organization’s production process consists of smaller micro-processes that eventually create the company’s business processes essential for strategy definition and its implementation into the production process. The key is a perfect understanding of company’s mission, vision and eventually the quality polices.

According to ISO 9000 standards (iso.org, 2015) a company must be able to form integrated business systems that correspond and fulfill the stated criteria. Although every company might have a special mission, vision and company culture, it is highly possible to achieve a common level of quality and business excellence when creating integrated systems within ISO 9000 standards.

According to IATF (IATF, 2016) process approach is a set of management tools guiding an organization as a system of processes, not micromanaging people neither individual process. If the process is correct, the resulting product will be exceptional. For a better understanding, look at the process approach diagram below. The output of one process/production stage represents an input for the following process.

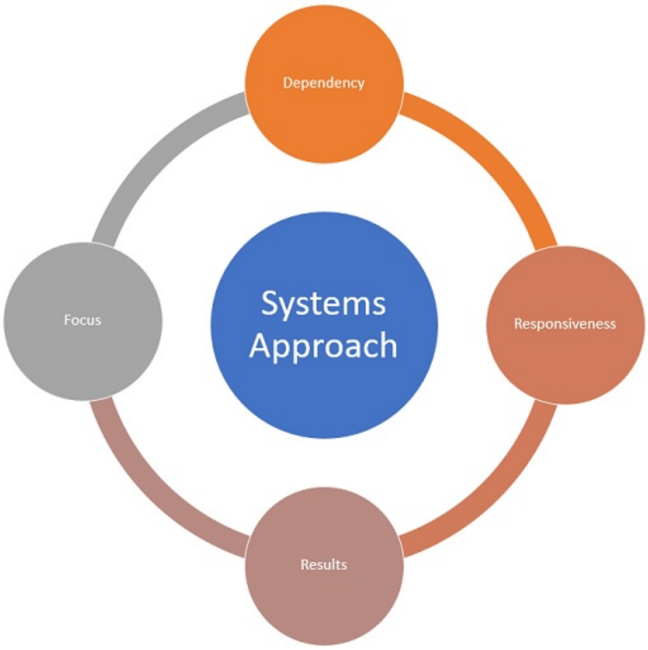
For a sustainable production the following steps of process approach are defined:

1. Identification of key processes
2. Definition of standards of key processes
3. Definition of process measurement and evaluation methods
4. Documentation
5. Continuous improvement

MBA School Team (January 14, 2022) defines the system approach as management perspective of any organization as one system. In other words, not considering an issue as individual parts, yet as a whole.

According to MBA Skool Team the system approach is helpful when seeing an issue from holistic perspective. Moreover, it brings more effective solutions and an overall understanding. Finally, system approach defines the scope of the issue and defines influential external and internal factors.

Yet MBA Skool Team states few drawbacks of system approach. Problems can be complex and distribution in smaller parts is needed. If solving sub-problems, the overall mindset of system approach is left out.

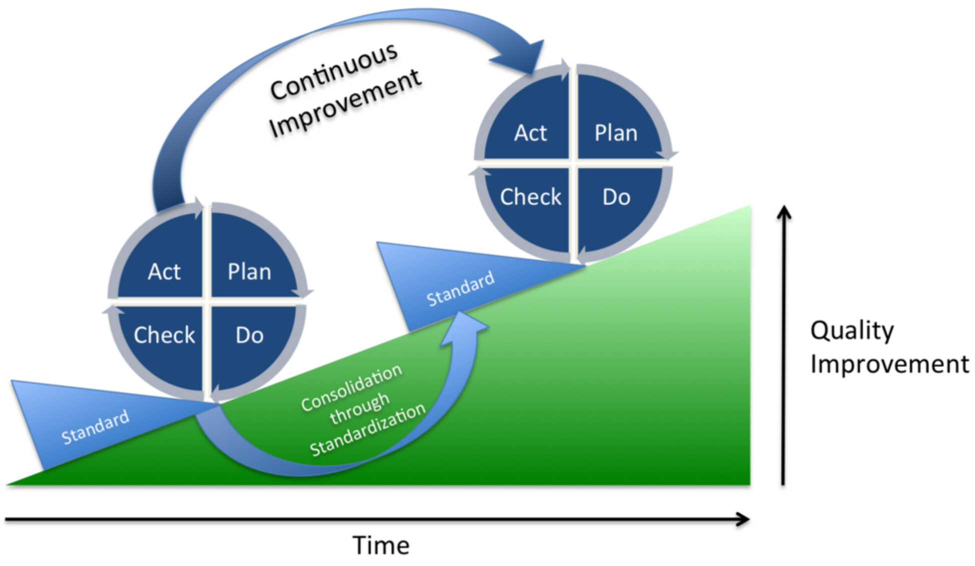



Source: (MBA Skool Team, 2022)

***Figure 2 Systematic approach scheme***

Kenton (Kenton, 2022) describes the never-ending effort to systematically identify and analyze weak points in an ongoing process by external and internal audits. This approach results in opportunities for improvement in a certain process and more efficient fulfillment of customer needs. With this tactic or philosophy in mind, managers are able to increase quality of a product or service in time and deliver a sustainable production process which will last for long periods of times.

As believed by Kenton (Kenton, 2022) without continuous improvement it is highly possible that the process will not work right at the beginning of the production and the eventually production without CPI will lead to increase in nonconformities, low level of efficiency and no fulfillment of customer needs.




Source: (Vetter, 2022)

***Figure 3 Continual improvement PDCA***

According to Hans Rosling (Rosling, 2018) the majority of employees in huge international corporates in the west still uses during their work deeply grounded non-actual principals. In age where global understanding and decision making on facts is highly demanded, managers and quality representative must consider the following rules of thinking.

Observing and problem identification leads to the determination of root factors that create the need for change and action. A deep observation and analysis of the cause is suggested with the focus on objective facts. The key approach is excluding all emotions, which will tough.

Rosling follows (Rosling, 2018), collection of empirical data, such as real measured values, and their raw record excluding any commentary is essential when applying the mindset of decision making based on facts. When collecting data in the human department through employee interview it is advised to state fact-based questions leaving the emotions and feelings aside.

When evaluating data based on facts the first step should be criteria identification used in the analysis and overall evaluation. The data should be spread into categories by the identified criteria. As humans we tend to fall into emotional decision making, therefore it highly important to create evaluation teams of more than one so the risk emotions is eliminated.

On the authority of Rosling (Rosling, 2018) all decisions made based on fact will certainly help the business grow, will enrich the product quality and fulfill all customer needs and requirements. Moreover, decision making based on facts also brings many benefits in the HR side of a business. For instance, it could refine the evaluation and analysis skills of an employee, speed up his ability to act and improves overall efficiency.

As belived by Nenadál (Nenadál, 2018), when discussing the dependents of an organization on its supplier and vice versa, many experts come to the same basic answer. These two entities are highly dependent on each other and should develop positive and mutually beneficial relationship in time. In this sense both organizations are able to produce more value in a more efficient and effective way.

Stamitas continues (Stamatis, 2016), furthermore, they can be more flexible and faster in response to an emerging issue resolving into successful elimination of the problem. Finally, the most important benefit of this approach and mindset is the cost and resources optimization.

## 2 Metrology – the art of measurements

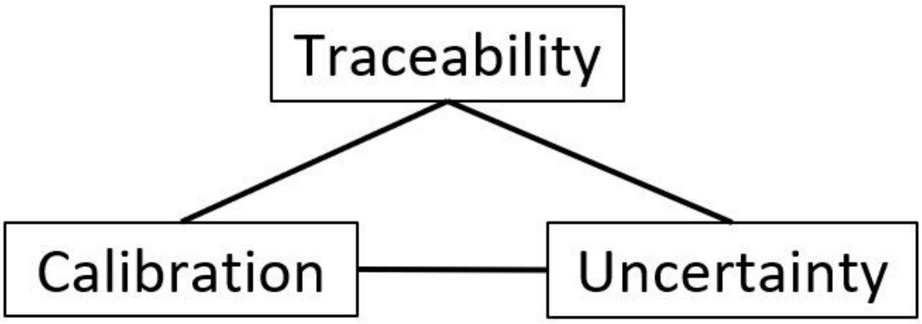
According to Raghavendra and Krishnamurthy (RAGHAVENDRA & KRISHNAMURTHY, 2013) the scientific study of measuring is known as metrology, and it covers all elements of measurement, including the creation of measurement standards, the design and manufacture of measurement instruments, and the application of measurements in business, research, and daily life. Ancient civilizations have a long history in the discipline of metrology. For many industries, including manufacturing, construction, and science, accurate measurements are crucial. Metrology has been crucial in maintaining the quality and safety of goods and services, and it is crucial in promoting trade and communication.

The authors continue as followed, the creation of measurement standards is one of the most crucial areas of metrology. These standards are necessary to guarantee that measurements are precise and uniform across various geographies and sectors. The most common system of measurement in use today is the International System of Units (SI), which is also the accepted system of units in the metrology industry. The seven base units of length, mass, time, electric current, temperature, amount of substance, and luminous intensity form the foundation of the SI units. These units, which form the cornerstone of the SI system and are specified by international agreement,

On the authority of Raghavendra and Krishnamurthy (RAGHAVENDRA & KRISHNAMURTHY, 2013) Designing and building measurement tools and instruments is a significant area of metrology. Physical quantities like length, mass, and time can be measured with these tools and equipment. In various fields, such as manufacturing, construction, and science, they are crucial for assuring precise measurements. In order to guarantee that measurements are trustworthy and consistent, measurement devices and instruments must be accurate and precise.

They continue, the discipline of metrology is crucial to the manufacturing process. For products to be of excellent quality and to adhere to the customer's specifications, accurate measurements are crucial. Metrology is also used to supervise the manufacturing process and guarantee that the goods are produced in accordance with the necessary standards. Utilizing metrology in the manufacturing process can help to lower costs, boost productivity, and raise product quality.

With the ongoing development of technology, metrology will continue to be essential for assuring precise measurements as well as for facilitating international trade and communication. As a reflection of the development ŠKODA AUTO a.s. invented a new measurement strategy iVMP 2030 elaborated more in this thesis.




Source: (WasyResearch, 2021)

***Figure 4 Basic concepts of metrology***

According to the Czech law (Zákon č. 505/1990 Sb. o metrologii), metrology in the Czech Republic, where ŠKODA AUTO a.s. is based, is governed by the Measures and Measurements Act, which was most recently updated in 2017. The act outlines the country's legal framework for the use of measuring instruments and the supply of measurement services. The Czech Office for Surveying, Mapping, and Cadaster is designated as the nation's metrological authority, in charge of enforcing conformity with the law and providing metrological certificates for measuring devices. The act also guarantees the application of EU legal metrology regulations and the reciprocal recognition of measuring findings throughout the EU.

## 2.1 Standardization of metrology

In accordance with ISO standards (iso.org, 2015), the measurement of physical quantities, the defining and application of units of measurement, the statistical analysis of measurement data, and the proficiency of laboratories and reference material providers are all governed by the following ISO standards:

- ISO 1000:1992, "SI Units and Recommendations for the Use of their Multiples and of Certain Other Units"

- ISO 31-0:1992, "General principles of quantitative metrology"
- ISO 3534-1:2006, "Statistics Vocabulary and symbols - Probability and general statistical terms"
- ISO/IEC 17025:2017, "General requirements for the competence of testing and calibration - laboratories"
- ISO/IEC 17034:2016, "General requirements for the competence of reference material - producers"

According to IATF (IATF, 2016) the standard mandates that businesses create and maintain a system for measuring, analyzing, and improving their processes. In order to verify that their procedures are effective, organizations must keep track of all measurements, analyses, and improvements.

In accordance with the IATF standard (IATF, 2016), businesses must also set up a metrology system that takes into account measurement staff, methods, equipment, uncertainty, and traceability. Additionally, organizations must set up a calibration system for all measurement tools used during manufacturing.

International Automotive Task Force continues (IATF, 2016), IATF 16 949 mandates that enterprises use metrology in the design and development process to guarantee that products adhere to the necessary standards. This entails confirming that the measurement tools used during the design and development phase are appropriate for their intended function and that they are calibrated prior to usage.

## 2.2 Metrology of systems

On the authority of Petřkovská and Čepová (Petřkovská, Čepová, 2012), system metrology is a subfield of metrology that focuses on measuring systems, which are groups of connected parts that cooperate to carry out a particular task. System metrology includes both the measurement of a system's overall performance and the measurement of each of its constituent components.

System metrology's objectives include ensuring that the system is performing at its peak level and locating and fixing any problems that might be impairing that performance. This includes measuring the system's inputs, outputs, internal operations, as well as the ambient circumstances that it operates in.

The two authors continue, numerous industries, including manufacturing, construction, transportation, energy, and telecommunications, use system metrology. System metrology is used in manufacturing to keep an eye on and manage the operation of production processes including automated systems and assembly lines. The performance of structures and infrastructure, such as bridges and highways, is measured in construction using a technique called system metrology. The performance of vehicles and transportation systems, such trains and airplanes, is measured in transportation by means of system metrology.
Petřkovská and čepová (Petřkovská, Čepová, 2012) finish, system metrology employs a variety of methods, including sensor technologies, signal processing, data analytics, and modeling. These methods are employed to gather information on the system's inputs, outputs, internal processes, environmental conditions, and external factors. The system's performance level is then determined from the data, and any problems that might be influencing it are found.

## 2.3 Measurement System Analysis

According to AIAG (AIAG, 2010), a technique for estimating the degree of variance within a measurement process is called measurement system analysis (MSA). By assessing the measuring system's accuracy, precision, and stability, it is utilized to certify the system for use. For manufacturing businesses, MSA is crucial because it ensures that the data being gathered is correct and that the system being used to collect it is suitable for the process. It stops manufacturing processes from wasting time, labor, and scrap. It also stops bad components from being accepted and good ones from being rejected.
AIAG continues (AIAG, 2010), MSA is a group of experiments and analysis that examines the measurement data being gathered, the procedures and instruments used to gather and record the data, the effectiveness of the measurement system, the variance in the data, and its likely cause.

Analysis of measurement systems is a challenging task. In accordance to Six Sigma (Kenton, 2022) a step-by-step guide for carrying MSA out is provided in Six Sigma. The executives should, as usual, concentrate on comprehending the exercise's purpose and how to evaluate the outcomes. Software is capable of carrying out the intricate calculations. The 4 steps are elaborated below.

**Step 1: Determination of data collection**

In accordance to the website Simplilearn (Simplilearn, 2022), a proper plan must exist before any study needs to be carried out. This makes sure that the least amount of time, money, effort, and other resources are wasted throughout the study's execution. This is true of measurement system analysis as well. Creating a fundamental strategy for measuring system analysis is as follows:

Verify the Important Measures. Every process comprises of numerous measures. The measurement system is the totality of these measurements. Similar to how there are many inputs but only a select handful are essential and have any real influence on the outputs, so too with measurements. The same method, a Pareto analysis, must be used, and important measures must be devised. The crucial inputs or outputs that were already determined in the Define stage usually correlate to the key metrics.

Develope an operational definition: Developing precise operational definitions for these measures is the next stage. These measures must be standardized because a complete analysis will be based on them. Any uncertainty is eliminated by the operational definition.

**Step 2: Sample and operator selection**

As the second step the Simplilearn site suggests (Simplilearn, 2022), a decision on the ideal number of measurement trials that will suffice to determine if a measure is appropriate or not. This is comparable to the sample size used in experiments, in that sense.

Determine the Trial Organization: Trials might be gathered simultaneously or at various intervals throughout the day. In the analysis, the frequency at which the trials are gathered is crucial. Therefore, a thorough decision must be made.

Different Operators: The study needs to be set up to counteract the impact of a particular operator. Data must therefore be gathered from several sources.

Different Equipment: The research must also discount the impact of particular machineries. For instance, if one machine is more recent than another, it might perform better than the

other. For the measurement variation to be accurate, these influences must be eliminated.

Different Situations: The study's design must ensure that trials are carried out under as many different conditions as is practical. The entire purpose of this is to minimize the impact of any one element.

**Step 3: Analysis of results**

In regard to Simlilearn (Simplilearn, 2022), analyzing the results to see whether they meet your standards comes after the study has been completed. The intended use of the measurements will determine whether the measurement system is adequate. The measurements must be extremely exact if they are to be utilized for precision engineering.

There are, nevertheless, certain set guidelines. If no extra care needs to be taken during the process, they are effective. These are what they are:

Less than 10%: The Six Sigma approach states that the measuring system is adequate if the measurements deviate from the real process variation by less than 10%.

There is a presumption that the procedure is not as crucial as in precision engineering or the medical sciences, where accuracy is higher. 10% to 30% of the time: Depending on the level of accuracy expected by the team, measurements that are off by 10% to 30% of the actual process variation may or may not be acceptable. More than 30%: There is a major measuring system issue if the measurements are more than 30% off, and action must be made to prevent wasting time and money by making decisions based on inaccurate data. The process comes to an end if the measurement system is appropriate. If not, a further step must be taken in order to correct the measurement system.

**Step 4: Take corrective action**

Eventually Simplilearn suggests (Simplilearn, 2022), it is challenging to suggest a universal method to address measurement system faults. However, since we are aware of a few elements that account for the majority of process variation, we may attempt to address them in order to correct the measurement system.

Alter Equipment: In most cases, flawed systems lead to inaccurate measurements. This indicates that if data collection is currently being done manually, the company needs to think about automating it. It might also imply that the measurement methods need to be updated because they are outdated and defective. The measuring system can be fixed based on the management's requirements and available funds.

Train operators: The measurements are frequently made by hand. This can be as a result of how the procedure is designed. Alternately, it can be as a result of management's hesitation to make an investment in automation. In this situation, it is necessary to train the operators to reduce error.

Additional Analysis: If results indicate that neither the operators nor the equipment are to blame for the measuring systems' poor performance, additional analysis will need to be conducted in order to identify and address the issue. The exercise must then be finished by performing an iteration of the preceding step.

## 2.4 Advanced Product Quality Planning

On the authority of Automotive Industry Action Group (AIAG, 2008), in order to guarantee customer satisfaction with new products or processes, advanced product quality planning (APQP) is an organized approach. Businesses utilize it to ensure performance and quality through planning. It was first established by Ford Motor Company at the beginning of the 1980s, was later upgraded in 2008, and is largely used in the automobile industry to consolidate the common planning tasks that all automotive OEMs demand into a single process. In order to ensure that the Voice of the Customer (VOC) is fully understood and turned into requirements, technical specifications, and unique characteristics, APQP is designed to ease communication and collaboration between engineering operations.

AIAG continues (AIAG, 2008), the main objective of APQP is to reduce the risks related to modifications to new products or processes, and it helps the ongoing quest for continuous improvement. Statistical Process Control, Measurement Systems Analysis, Failure Mode and Effects Analysis, Production Part Approval

Process, and Advanced Product Quality Planning are the other five basic tools used by APQP.

The important steps of the APQP process, which is structured, range from idea approval to production. The goal is to build a plan for product quality that will guide the development and production of goods that satisfy consumer needs. AIAG (AIAG, 2008), describes the following 5 phases of PPAP:

**Phase 1 – Product planning and Quality Program Definition:**

Even before discussions of product design or redesign, preliminary planning takes center stage when client demands necessitate the introduction of a new product or a redesign of an already existing one. Planning throughout this APQP phase aims to comprehend client demands and product expectations.

To define what the consumer wants, it is required to acquire the data, which can then be used to determine the qualities of the product. Following that, the quality program required to produce the product as described can be established. This work's results include objectives for product design, dependability, and quality.

**Phase 2 - Product Design and Development**

The goal of this stage is to finish product design. An evaluation of the product's viability is also relevant here. The following are the results of this phase's work:

- Completed design verification and review
- Specified equipment requirements and material specifications
- A design failure mode and effect analysis was completed.
- Developed control plans for producing product prototypes

**Phase 3 – Process Design and Development**

Planning the production procedure that will create the new or improved product is the main objective of this phase. The objective is to build the production process while keeping in mind the product's standards, quality, and cost of production. The procedure must be capable of producing in sufficient quantities while retaining efficiency to satisfy anticipated consumer demand. Instances of this phase's results include:

- Configured process flow in its final state

- A finished failure mode and effect analysis of the process to locate and address hazards
- Standards for the quality of operational processes
- Requirements for product finishing and packaging

**Phase 4 – Product and Process Validation**

This is the testing stage where the manufacturing procedure and the finished product are validated. This phase's activities include:

- Confirming the production process's reliability and competence, as well as the standards for acceptable product quality.
- Performing test runs for production
- Product production is being tested to confirm the viability of the manufacturing strategy being used.
- Making necessary adjustments and moving on to the next step

**Phase 5 – Launch, Assesment and Improvement of the product**

The final phase sees the start of full-scale manufacturing with a focus on reviewing and enhancing procedures. Reducing process variances, spotting problems, and launching corrective measures to support continuous improvement are key components of this phase. Other key components include gathering and analyzing customer feedback and data related to process efficiency and quality planning effectiveness. Most common results include:

- A more efficient production process that reduces process variation
- Enhanced product delivery and customer service quality
- Increased client satisfaction

# 3 Quality management in the automotive

"*The short successes that can be gained in a brief time and without difficulty, are not worth much*", Henry Ford. Henry Ford was one of the biggest influencers when talking about the automotive industry and quality management itself. Great leaders of the automotive industry are aware that uncovering and fixing a defect in production early is essential for a sustainable production. Otherwise, a defect can lead to many problems like an international scandal in case of Volkswagen and their Diesel Gate in 2015.

With this philosophy in mind, many Quality measurement methods and tools are utilized within the automotive industry, mostly originating in Japan – the worlds leader of quality development and quality assurance. The thesis will further elaborate more on the following:

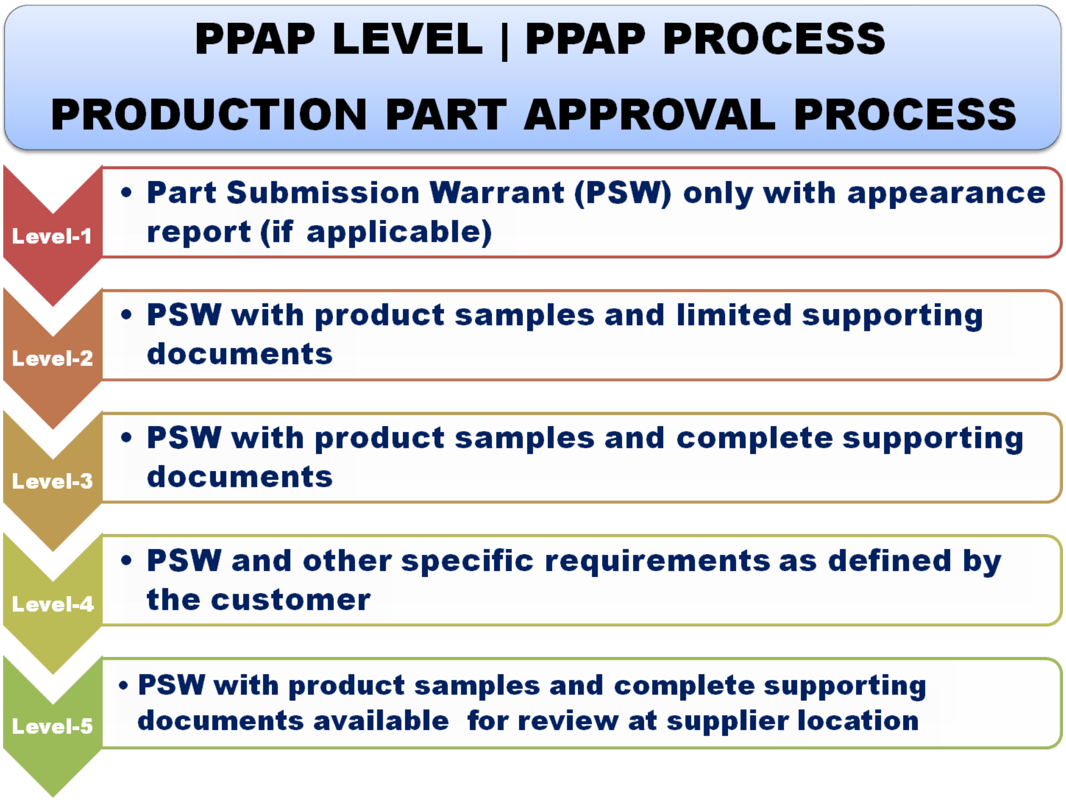
1. PPAP – Product Part Approval Process
2. Failure Mode & Effects Analysis
3. SPC– Statistical Process Control
4. Lean Six Sigma

## 3.1 Product Part Approval Process

On the authority of Gerardus Blokdyk (Blokdyk, 2018) as the name suggests, PPAP method deals with the approval process of parts. The biggest contribution of PPAP in the automotive industry is in the minimalization of non-conforming products appearance and reduction of delays through a consistent approval process. With this method suppliers and customers consent to requirements that must be met in order the part to be approved.

PPAP as a part of APQP ensures a deep understanding, standardization and know-how to meet requirements of the customer. Moreover, PPAP brings the ability to trace non-conforming parts in case the parts do not meet customer requirements. Eventually PPAP controls the production and all change processes implemented in time.

Blokdyk ends (Blokdyk, 2018), PPAP brings many benefits in Quality Assurance. With this method the approval process is consistent, parts are registered and trackable. The PPAP method is required by, among other OEM requirements, Stelantis Groupe, Ford Motor Company and Genral Motors. The five categories or levels that make up the PPAP submission requirements are shown on the following Figure 4.




Source: (Quality 1, 2022)

***Figure 5 Levels of PPAP***

According to AIAG (AIAG, 2008) a complicated check list, like the one shown in Appendix 3, is used to perform PPAP. When using PPAP, the following 18 fundamental PPAP elements are considered:

1. Design Documentation
2. Engineering Change Documentation
3. Customer Engineering Approval
4. Design of FMEA

5. Process Flow Diagram
6. Process FMEA
7. Control Plan
8. MSA Studies
9. Dimensional Results
10. Records of Material / Performance Tests
11. Initial Process Studies
12. Qualified Laboratory Documentation
13. Appearance Approval Report (AAR)
14. Sample Production Parts
15. Master Sample
16. Checking Aids
17. Records of Compliance with Customer Specific Requirements
18. Part Submission Warrant (PSW)

## 3.2 Failure Mode & Effects Analysis

In consonance with Kiemel and associates (Kiemel, Schmidt, & Berdine, 1997) Failure Mode and Effect Analysis is a quality planning tool used to identify potential product and process failures or defects. When using FMEA potential failure modes can be identified, analyzed, documented and prevented.

In quality prevention is the key to waste reduction and lean manufacturing (Machan a kol., 2008). Many organizations use FMEA as a risk analysis in manufacturing, administration, software design even design stage and financial processes of their operations. The final product of FMEA is a FMAE form reflecting all process steps their failure mode and their failure mode effect-consequence. According to SIEMENS (SIEMENS, 2016) FMEA could be executed in four steps:

**Step 1 - Identify potential failures and their effects**

Analyzing functional requirements and their impacts in order to identify all failure modes is the first stage in the FMEA process.

Warping, electrical short circuits, oxidation, and fracture are a few examples.

A component's failure mode can cause failure modes in other components. List each failure mode for each function in technical words, taking into account the failure effect of each failure mode (s).

The following are a few examples of failure effects: overheating, noise, unexpected shutdown, and human damage.

**Step 2 - Determine the Severity of each failure**

The seriousness of failure repercussions or failure impacts is referred to as severity. Typically, failure effect severity (S) is rated from one to ten, with one denoting the least severity and ten denoting the worst. The typical FMEA severity ratings and their definitions are shown in the following table:

***Table 1 FMEA - Failure Severity determination***

| **Rating** | **Meaning** |
|---|---|
| 1 | No effect, no danger |
| 2 | Very minor – usually noticed only by very observant users |
| 3 | Minor – only minor part of the system affected; |
| 4-6 | Moderate – most users are inconvenienced and/or annoyed |
| 7-8 | High – loss of primary function; users are dissatisfied |
| 9-10 | Very high – hazardous. Product becomes inoperative, |

Source: (SIEMENS, 2016)

**Step 3 - Determine the chances of occurrence**

Analyze the reason(s) for each failure mode and the frequency of failure. Examine related items or processes and their documented failure mechanisms. The technical identification and documentation of all probable failure reasons is required. Failure reasons frequently point to flaws in the design.

A few causes are a bad algorithm, too little or too much voltage, a hot or cold or humid operating environment, etc. As illustrated in the accompanying table, failure modes are given an occurrence ranking (O), again ranging from one to ten.

***Table 2 FMEA – Chance of failure occurrence determination***

| Rating | Meaning |
|---|---|
| 1 | No documented failures on similar products/processes |
| 2-3 | Low – relatively few failures |
| 4-6 | Moderate – some occasional failures |
| 7-8 | High – repeated failures |
| 9-10 | Very high – failure is almost certain |

Source: (SIEMENS, 2016)

### Step 4 - Failure detection

Following the selection of corrective measures, their effectiveness and efficiency should be evaluated. The design should also be validated, and inspection methods should be defined.

1. Engineers examine the system controls in place to identify problems before they have an impact on users or customers or to prevent failure modes from occurring.

2. Identify methods used to find problems in similar products or systems.

Engineers can assess the possibility of recognizing or detecting faults using these steps. The detection value (D) is then given to each combination from stages one and two, indicating the likelihood that problems will be discovered and ranking the effectiveness of the identified measures to identify failures or remove flaws. The likelihood that the failure won't be discovered increases with increasing D values.

***Table 3 FMEA - Failure detection determination***

| Rating | Meaning |
|---|---|
| 1 | Fault is certain to be caught by testing |
| 2 | Fault almost certain to be caught by testing |
| 3 | High probability that tests will catch fault |
| 4-6 | Moderate probability that tests will catch fault |
| 7-8 | Low probability that tests will catch fault |
| 9-10 | Fault will be passed undetected to user/customer |

Source: (SIEMENS, 2016)

As a result risk assessors determine Risk Priority Numbers (RPNs). These have an impact on the choice of countermeasures for failure modes. From the values of S, O, and D, the RPN is computed as follows: RPN = S * O * D

According to SIEMENS the main aim is to execute corrective actions in order to meet the production excellence that will eventually lead to:

- Failure modes elimination
- Severity of failure modes minimalization
- Reduction in failure modes occurrence
- Detection of failure modes improvement

## 3.3 Statistical Process Control

Regarding James T. McClave (McClave & Benson, 2018) the main aim of SPC is monitoring of an ongoing process and maintaining its steady variation utilizing the process of sampling and graphical representation of the process variation. SPC is mostly used at the assembly line by the OEM and its suppliers.

McClave and Benson continue (McClave & Benson, 2018), choosing between variable and attribute data collection is the first step. Whenever possible, it is highly recommended to employ variable data because it offers information of a higher caliber. Once the data type is chosen a suitable control chart is applied.

Basic control charts for variables include:

- X-bar and R-bar charts – charts for grouped data (subgroup size ≤ 10)
- X-bar and S-bar charts – charts for grouped data (subgroup size ≥ 10)
- Xi and MR charts – charts for individuals

Basic atribute control charts include:

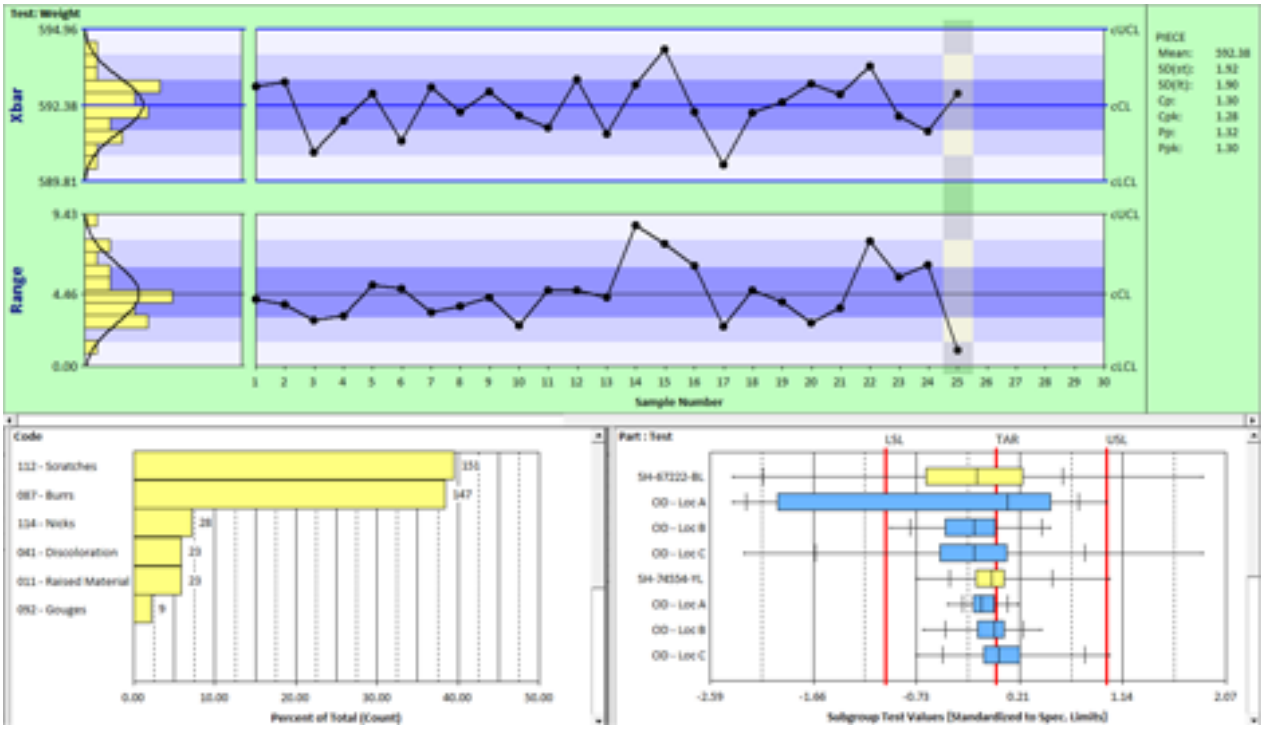
- **np chart** - chart for number of nonconforming in a subgroup
- **p chart -** chart for fraction nonconforming
- **c chart -** chart for count of nonconformities
- **μ chart -** chart for count of nonconformities per unit

On the autority of McClave and Benson continue (McClave & Benson, 2018), in the preparatory phase the time period of data collection, Upper and Lower control limits, that represent the Six Sigma variation of the process (LCL -3σ UCL +3σ), and the center line are determined. The goal is to determine whether the process is under statistical control when the data is plotted to the control chart.

Phase 2's goal is to keep the process running at the optimal level or possibly improve it more, quote on quote maintaining the process under statistical control.

Mark any data points that fall outside the control ranges on the chart, then look into the reason why. Additionally, keep records of what was looked into, the reason why it got out of control, and the actions required to get it under control. A corrective action matrix can be used to establish roles and deadlines for tracking the activities completed (McClave & Benson, 2018).

According to Kiemel (Kiemel, Schmidt, & Berdine, 1997), the result of SPC analysis and process control are control charts representing the variability of process outputs in time. As a result, causes of process variation such as raw material, equipment missuses, human factor, method utilized or environment can be uncovered and further eliminated.




Source: (InfinityQS, 2022)

***Figure 6 SPC analysis***

As belived by McClave and Benson (McClave & Benson, 2018) in this process usually a cause-and-effect diagram is structured and with contribution of factual brainstorming root causes are uncovered and further analyzed and eventually eliminated.

## 3.4 Lean Six Sigma

On the authority of Kenton's book *Lean Six Sigma Pocket Toolbook* (Kenton, 2022) Lean Six Sigma methodology combines the Six Sigma approach and Lean strategy that first appeared in the 1940s in Toyota Japan. The main aim of Lean approach is to eliminate all activities with zero added value from the production process. In other words, the elimination of the eight different kinds of waste that add no value to the process have to be left out:

1. Defects
2. Overproduction

3. Waiting
4. Non-utilized talent
5. Transportation
6. Inventory
7. Motion
8. Extra-processing

Six sigma as a methodology was introduced in 1980s by a telecommunication company Motorola in the United States of America. Six Sigma is hugely inspired by the Japanese Kaizen model which is going to be described further in this thesis. Six Sigma method focuses on defects in production and the aim of this method is defect prevention, defect elimination and production improvement.

Kenton continues (Kenton, 2022), during utilization of Six Sigma techniques, it is essential to focus on so called DMAIC phases. DMAIC stands for define, measure, analyze, improve and control of all the processes leading to a stable and optimized production.

Lean Six Sigma combines the two techniques – Lean and Six Sigma. The Lean Six Sigma and it’s tool will certainly uncover processes inclining to waste, defects or any variation. The aim of quality representatives is to analyze the results of Lean Six Sigma approach and manage changes in processes leading to above mentioned non-desired states elimination.

## 4 Introduction and analysis of iVMP 2030

The analysis was conducted in cooperation with th GQF 3/1 department of ŠKODA AUTO a.s. by utilization of dialogue, internal documentation study and observation.

The term iVMP stands for a new form of vehicle measuring. In full Intelligent Vehicle Measurement Process, where the abbreviation I represents not only the word "*Intelligent*", yet it reflects the company's focus on *"Inventive", "Intuitive", "Individual", "Iconic", "Inspiring"* view of quality and it's assurance.


Source: (Internal documentation ŠKODA AUTO a.s., 2019)

***Figure 7 iVMP 2030***

The new strategy - iVMP 2030 is built on three ground pillars:

1. Technology
2. Big data
3. Human Capital

The motto of iVMP 2030 is „*Produktionsnähere optische Messtechnik, Robotisierung und Digitalisierung der Messtechnik*. " in translation to English "*Production-related optical metrology, robotization and digitization of metrology.* "

As a part of INDUSTRY 4.0 the iVMP 2030 is setting groundbreaking and innovative standards in the process of quality assurance, not only in the production facilities of ŠKODA AUTO a.s., yet it has influence on the whole automotive industry.

In this regards the whole production of new ŠKODA vehicles is shifting towards automatization, digitalization and big data analysis. iVMP 2030 has a huge influence on all production facilities of ŠKODA AUTO a.s. not only in the Czech Republic.

The newly set standards of iVMP 2030 are being integrated into projects such as INDIA 2.0 and 2.5, projects in Vietnam and Pakistan, also for the measurement points for Slovak Republic – Bratislava and nevertheless for all projects within the home country (Mladá Boleslav and Kvasiny) of the Czech Republic.

## 4.1 Technology

iVMP 2030 strategy mainly elaborates more on many ways to measure parts within the production. The three most spoken about plans are OFF line, IN line and AT line measurements.

OFF line measurement centers are special departments of ŠKODA AUTO a.s. such as the GQF 3/1 department focusing on measurements. Now, two types of measurements are utilized – touch-based measurements and optical measurements. These measurements are assured with the KMG measurement machine, Smart Cell device in cooperation with a cooperative robot. After the measurement is proceeded the measured part is not returned to the production sequence.

In-line measurements are designed to be a part of the production line as displayed below. Measurements done in this sense are touch-based and optical. Similarly, as in case of OFF-line measurements, the KMG machine is utilized along with an robotic arm. The benefit of In-line measurements is that the measured parts stay in the production sequence. On the contrary the drawback is that only one type of a part produced could be measured at time.

Lastly in case of AT-line measurements, the above-mentioned approaches are combined. The measurements are proceeded close to the production line and all measurements are optical with in a special device called Messzelle (measuring cell). After the measurement the proceeded parts are not returned to the production sequence. The At-line strategy of measurements can proceed with more types of parts at the same time.

At ŠKODA AUTO a.s. the AT line strategy is already being implemented and used in the Mladá Boleslav and Kvasiny plant. The following steps and discussions lead to a graduate integration of IN line strategy to the Czech production plants. The deadline for this implementation is until the year 2025.

Further integration of IN line strategy to the production process at the welding shop M14 as a pilot project is aimed to be achieved until the year 2030. The desired state is visualized in the following pictures.

From the status quo considering measurements AT line bring negative downtimes when moving parts from the line to the measuring point. In case of the desired state, measurements will be done directly in the line. Downtimes will be eliminated and defects uncovered early.

The new iVMP 2030 strategy of ŠKODA AUTO a.s. opens many possibilities in regard to measurement devices utilized in the production process. One such a solution PMD – Promess Measurement Device allows automatic setting of parts, setting of a bigger variety of parts, more frequent measurements which leads to early defect identification even area cost savings.

Source: (Internal documentation ŠKODA AUTO a.s., 2022)

***Figure 8 PMD Device***

## 4.2 SWOT analysis of IN line strategy

When considering the iVMP 2030 strategy the management team of ŠKODA AUTO a.s. must be aware its strengths, weaknesses emerging from inside of the organization, yet opportunities and threats emerging from inside the automotive industry emerging mostly from the competition.

The SWOT analysis was conducted after a discussion within the Quality department with the use of existing internal documentation of ŠKODA AUTO a.s. and the authors own point of view to the issue. As a result the following strengths, weaknesses, opportunities and threats of the IN line measurements were plotted to the Table 4 displayed below.

***Table 4 SWOT analysis of IN-line strategy***

| | |
|---|---|
| **S** | Management of the car production process<br>Quick response<br>WLTP homologation measurement<br>Better use of IN+AT line technology<br>Automation and Robotization |
| **W** | Lack of professional staff<br>Service costs<br>Support for 3-shift operation<br>Measurement points concept<br>Comparative measurement in MS |
| **O** | MS capacity savings - analysis<br>Reduction of logistics costs<br>Reduction of MS staff - after implementation<br>The technology is available |

| | |
|---|---|
| **T** | Slow strategy commissioning<br>Unavailable places<br>The influence of the environment in production<br>Missing surfaces in production<br>Standards are missing |

Source: (Toráč, 2022)

In accordance with the SWOT analysis of the issue, one of the biggest strengths of iVMP 2030 implementation is quick response to defect occurrence along with utilization in WLTP and homologation measurements. On the contrary, the biggest weaknesses are lack of professional and highly skilled personnel and higher costs of measurement devices.

However, iVMP 2030 provides the industry with huge opportunities like reduction of logistic costs within the supply chain and availability of needed technology. Along with opportunities threats are also an important part of the SWOT analysis. The biggest one occurring from the analysis are no standardization for these kind of measurements, slow strategy commissioning along with the influence of environment.

## 4.3 Big data

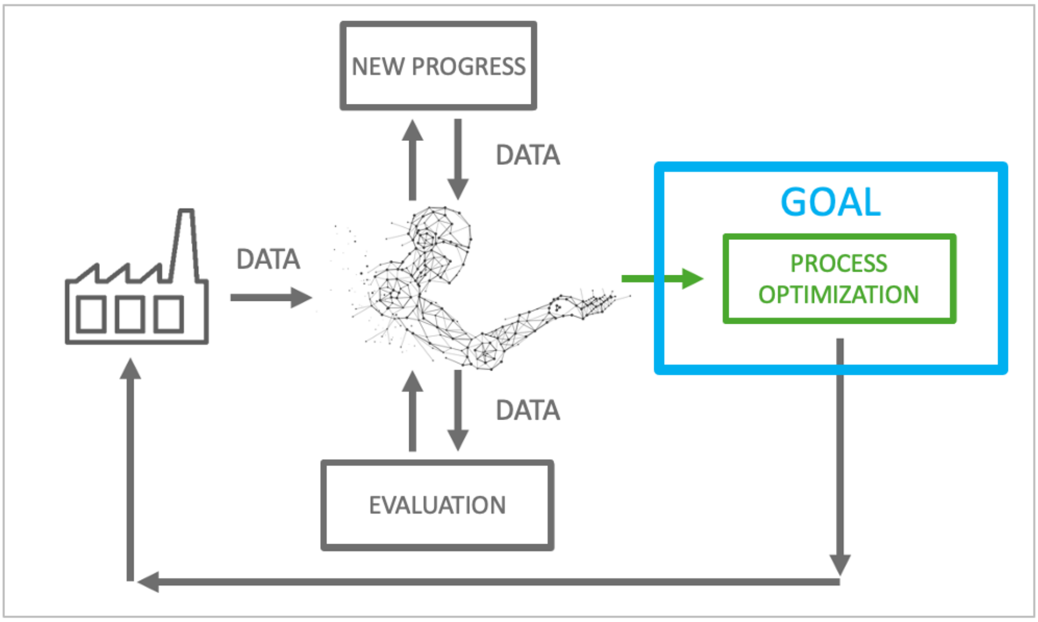
The biggest issue of iVMP 2030 strategy is big data management. Big data combine structured, semi structured and unstructured data in a way usable for machine learning, predictive modeling of production even advanced analysis further utilized in further use.

Management of big data is combined with further deep analysis. These two processes are characterized by large *volume* of data, the wide *variety* and frequency of data stored and the *velocity* at which data is being generated. The three attributes are generally known as three "*Vs*" of big data management and analysis.

Big data where first described by the 3V by Dough Laney in 2001, later by the Meta Group Inc in 2005. Nowadays more and more "*Vs*" such *value, veracity, variability* are occurring to describe big data in greater depth than before.

There are many benefits arising from big data collection and analysis for the ŠKODA AUTO a.s. company not only regarding the innovative iVMP 2030 strategy. First of all, big data allow the producer a deeper understanding of customer needs and requirements, operations are improved and even the insight to the automotive market is deepened.

Finally, an agile supply chain management is achievable, innovations are driven by accurate data and finally customer targeting is smarter and hugely improved.




Source: (Internal documentation ŠKODA AUTO a.s., 2022)

***Figure 9 Big data scheme***

## 4.4 Human capital

According to ŠKODA AUTO a.s. to achieve a successful transition and implementation of full iVMP 2030 utilization three main pillars are arising from this strategy considering the changes in human capital:

1. Optical measurement know-how
2. Digitalization of operations
3. Effectivity

Optical measurement know-how is crucial when transitioning to iVMP 2030. The leaders and managers of ŠKODA AUTO a.s. have to consider a super training of people working with the measurement devices on daily basic. The first priority should be to hand over the know-how of optical measurements along with a clear hand over of the mission and goals the company is going to fulfill by implementation of iVMP 2030.

All know-how of the personnel about parts measured will have to be transition to the optical measurement process, where more than 870 parts, 14 000 000 measurement points, 370 purchased parts from 32 suppliers are considerate.

Following by the second pillar – digitalization of operations. In production many workplaces are going to be robotized and digitalized. This evolution leads to a big loss of jobs in the industry, yet at the same time a huge occurrence of new job possibilities, where digital skills are demanded.

New job opportunities are created, few of them are listed below:

1. Robotic measurement specialist
2. Optical measurement specialist
3. AT-line and OFF-line planning expert
4. AI and Big Data AT-line, OFF-line measurement specialist
5. AI and Big Data IN-line, OFF-line measurement specialist
6. Project manager of IN-line digitization, OFF-line measurement

Finally, employees will have to be more effective. Although some specializations cannot be taken over by robots and computers immediately, employees will have to be as effective as possible, because the artificial intelligence, that is able to replace a human, is being developed at a very fast pace.

Alongside with the occurrence of new skills demanded, many future challenges are arising too. Managers will have to overcome issues such as the pressure to signal out the key activities of iVMP 2030 in human capital part, the optical measurement itself, planning and support of all facilities outside the Czech Republic and even the requirements on the personnel of the department of GQF 3 are not an easy challenge to be overcome.

For the leaders, managers and employees themselves to achieve success in the above-mentioned challenges, strong managerial an leadership skills will have to be applied among with huge motivation of employees and a detailed understanding of the companies mission and goal of iVMP 2030 implementation.

## 4.5 Goals and commitments of iVMP 2030

The first goal of iVMP 2030 in ŠKODA AUTO a.s. is a transformation of the company to an Industry 4.0 ready company. Industry 4.0 is the fourth and the most important industrial revolution yet. It merges state of the art production techniques and smart systems integrated with artificial intelligence and humans into one beautiful working body.

As a result the measurement process and quality of production is going to be hugely improved and eventually will lead to greater efficiency, safety and productivity while reducing the effect on the environment. Moreover, the goal of iVMP 2030 is to bring enhanced decision making based on facts and data.

The following big goal of iVMP 2030 implementation is the overall digitalization of GQF 3 department at ŠKODA AUTO a.s. . This will lead to a greater accessibility and recording of data, quicker response of the team to an occurring problem and eventually to a greater effectivity.

Effectivity not only within ŠKODA AUTO a.s. yet within the whole supply chain. With an effective supply chain allows a better cooperation between organization, increase in overall quality produced by reducing scrap, reworks and downtimes. Effective supply chain also allows the producers to keep up with the demand and stay sustainable in the long run.

According to ŠKODA AUTO a.s. by the year 2025 the goal is to have at least 85 % of measurements done with the use of optical measurement devices that bring many benefits as compared with the actual touch-based measurements.

First of all, ŠKODA AUTO a.s. is proposed to be a strong partner for the Volkswagen Groupe in regard to above mentioned goals of iVMP 2030 strategy implementation. With this respect ŠKODA AUTO a.s. is bound to be proactive in case of iVMP 2030 strategy and should actively communicate not only with the VW group, yet with all involved departments of ŠKODA AUTO a.s. itself.

Besides, the newly adopted strategy should be in accordance with the adaptation of upcoming projects and upcoming concepts of the concern. Considering the iVMP 2030 strategy implementation most measurement processes should be executed with the use of optical means and should be highly automated.

Last but not least, as new personal challenges occur ŠKODA AUTO a.s. is bound to develop new job opportunities along with comprehensive training of current and newly hired employees.

# 5 Analysis of the current state in ŠKODA AUTO a.s.

For a better understanding of the importance of iVMP 2030 measurement strategy an analysis of the current state regarding measurement methods was composed at the quality department of ŠKODA AUTO a.s. responsible for measurements.

The analysis was carried out combining discourse and observation. Discussion entailed doing focus groups and interviews to collect data considering the iVMP 2030 strategy and the current state of the department, so that the author can fully comprehend the current state at the department. This method was successful in obtaining a complex and complete comprehension and the results are following.
This thesis was done with cooperation with the GQF 3/1. As part of the division of quality the GQF 3/1 department is directly supervised by the CEO Dipl-Betriebsw. Klaus Zellmer, Dr. Ing. Florian Weymar the head of quality, Ing. Tomáš Boháček the head of quality control of vehicle production in Mladá Boleslav and the head of quality control of measurement equipment Bc. Tomáš Biksadský.

The department focuses on investments, new project ramp up and overall measurement strategies of ŠKODA AUTO a.s.. Further activities are following:

1. Structural and product investments for new projects within ŠKODA AUTO a.s.
2. Planning and realization of measurement capacities and builds
3. Planning and realization of measurement equipment
4. Planning and realization of test devices (Cubes, Master jigs, Joining master jigs)
5. Measurement preparation and measurement points preparation for inhouse and supplied parts
6. Monitoring, analysis and realization of technical changes in pre-series and series stage
7. iVMP strategy within ŠKODA AUTO a.s.
8. Measurement devices

The head of the GQF 3/1 department is Miroslava Výmolová as the coordinator and supervisor of all activities within the department. The organization structure of GQF 3/1 is closely displayed in the appendix 1 and processes of the department are described in the process flow diagram in appendix 2.

The analysis resulted in a deep understanding of the structure of the department. As a result, the author would suggest a greater focus of employees on their specialization and a more agile management style, due to the fact that some eployees are involved in projects outside their focus. This can lead to a less effective workflow.

In accordance to the process analysis, the GQF 3/1 Quality department is also an important part of quality meetings of the Volkswagen Groupe. In the investment process. The department is responsible for budgeting and planning of the measurement strategies for the upcoming periods.

After the Volkswagen Groupe management gives approval of a proposed project, the GQF 3/1 department is responsible and obliged to deliver or technical documentation needed for the supplier in regards to all measurement devices needed for the upcoming project.

Finally, GQF 3/1 hands over the produced device at the latest 8 months before the start of production of the upcoming project. The last two steps are administrative. GQF 3/1 is obliged to proceed with the invoices and is bound to activate the newly obtained devices. This process of investments applies also when building a new measuring center or implementing a new measurement strategy, such as the iVMP 2030 measuring strategy.

## 5.1 Metrology in ŠKODA AUTO a.s.

According to the analysis of this Quality department the author can tell that the department uses state of the are technology in accordance to the news trends such as master jig being the biggest measuring device utilized in case of part alignment. The master jig allows of a complete alignment of the body of the vehicle. Afterwards the body is measured with the utilization of touch-based devices. The biggest benefit of master jigs is that a vehicle in its finished form is able to be measured. Moreover, bigger parts such as the vehicle's frame could be measured.

Furthermore, measuring cubes are frequently used when measuring bigger parts of the vehicle such as the front part of the vehicle or the dashboard. The measuring process is nearly the same as in case of the master jig, yet smaller parts are being measured. At the GQF 3/1 ŠKODA AUTO a.s. focuses on three types of measuring cubes:

1. Combined Cubes
2. Front Cubes
3. Dashboard Cubes

Nevertheless, the last way to align a part for measurements fixtures. At GQF 3/1 ŠKODA AUTO a.s. utilizes special FIVE UNIQ fixtures. These are the most modular fixtures possessed. FIVE UNIQUE as shown below are completely personable to requirements of the measured parts. The position and height could be altered. As a result all serial models are measured with the alignment of this fixtures.

SKODA AUTO a.s. utilizes cubes, master jigs, joining master jigs, measurement recordings, measurement points for the assessment and sampling of the purchased parts and outer skin parts for each new model.

After a deep analysis via a focus group, at the moment for projects SK316/5 and SK316/6, ŠKODA does not have any cubes, master jigs, joining master jigs, measuring fixtures, measurement points and programs.

Moreover, ŠKODA AUTO a.s. possesses with insufficient measuring capacities for e-mobility and lacks measuring devices for ongoing projects. As a result, the risk of not OK series quality is increasing.

Another issue is insufficient space for new measuring devices and measuring technologies and unproductive measurement speed along with non-innovative measurements, contrary to the strategic objective for the shift to optical measurements by the year 2025.

Following, outdated format of measurement evaluation and reports is utilized and the logistical concept for delivery of parts is too complicated. The measuring machines Bravo NT10 and Bravo NT11 from 1999 is outdated, ineffective and it is not possible to make optical measurements with this kind of device.

Lastly, the current status does not meet the requirements for measurement technology at ŠKODA AUTO a.s. for the year 2025. Insufficient measurement speed does not meet the requirements for series measurements and the movement of the machine is not possible without demanding construction work. Moreover, repairs are no longer possible due to the lack of spare parts.

In the authors opinion, due to the above-mentioned shortcomings, it is crucial to move towards digitalization and promptly shift towards new metrology means for the upcoming projects and a fast shift towards electromobility. In this instance the author feels a necessary shift towards the iVMP 2030 measurement strategy, otherwise it could lead to a low customer and industry satisfaction and overall reduction in competitiveness of ŠKODA AUTO a.s.

# 6 Proposal of iVMP 2030 strategy

The desired state shows that at the latest by VFF milestone, GQD-1, GQF-3 will have cubes, outside master jigs, joining master jigs, measurement recordings, measuring points and measurement programs ready for the new project along with all relevant purchased parts and outer skin parts coordinated and sampled in time.

At the same time, the cubes and master blocks are used for analyzes of the series parts up to the end of production. The measurement recordings will ensure measurement capacity, dimensional accuracy, and repeatability, ensuring the most necessary measuring capacities for ongoing projects and its derivatives, ensuring capacities for areas and premises for measuring technologies for ongoing projects and its derivatives.

## 6.1 Transformation from touch-based to optical measurements

Optical measuring cell will provide better accessibility and greater variability of measured parts. With this solution this innovative measuring method will be in accordance with the strategic objectives - measuring concept 2030 much faster.

The optical measurement solution is compatible with inline measurement methods and provides digitization of measurement technology and digitization of the measurement results in accordance to Industry 4.0.

Optical measurement methods provide more effective evaluation, more variable usability of measurement results and the new technology of the optical measuring cell can be set up directly on the production hall floor without necessary and demanding constructions.

Nevertheless, the innovative solution concept includes a reduction in the measurement frequency of existing models, achievement of goals regarding optical measurement in 2025 by using a new concept optimization of the logistic flow for parts delivery to the individual measurement centers.

When analyzing the current state regarding measurement methods utilized in comparison of the desired state and occurring opportunities, the iVMP 2030 strategy seems to be a great fit and is proposed to be implemented into ŠKODA AUTO a.s. with the focus on optical measurements replacing the outdated touch-based measurement method.

In the authors opinion it is a great idea to put an optical measuring cell into practice in order to accomplish the strategic goals of the measuring concept 2030. The use of this measurement technique would improve accessibility and increase the diversity of measured parts, as mentioned above, and it is consistent with the industry's aims for digitalization and automation.

The optical measuring cell's compatibility with inline measurement techniques and capability to digitize measurement technology and results, including the presentation of virtual master jigs, are two of its key features. As a result, measurement data may be evaluated more effectively and may be easier to use for further continuous improvement. In addition, there is no need for complicated constructions, because the new technology can be set up right on the manufacturing floor creating a great flexible environment in case of device relocation.

It is important to keep in mind, though, that the adoption of this new technology can necessitate a decrease in the measurement frequency of current models at the first stage of implementation. As a result, the authors suggestion in order to meet the objectives for optical measurement by 2030, is to streamline the logistics flow for components supply to the various measurement sites.

## 6.2 Utilization of iVMP 2030 in assembly and EOL inspection

In assembly, there is an increasing need for inspection procedures that are more effective and precise. This is because items are becoming more complicated and higher quality standards are required to satisfy client needs. In response utilization of successful iVMP 2030 strategy in pre-production stage could be implemented into the assembly and end-of-line quality inspection process.

Smart inspection automates the inspection process and boosts accuracy by utilizing cutting-edge optical technologies including machine learning, computer vision, and sensor data. It involves the use of cameras and sensors to record information about the assembly process, which is subsequently examined by machine learning algorithms to find any flaws or deviations from the intended results.

In the opinion of the author, the smart inspection could be carried out as a optical gate, where the finalized vehicle would be carried by a conveyor belt through a gate with optical measurement devices as shown in the Figure 9 below.

Source: (Internal documentation ŠKODA AUTO a.s., 2022)

***Figure 10 Optical gate EOL inspection***

Yet, there might be another possibility for the optical means of metrology implementation to the EOL quality control process. Similar to the measurements carried out in the pre-production phase the finalized vehicle could be inspected by optical means mounted to a robot arm as shown on the Figure 10 below.


Source: (Internal documentation ŠKODA AUTO a.s., 2022)

***Figure 11 Optical Robotic arm EOL inspection***

Smart inspection has a number of benefits, one of which is its real-time flaw detection capability, which enables quick corrective action. The time and expenses involved with conventional inspection techniques, which frequently entail manual inspections and testing, can be greatly reduced by doing implementing this approach.

Smart inspection's capacity to adjust to shifting circumstances and product variances is another significant benefit. The accuracy and productivity of the inspection process can be continuously improved over time using machine learning algorithms, which can learn from the data gathered during the inspection process. This enables precise, effective inspections when working with complicated products that have a wide range of characteristics.

The way inspection procedures are carried out in assembly might be completely changed by smart inspection. Compared to conventional inspection techniques, it has a number of advantages, including increased accuracy, the capacity to spot problems in real time, and the flexibility to adjust to shifting circumstances and product differences.

## 6.3 What happens if the strategy is not implemented?

When implementing new solution, it is highly important to think about consequences when not implementing the iVMP 2030 measurement strategy and possible alternatives. First of all, there is a risk of non-compliance with the project start, where capacities for A-SUVe derivative will not be available.

Moreover, there is a risk of failure to meet quality requirements for project approval and meet the quality requirements for the series production. As a result, there is the possibility of customer complaints increase. At the same time there is a high risk of failure considering the issue of meeting legal requirements for BEV vehicles.

Next, the declaration of Conformity is going to be slow and not accurate. Along with this issue another is occurring. Failure to meet homologation requirements and no fulfilment of absolute rise measurements of models A-SUVe represents a huge risk in regards to future development and quality assurance of ŠKODA AUTO a.s..

As a result, non-productive assessment of dimensional accuracy in the production flow - accuracy, repeatability and long measurement time, non-compliance with requirements for conformity and requirements for series measurement and measurement for the launch of new models cannot be respected.

The author thinks positively about the use of the iVMP 2030 strategy including suggestions such as an optical measuring cell that will represent a positive move for the sector. A more effective and economical way to assess and measure items is to use this strategy in combination with digitalization of measurement technology and findings allowing for better accuracy, precision and customer satisfaction.
Overall, it appears that ŠKODA AUTO a.s. would benefit from implementing the iVMP 2030 plan, which emphasizes on optical measurements replacing touch-based tools. However, it's crucial to assess the potential effects on current measurement procedures, logistical considerations, and any difficulties that might emerge during implementation, as well as the potential of usage in combination with other technologies such as artificial intelligence for further data analysis, so the shift will lead to an even more efficient workflow.

## Conclusion

In conclusion the thesis elaborated on all the objectives set in the introduction of the thesis. As part of the theoretical part, the author has successfully approached the theoretical background to Quality management including Quality characteristics, concepts, principals of quality management and the standardization of quality in regards to.

Further in the theoretical part the background of Metrology is elaborated, as well as its concepts, it's anchoring in law, ISO and IATF standardization. More over the metrology of system is approached successfully along with the practical metrology discussing Measurement System Analysis and Advanced Product Quality Planning.

The following successfully elaborates more on the quality management within automotive industry, bringing the public closer to issues such as Product Part Approval Process, Failure Mode & Effects analysis, Statistical Process Control and Lean Six Sigma. As a result, this part leads the reader with a complete understanding of the basic principal mentioned utilized in the automotive industry leading to high customer satisfaction, sustainability of the business and broad ability to compete.

In the practical part the iVMP 2030 measurement strategy itself is elaborated, so that the reader is able to understand the basic principles of the strategy. As a result, it was necessary to introduce the technology utilized when implementing this strategy. Furthermore, a SWOT analysis was constructed for the strategy and the results are summarized in the Table 4. As mentioned in the chapter with iVMP 2030 strategy new measurement means and devices occurs such as the PMD measuring tool further described.

Human capital as one of the pillars of this strategy along with big data analysis and use is also elaborated in the third chapter. Bringing the public a complete overview of the upcoming necessary fields to be considerate when implementing the iVMP 2030 strategy, it's goals and commitments.

Moreover, the practical part of the thesis further analyses the current state in ŠKODA AUTO a.s. in regard to the organizational structure, competence an measurement means as part of the metrology. As a result of the analysis ŠKODA

AUTO a.s. does not possess metrology means for future quality assurance of new projects and upcoming shift to all electric vehicles.

Therefore, the iVMP 2030 strategy was proposed considering the transformation from touch-based to optical means of measures due to a higher accuracy, greater flexibility and state of the art efficiency in the quality assurance process. In this sense the key benefits of the strategy are elaborated as well as the possible scenarios of iVMP 2030 implementation to the production line as an EOL quality assurance mean, resulting into an optical gate ore a cooperative robot with an optical measurement device at the EOL inspection.

The analysis brought the author as well as the reader to the elaboration of possible scenarios if this kind of approach, meaning the iVMP 2030 implementation, would not be taken into account. Resulting into a danger of non-compliance with project start, failure to achieve quality criteria, and an increase in customer complaints. Additionally, there is a chance of not meeting homologation criteria, sluggish and erroneous declarations of Conformity, and regulatory requirements for BEV automobiles. This could have a negative effect on ŠKODA AUTO a.s. in th future.

Therefore the author thiks it is inevitable to approach the iVMP 2030 measurement strategy in all its stages, so that the company is able to compete in the ongoing Industry 4.0 revolution and upcoming shift towards artificial intelligence.

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## List of figures and tables

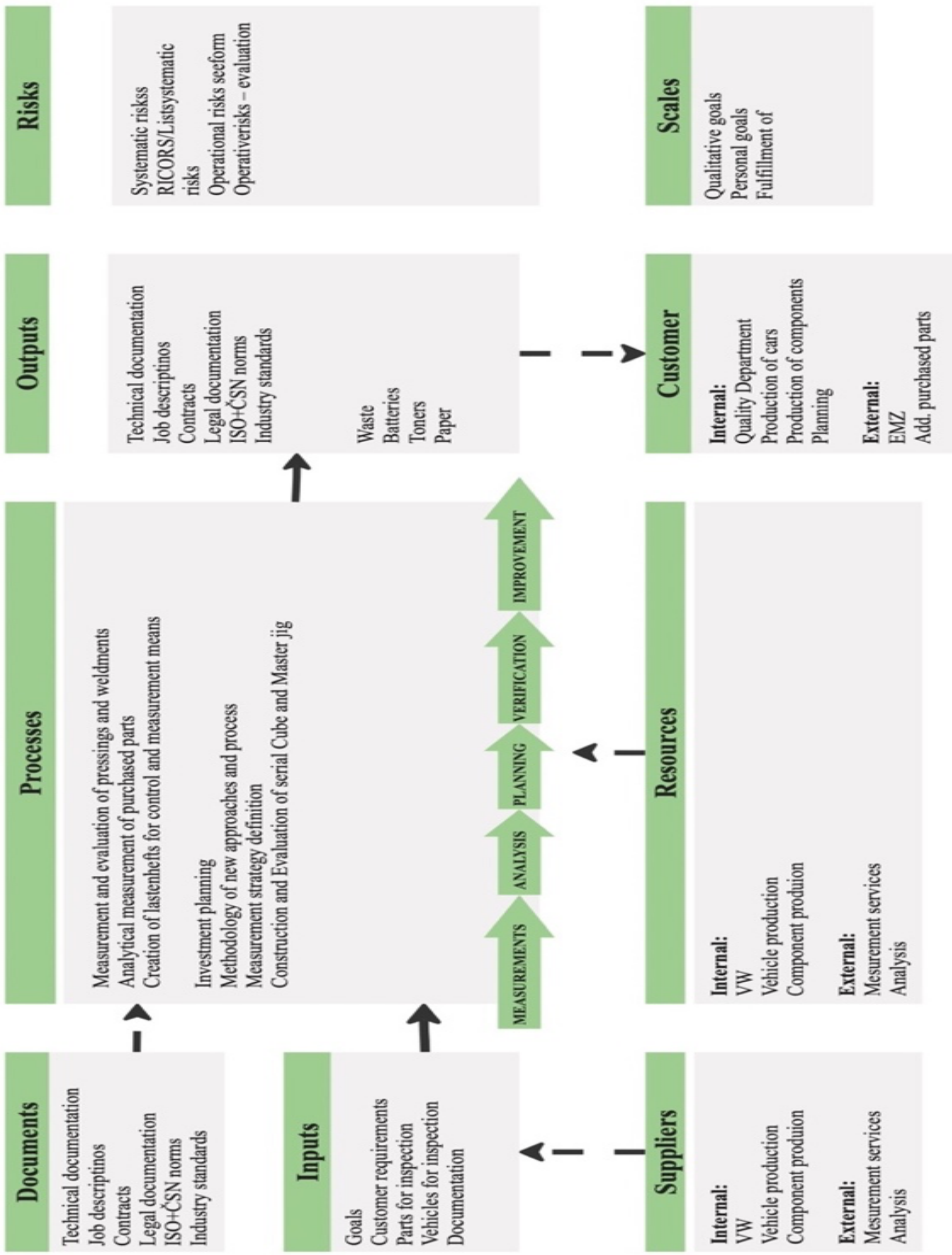
### List of figures



### List of tables

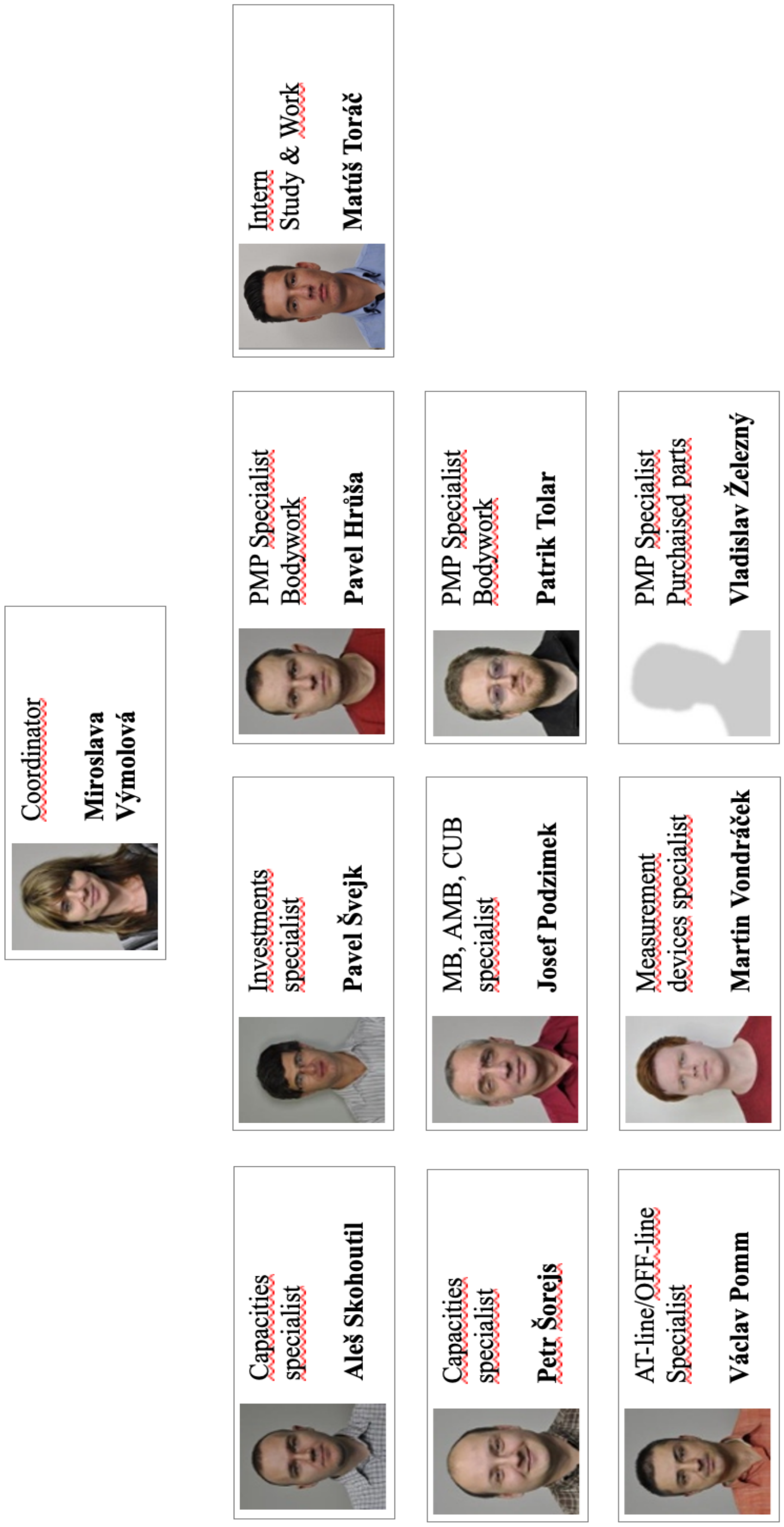
## List of appendices

## Appendix 1 GQF 3/1 process flow




Source: (Toráč, 2022)

## Appendix 2 GQF 3/1 organizational structure




Source: (Internal documentation ŠKODA AUTO a.s., 2022)

## Appendix 3 PPAP checklist

| Requirement | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
|---|---|---|---|---|---|
| 1. Design Records<br>- For proprietary components/details<br>- For all other components/details | R<br>R<br>R | S<br>R<br>S | S<br>R<br>S | *<br>*<br>* | R<br>R<br>R |
| 2. Engineering Change Documents, if any | R | S | S | * | R |
| 3. Customer Engineering Approval, if required | R | R | S | * | R |
| 4. Design FMEA | R | R | S | * | R |
| 5. Process Flow Diagrams | R | R | S | * | R |
| 6. Process FMEA | R | R | S | * | R |
| 7. Control Plan | R | R | S | * | R |
| 8. Measurement Systems Analysis Studies | R | R | S | * | R |
| 9. Dimensional Results | R | S | S | * | R |
| 10. Material, Performance, Test Results | R | S | S | * | R |
| 11. Initial Process Studies | R | R | S | * | R |
| 12. Qualified Laboratory Documentation | R | S | S | * | R |
| 13. Appearance Approval Report (AAR), if applicable | S | S | S | * | R |
| 14. Sample Product | R | S | S | * | R |
| 15. Master Sample | R | R | R | * | R |
| 16. Checking Aids | R | R | R | * | R |
| 17. Records of Compliance with Customer Specific Requirements | R | R | S | * | R |
| 18. Part Submission Warrant (PSW)<br>Bulk Material Checklist | S<br>S | S<br>S | S<br>S | S<br>S | S<br>S |

S - Submit to the customer
R - Retain at manufacturing location and make available to the customer if requested
* - Retain at manufacturing location and submit to the customer if requested

InspectionXpert

Source: (InspectionXpert, 2022)

# ANNOTATION

| | | | |
|---|---|---|---|
| AUTHOR | Matúš Toráč | | |
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| | |
|---|---|
| SUMMARY | The thesis emphasizes the value of metrology and quality management in the automobile sector, particularly the iVMP 2030 measurement approach in ŠKODA AUTO a.s. The background of quality management, metrology, and its standards are covered in the theoretical section. The thesis' application section outlines the iVMP 2030 measurement strategy and how it could be put into practice, outlining its use of technology, value of human capital and big data analysis.<br><br>Analysis of ŠKODA AUTO a.s. metrology reveals that the business lacks the tools needed to ensure quality of new projects in the future and the transition to BEV. The potential outcomes of not putting this approach into practice are covered, emphasizing the dangers of non-compliance, inability to satisfy quality standards, and detrimental effects on the company's future. |
| KEY WORDS | Quality, Quality Management, Metrology, Measurement Strategy, iVMP 2030, Optical Measurements, Industry 4.0 |