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"Quality Audit" Process:

Assessment of its Maturity Level

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Wien, im März 2019

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Jeff Mangers

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Abstract

"Quality Audit" Process describes the process-audits procedure, in other words, the necessary steps to conclude conform and uniform process-audits. Process-audits verify if processes are working within established limits by checking their conformity against given requirements and specifications and are a type of internal audits. They help an organization to accomplish its objectives by bringing a systematic approach to evaluate and improve the effectiveness of different processes. Consequential, the quality within an organization will improve by identifying and rectifying weak spots.

Maturity models are used to measure the ability of an organization in a particular discipline. The different levels of a maturity model are stages building on each other, which mature continuously with increasing levels. The continuous representation, which is used in this work, allows to divide a process-audit into different individual steps, the process-audit procedure, which are represented by the different process areas of the new maturity model.

The aim of this thesis is to create a new assessment model, which can be used to assess the individual process-audits steps. The structure of the process areas is constructed in a way that it can be used as a specified procedure to conduct conform and uniform process-audits. Every process area represents in a sequencing way, the individual steps to conduct process-audits, from the planning to the following-up.

Since quality is an immeasurable parameter, a new maturity model was developed to assess the quality of the different process-audits steps. By using the Predictive Validity Framework (PVF), it is possible to connect conceptual definitions with operational definitions. In other words the PVF is used to measure immeasurable parameters. One example is the high-school grades which are used to predict the preparedness of a student for later success at university (admission procedure). The development of the new maturity model is based on the six activities of the Design Science Research Methodology (DSRM). The problem statement and the later demonstration of the new maturity model are realized in cooperation with the PS-Organization. That is why this thesis consists of an Action Research Methodology, which is a combination of a solution for a given problem to the concerning organization (Action) and a contribution to the world of science (Research).

Scientifically, the result is a new assessment model, which can be used within any production plant. The outcome for the PS-Organization is an accurate assessment of their currently used process-audit procedure with suggestions for improvement.

Kurzfassung

“Quality Audit” Process beschreibt das Verfahren von Prozessaudits, anders ausgedrückt, die einzelnen Schritte welche notwendig sind, um übereinstimmende Prozessaudits durchzuführen. Ein Prozessaudit ist eine Methode zur unabhängigen Analyse und Beurteilung von Produktentstehungsprozessen und deren Wirksamkeit für festgelegte Produkte. Ziel ist es, die Übereinstimmung betrachteter Prozesse mit den Anforderungen und Vorgaben zu überprüfen. Daraus folgend steigt die Qualität innerhalb eines Unternehmens, da Schwachstellen ausfindig gemacht werden um dann später verbessern zu werden.

Ein Reifegradmodell beschreibt die Reife eines Betrachtungsfeldes hinsichtlich einer bestimmten Methode und besteht aus aufeinander aufbauenden Stufen. Die kontinuierliche Darstellung ermöglicht es, die einzelnen Schritte eines Prozessaudits innerhalb der Prozessbereiche darzustellen, und somit einzeln zu bewerten.

Ziel dieser Arbeit ist es, ein neues Bewertungsmodell zu erstellen, welches es ermöglicht die einzelnen Schritte von internen Prozessaudits zu bewerten. Das neue Reifegradmodell ist so aufgebaut, dass die einzelnen Dimensionen in einer entsprechenden Reihenfolge aufgebaut sind, damit jede Dimension einen bestimmten Vorgehensschritt eines Prozessaudits darstellt. Dies ermöglicht es übereinstimmende Prozessaudits durchzuführen, zu bewerten und somit Schwachstellen ausfindig zu machen. Zudem geben die einzelnen Stufen vor, was notwendig ist, um sich zu verbessern, jedoch nicht, wie man dies umsetzt.

Da Qualität einen unmessbaren Parameter darstellt, wurde bei der Erstellung des neuen Reifegradmodells auf das Predictive Validity Framework (PVF) zurückgegriffen. Dieses ermöglicht es, konzeptionelle Definitionen mit operativen Definitionen zu verbinden und somit, unmessbare Parameter zu messen. Ein bekanntes Beispiel hierfür sind Abiturnoten, welche von Universitäten oft als Aufnahmekriterium genutzt werden um die Zuversicht auf ein erfolgreiches Studium widerzuspiegeln. Einen strukturierten Aufbau bei der Entwicklung des neuen Reifegradmodells wird durch die sechs Tätigkeiten der Design Science Research Methodology (DSRM) sichergestellt. Da die Problemstellung sowie die Vorführung des neuen Bewertungsmodells in Verbindung mit einem Unternehmen durchgeführt wurden, handelt es sich hierbei um eine Action Research Methodology.

In Bezug auf die Wissenschaft wurde ein neues Bewertungsmodell für Prozessaudits erstellt, was in jedem Produktionsunternehmen anwendbar ist. Dieses wurde in einem Unternehmen getestet, was eine genaue Bewertung deren Prozessaudits, mit anschließender Auflistung von Verbesserungsmöglichkeiten, ermöglichte.

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1 Introduction

1.1 General introduction to the topic

In the automotive industry, quality plays a decisive role, and to guarantee the highest possible quality, it is necessary to conduct audits. Audits are not only used to verify conformity to the given requirements, but also to identify weak spots and hence support continuous improvement[1]. Concerning the production process, process quality controls allow organizations to offer a higher quality product, which has positive impacts on customer satisfaction[2]. Process-audits generate a new perspective by questioning the activities and the meaning of the results received from every process. The rising importance of process-audits is a logical consequence, since they can help to improve the effectivity and efficiency of production processes[3].

This thesis deals with the importance of process-audits for production industries within the automotive industry. Which steps organizations need to follow to implement conform and uniform process-audits and how they can assess their current process-audits, and hence improve them, will be elaborated within this thesis. Concerning this matter, Watts S. Humphrey, one of the pioneers of maturity models, made an interesting statement:

"If you don't know where you are, a map won't help. "[4]

This statement intensifies the idea that, before you are able to know where to go, you need to understand where you currently are. To be competitive in today's world, it gets more and more important to save time and extract as much useful information out of every audit as possible. Additionally, regarding 'Industry 4.0', digitalization and automated handling of data become more and more important. All these matters are taken into consideration in this thesis. The result will represent an assessment model to assess the maturity level of process-audits and thus detect weak points, while always keeping in mind the progress of technology. Additionally, the result should satisfy the requirements of IATF 16949, which is based on ISO 9001 and combines the existing requirements of quality management systems in the automotive industry.

The following sections are divided into three parts. Firstly, the Initial Situation will be stated in the available literature and in the PS-Organization. Secondly, the Problem Statement will be elaborated for the available literature and afterwards for the PS-Organization. And lastly, a Solution Statement will be given to fill the gap in literature and improve the prior stated problems for the PS-Organization.

[1] J. Brauweiler et al. , 2015
[2] Blanco-Encomienda et al. , 2018
[3] G. Gietl, 2016
[4] S. Humphrey, 1989, p.1

1.2 Initial Situation – Literature and PS-Organization

The statement of the initial situation will be divided into two parts. The first part examines the currently available literature, to understand better what process-audits are and see what has already been treated within previous researches. The second part surveys how the PS-Organization currently handles process-audits. This part mainly refers to the work of the quality inspectors, which represent the worker's level and are conducting daily process-audits. Additionally, parts of the work of the Plant Quality Assurance Team (PQA), who are analyzing the results and are ensuring that quality requirements are fulfilled the same as improvements are established, will be discussed.

Concerning the first part, a precise definition of what process-audits are, will be given in 2.3. This definition helps to understand better what process-audits are about and highlights the most important aspects of them. Two main aspects of process-audits will be retained here. The first aspect handles the importance of having an explicit procedure on how to conduct or implement process-audits within an organization. This means having guidelines from the planning of process-audits to the feedback/ follow-up of process-audits. Secondly, the importance of the production process itself for process-audits should be highlighted. A lot of literature concerning system audits is available; however particular literature for process-audits is limited.

Regarding the initial situation within the PS-Organization, the first sub-part is to state the initial situation of the quality inspectors. Most of the process-audits are conducted by quality inspectors and they are hence responsible for surveying the different production processes on a daily basis. The manager of the quality inspectors is preparing checklists, based on previous experiences. Currently, 25 different checklists are available. The scheduling is done either by revising excel sheets which show the areas which have already been checked or on random basis. The process-audits themselves are conducted with printed checklists, with as answer possibilities 'ok' and 'not ok'. For monitoring, excel and a web-based issue tracker called JIRA are used. This software offers ticket tracking as well.

The second sub-part is the analysis of the work from the PQA. Within the PS-Organization, so-called Layered Process Audits (LPAs) are conducted. These are process-audits which are conducted by different layers. Layer one consists of quality inspectors who are conducting daily audits, layer two is composed of responsible engineers who are conducting weekly audits and at layer three the plant-management is conducting monthly audits. All these audits are carried out with printed checklists, which are later registered within excel and JIRA. The audits are focusing on areas which were classified as important in the past and try to cover every area during a one-year period.

1.3 Problem Statement – Literature and PS-Organization

The structure of the problem statement will be the same as for the statement of the initial situation, divided into a problem statement for the literature and one for the PS-Organization. At the end, a combined problem statement, the same as research questions will be derived.

The first part is to establish a problem statement for the available literature and to quote a gap in the available researches. A procedure on which steps are necessary to conduct consistent process-audits is missing in the currently available literature. Furthermore, no model through which an assessment of the quality of process-audits is missing. There is literature available which states the different stages necessary to conduct audits (e.g. system audits and external audits), the same as there is literature available which focuses on what process-audits are and what is important, but there isn't any literature which combines the different steps to conduct process-audits with a tool to assess the quality of process-audits.

The second part is to determine a problem statement valid for the PS-Organization. This problem statement is valid on the one hand for the quality inspectors and on the other hand for the PQA. Currently, there isn't a structured and generic approach available which provides guidelines on how to conduct conform and uniform process-audits, from the beginning to the end. Checklists are composed based on experiences, without insuring that all the important aspects are verified, scheduling exists only partially, the completion of the checklists is time-consuming and fault-prone, and the monitoring mainly consists of numbers (e.g. specified quantity of realized process-audits) and only partially of useable information to detect weaknesses and failures. Referring to the second sub-part, the work of the PQA, LPAs represent a valuable tool, which allows getting many various insights into the sequence of process-audits. A problem for the PQA is the partially missing standardization and evaluation tool to assess their currently used process-audit procedure. Additionally, with a link towards the worker's level, the supervision possibilities of the PQA to verify their conformity are insufficient. Thus, the daily process-audits need to follow a strict procedure, to ensure that they are focusing on the right areas and to be able to compare the results. Besides, a digitalization of internal audits is required, to save time, paper and to be less fault-prone.

In order to have the different problem statements at one glance, they can be summarized into the following two problem statements:

- **Missing procedure to conduct consistent process-audits**
- **Missing model to assess the quality of process-audits**

➔ **Missing combination of both**

The definition of the research questions combines the different problem statements into one global problem statement. Therefore, one main research question with three sub-questions was developed:

> *Which steps do organizations need to follow, to be able to cover all phases/ aspects of process-audits?*
>
> 1. *How does an organization assess their current situation statement?*
> 2. *How does an organization ensure that process-audits are focusing on the right areas?*
> 3. *How does an organization ensure continuous improvement within the process-audit procedure?*

1.4 Solution Statement – Literature and PS-Organization

The solution statement will be structured the other way around. First, there will be a short explication of what a combination between a research and client problem is. Afterwards, a global solution statement which covers all the requirements will be given, before clarifying that the global solution statement satisfies all the individual problem statements.

This master's thesis consists of an Action Research Methodology. This means, that the results of the thesis will provide on the one hand a solution for a given problem for the concerning organization (Action) and on the other hand provide a contribution to the world of science (Research).

After thorough analysis of the initial situation and of the problem statement, the same as crucial conversations with the responsible professor at the university and the responsible engineers at the PS-Organization, the development of a new maturity model for the *"Quality Audit" Process* was adjudged as suitable. The main idea of maturity models are stages building on each other, which mature continuously with increasing levels. This new maturity model is based on the Predictive Validity Framework and is a continuous representation, which allows an improvement in individual process areas. The different capability levels (continuous representation) will be deduced from the CMMI and the different process areas represent the different steps which are necessary to conduct conform production process quality audits and are derived from a systematic literature review. This approach allows dividing process-audits into different sub-frames with the possibility to assess a certain capability level to every step and provide a map for continuous improvement. Herewith, issues can easily be detected and ameliorated.

Concerning the contribution for science, this new maturity model represents a combination of a procedure to conduct consistent process-audits and an assessment model. Herewith, it represents a combination of both problem statements and thus tries to solve both. Through the inclusion of the PDCA-Cycle, continuous improvement can be ensured as well.

For the worker's level, the maturity model ensures that different stages of conducting process-audits can follow a structured plan. With a working maturity model, the assessment of the initial situation will no longer represent any problems. For the PQA-Team, the main issues were to ensure that the process-audits were focusing on the correct areas and that the information and feedback flow would be improved. All of these issues will be treated within different process areas. This enables that, while maturing continuously through the different levels, organizations can ensure to focus on the right areas during process-audits. One of the main characteristics of maturity models is to provide guidelines on what is necessary to continuously improve. So, the continuous improvement of the information and feedback flow will be ensured within the different levels.

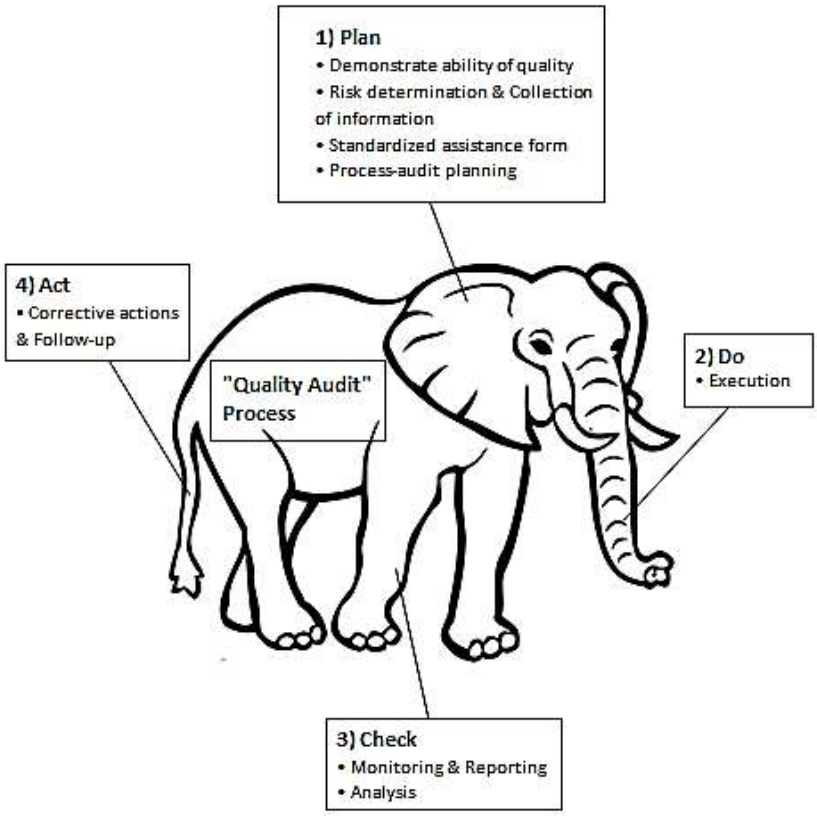


Figure 1: The Blind Men and the Elephant – "Quality Audit" Process

The above figure illustrates the metaphor of 'The Blind Men and the Elephant'. This metaphor is about blind men who analyze a different part of an elephant, respectively, and the combination of all the experiences provides a global image of an elephant. Relating to this work, the four dimensions, with in total eight sub-dimensions, generate a global representation of the process-audit procedure.

1.5 Research Methodology – Predictive Validity Framework

As research methodology, the Predictive Validity Framework (PVF) will be used. It is a useful description of the hypothesis testing process, which tries to provide a valuable mean to identify the disconnection between our conceptual and operational definitions. The conceptual level tells someone what the concept means, and the operational level tells someone how to measure it. The goal is to refine general problems down to clear, explicit and testable research questions. It is composed of two levels, the conceptual and the operational level, independent, dependent and control variables, five different boxes, the same as five different links. The basic structure of the Predictive Validity Framework can be seen in figure 2.

The overall goal to use the PVF is to measure the immeasurable parameters of quality within the process-audit procedure. This transformation is possible using the PVF. The later measurement will be done by concrete questions, which are established on the generic goals and practices from the CMMI.

Later, a more precise explication of the Predictive Validity Framework will be included in the theory. At that time, the main goal, the different levels and structure will be elaborated in detail. This elaboration is concluded by two articles from Robert Libby[5] [6], one article form Josep Bisbe et al.[7] which refers to Libby and one latter composed article from Joan Luft et al.[8]. This detailed elaboration should help to get a clear idea of the used methodology and help to guide through the development of the maturity model.

The following figure shows the structure of the PVF.

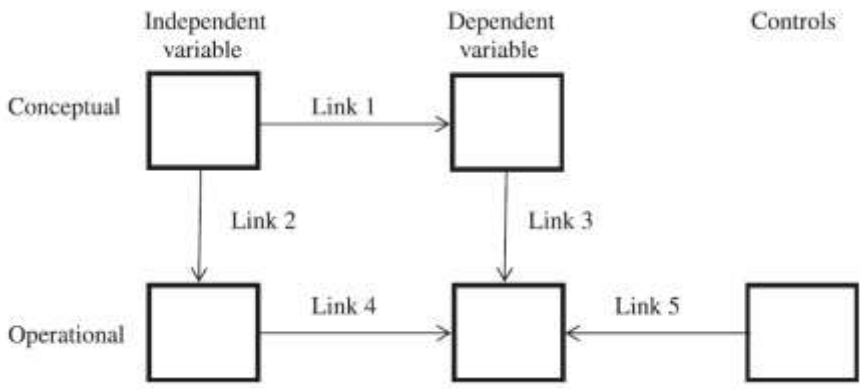


Figure 2: Predictive Validity Framework (PVF)[9]

[5] R. Libby et al. , 2002
[6] R. Libby, 2017
[7] J. Bisbe et al. , 2007
[8] J. Luft et al. , 2014
[9] (J. Luft et al., 2014, p. 553)

1.6 Work Packages of this Master's Thesis

The following figure overviews the structure of this master's thesis, with the three work packages. The content of the work packages converts from theory (Theoretical Foundations) to a practically application (Methodical approach to develop the new Maturity Model) to a final review (Conclusion).

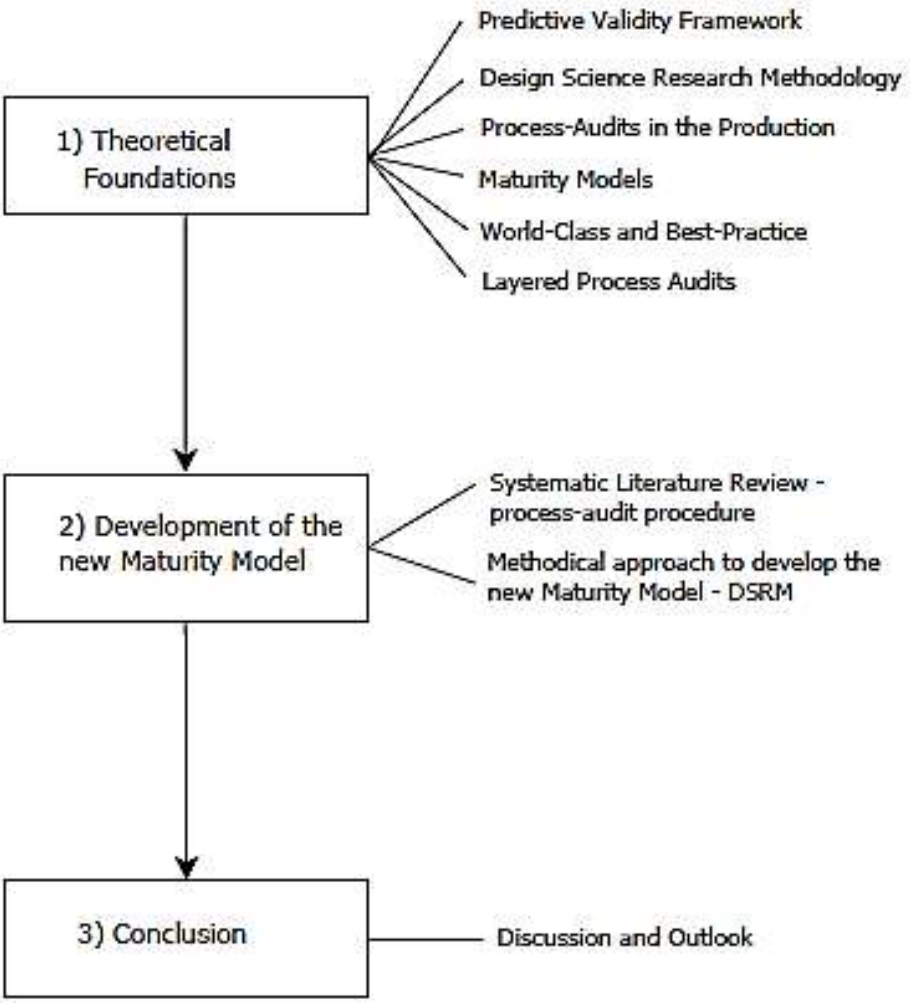


Figure 3: Work Packages of this thesis

The first work package defines all the important expressions and thus helps to provide the needed knowledge for the second work package. The second work package consists of the actual work and novelty of this master's thesis. Here, firstly a systematic literature review was conducted to see what already exists in the literature and to define the individual steps of the process-audit procedure. Secondly, the new maturity model was developed, based on the six activities of the Design Science Research Methodology. The final work package serves as conclusion of this thesis and gives a prospect for future works.

2 Theoretical Foundations

2.1 Predictive Validity Framework (PVF)

The methodology of this thesis is the Predictive Validity Framework (PVF). To start with the elaboration of the methodology, the individual words from the Predictive Validity Framework will be illustrated more clearly and proven by a figurative example of predictive validity in the everyday life. Only after having a clear overview of the different terms, the conceptual analysis and later the methodology itself will be elaborated.

Before starting to elucidate the Predictive Validity Framework, a brief definition of what a methodology is, will be given. A methodology is a set of methods used in a particular area of study or activity[10]. The methodology pretends the general research study which guides the researcher through the process of his work. It shows the way in which the research should be undertaken and identifies the methods to be used in it. The methods for their part, define the modes and means of data collection[11]. It is important to understand the difference between methodology and method.

Predictive is the fact of forecasting or prognosticating a future occurrence. Validity is the state or quality of being valid. In this composition it means, how exact and how probable does the predicted future event occur. A framework is a skeletal structure designed to support or enclose something[12].

The process of predictive validity includes the testing of a group of subjects for a certain construct and then comparing them with the results obtained at some later point. With the help of the following example, the basic idea behind this methodology should be made a bit more clearly.

Probably the best-known example of the use of predictive validity is the process of selecting students for a university. It is a commonly fact, that universities use high-school grades to decide, which students to accept for a certain program. The idea is, that the high-school grades reflect the qualities and performance of a certain student. The hope and expectations are that the grades reflect the preparedness of a student for later success at the university. It can be said that, the predictive validity reflects the degree to which the results from a test of interest can predict future outcome, preferably measured by a reference standard. For this, the same as for most other usages, the validity of the test can only be proven or verified at a latter point.

[10] www.dictionary.cambridge.org
[11] Howell, 2013
[12] www.dictionary.com

Professor Dr. John de Jong explained predictive validity as followed: "*How much is a test able to predict what kind of behavior the candidate is going to show after taken the test and when confronted in a situation where he is taken the test for.*"[13]

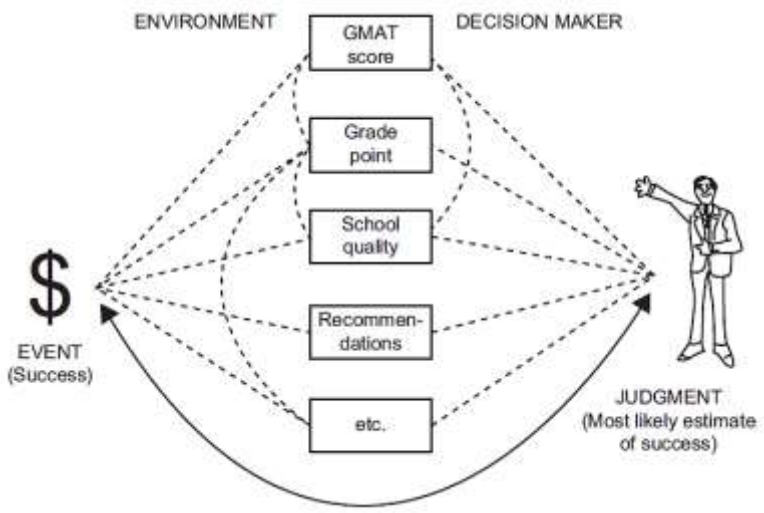


Figure 4: The graduate business school admissions decision[14]

The enclosed figure shows a situation of decision-making under uncertainty, the so called 'graduate business school admission decision'. The figure presents a general structure which highlights the most important features of such a situation. While taking this situation, the admission committee, which are here the decision makers, attempts to predict an applicant's future success as a student and in the job marked. The problem is that the committee can't judge this future event directly, because the decision maker is separated from the event of interest by space or time. For this purpose, a student needs to give some indications, like grade points, recommendations, etc. However, since none of these indications are perfect indicators for future success, they are represented by broken lines. Nevertheless, the admission committee needs to take their decision dependent on this unconfident information. The accuracy of the judgments can only be measured after the student has completed his education. This is an example of the predictive validity in real-life.

The Predictive Validity Framework is a useful description of the hypothesis testing process. It provides a valuable mean to identify the disconnection between our conceptual definitions and operational definitions of key constructs adopted across both, quantitative and qualitative studies[15]. A so-called theory-based empirical research like the Predictive Validity Framework, aims to refine general problems down to clear, explicit and testable research questions. It provides a description of the process by which research questions are specified, operationalized and tested[16]. At this point it is important to mention for the first time the two different stages or levels within the Predictive Validity Framework and to understand the difference between them. The two levels which need to be distinguished are the conceptual level and the operational level.

[13] Professor Dr. J. d. Jong, 2009
[14] (R. Libby, 2017, p. 25)
[15] E. Curtis et al. , 2017
[16] J. Bisbe et al. , 2007

The conceptual level is the first stage of the Predictive Validity Framework. The utility of conceptual analysis for science can be stated by assessing the means of an explanatory evaluation in which the concept of evidence is analyzed. Conceptual analysis is a technique that treats concepts as classes of objects, events, properties, or relationships. It is mainly important, that the technique involves a precise definition of the meaning of a given concept. This is done by identifying and specifying the conditions under which any entity or phenomenon is classified under the concept in question. The ambition in using conceptual analysis as a method of inquiry is to improve the understanding of the ways in which particular concepts are used for communicating ideas about that field[17]. The idea of a conceptual model is, to represent a system which is made of the composition of concepts, with the aim of helping to better understand the subject represented by the model.

Specifically, for the Predictive Validity Framework, at the conceptual level, theory identifies the constructs of interest and specifies their meaning[18].

The operational level is the second stage of the Predictive Validity Framework. The operational level gives a communicable meaning to a concept by specifying how the concept is measured and applied with a particular set of circumstances. Two important aspects can be highlighted from this definition. Firstly, the operational level forms a ‘common language’ by giving a precise meaning to the conceptual level. And secondly, it defines how the so called ‘common language’ is used when it is applied in a specific context. This is important to avoid that things get misunderstood, it implies a specific meaning to the language. The operational model is an abstract or visual representation (model) of how an organization delivers value to its customers as well as how an organization actually runs itself.

Specifically, for the Predictive Validity Framework, the research moves from the conceptual to the operational level by engaging in an operationalization process. By this, constructs are translated into operational variables that measure the variability associate with the constructs[19].

In summary, the conceptual level tells someone what the concept means, and the operational level tells someone how to measure it.

[17] J. Furner, 2006
[18] J. Bisbe et al. , 2007
[19] J. Bisbe et al. , 2007

2.1.1 Libby boxes of the PVF

The Libby boxes are an illustration of the Predictive Validity Framework and were developed by Professor Robert Libby in 1981[20]. A similar framework was already developed by Runkel and McGrath in 1972[21]. As already mentioned before, they are composed of a conceptual level (Why?) and an operational level (How?). Furthermore, there are independent, dependent and control variables.

The different boxes and links will be described in the following sections[22] [23] [24] [25]. The first two boxes are on the conceptual level and serve as a design, which assesses a mean to an explanatory evaluation (theoretical). The first box, concept A, represents the construct of interest. The second box, concept B, specifies the meaning of the first box. The link in between those two boxes, Link 1, illustrates the theory which represents the expected relationships between the identified constructs. Here, it is mainly important to have a well formulated hypothesis, the same as to state a valuable and clear research question, which addresses the relation between two or more concepts. The theory suggests the expected answer to the research question and guides. To develop a good research question and hypothesis, four issues need to be considered. The first one is, that the hypothesis must have external validity, so the readers must believe that the theoretical concepts and the relationships between them capture important aspects of the target's environment. The second issue is, that experimental research questions should focus on how theories drawn from fundamental disciplines. The third issue is, that researches should frame their theories at the least specific level that can account for the data expected to arise from the experiment. The fourth and last issue is, that experimental research questions should be based on a theory that describes causal relationships between concepts, where the how and why phenomena arise.

The third box, operational definition A, represents independent variables which are operationalized during the experiment. The fourth box, operational definition B, represents depend variables which are operationalized during the experiment. The links 2 and 3 relate the conceptual level with the operational level. They make the transition between conceptual and operational and translate constructs into operational variables that measure the variability associated with constructs.

[20] R. Libby et al. , 2002
[21] P. Runkel et al. , 1972
[22] R. Libby et al. , 2002
[23] J. Bisbe et al. , 2007
[24] J. Luft et al. , 2014
[25] R. Libby, 2017

There are three particularly difficult issues in operationalizing variables. The first issue is choosing the appropriate realism of the stimuli presented to participants. Here, the challenge is to decide how realistic the stimuli should be. The second issue is choosing the appropriate levels of independent variables. A general goal is stated as to choose levels that are different enough that the experiment has sufficient power to yield strong effects yet be within the relevant range. The third issue is using measured independent variables, which gives a comparative advantage to the experimentalist.

The fifth box, other/ extraneous potentially influential variables, are control variables which could affect the dependent variable. The internal validity refers to the degree to which variation in the dependent variable can be attributed to variation in the independent variable. Link 4 rates the relations between the operational independent and dependent variable. The obtained data from the observations which are subjected to statistical analysis are used indirectly to test theory by testing the extent to which the data are consistent with the modelled relationships between constructs. Link 5 captures 'other/ extraneous potentially influential' variables besides the independent variable that could affect the dependent variable. One key advantage of the experimental approach is that the effects from the other/ extraneous variables can be controlled by simply holding them constant or through randomization.

The following figure summarizes the before mentioned construct and should help to visualize the later explained example.

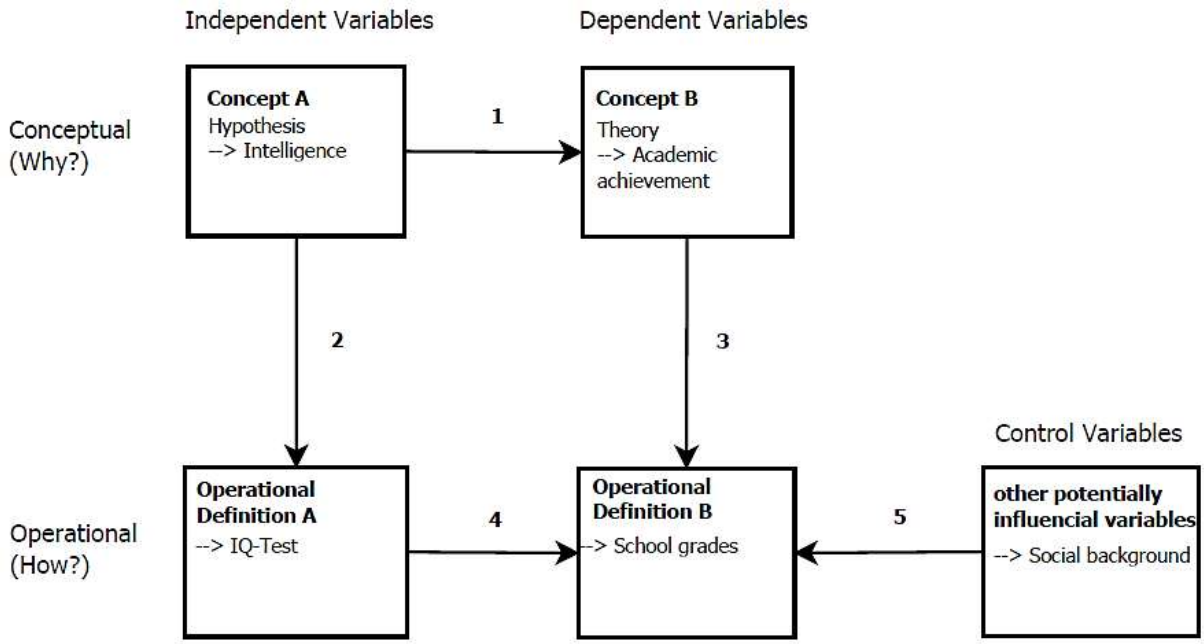


Figure 5: Libby boxes of the Predictive Validity Framework

In summary, it is not possible for a researcher to directly test the relationship between two concepts (Link 1), but only by assessing the relationship between the operational definitions of the dependent and independent variables (Link 4). Furthermore, the assumptions that the relations between the concepts and the operational definitions (Link 2 and 3) needs to be valid and other factors which might affect the dependent variable (Link 5) have either been controlled or have no effect. If those points are respected, the evaluation of the validity of a study is a function of the appraisal of the Links 1, 2, 3 and 5. So, if it has been determined once, that a logically consistent theoretical framework is being employed (Link 1), the evaluator should look closely at the ways in which variables are operationalized (Links 2 and 3) and how other factors are controlled (Link 5).

An example[26], to illustrate the Predictive Validity Framework is the following:

- **Concept A** = intelligence, is assumed to affect
- **Concept B** = academic achievement

Those two concepts are on the conceptual level. Concept A would be an independent variable and concept B would be a dependent variable.

- **Operational Definition A** = IQ-Test, is a direct measurement of intelligence
- **Operational Definition B** = school grades, are direct measurements of the academic achievement
- **Other potentially influential variables** = social background, can affect the school grades as well

This example shows how intelligence, academic achievement, IQ test, school grades and social background are connected through the PVF.

The different concepts and operational definitions are included within the above figure. They should help to visualize the idea and approach of the Libby boxes.

[26] R. Libby, 2017

2.2 Design Science Research Methodology (DSRM)

Within information systems discipline, two paradigms characterize the research: behavioral science and design science. The first one, behavioral science aspires to develop and verify theories that explain or predict human or organizational behavior. The second one, the design science paradigm aims to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts[27].

Information systems are implemented within an organization for improving the effectiveness and efficiency of an organization.

The following table[28] summarizes the nominal sequence of six activities of the design science research methodology. The three main objectives are: provide a nominal process for the conduct of design science research, build upon prior literature about design science in information systems and reference disciplines, and provide researchers with a mental model or template for a structure for research outputs. The first column lists the six activities, the second column specifies each of the activities and answers the question: what to do? The last column links the knowledge base with the different activities and answers the question: how the activities are executed?

DSMR activities	Activity description	Knowledge base
1) Problem identification and motivation	*What is the problem?* Define the research problem and justify the value of a solution.	Understand the problem's relevance and its current solutions and their weaknesses.
2) Define the objectives of a solution	*How should the problem be solved?* In addition to general objectives such as feasibility and performance, what are the specific criteria that a solution for the problem defined in step one should meet?	Knowledge of what is possible and what is feasible. Knowledge of methods, technologies, and theories that can help with defining the objectives.
3) Design and development	*Create an artifact that solves the problem.* Create constructs, models, methods, or instantiations in which a research contribution is enclosed.	Application of methods, technologies, and theories to create an artifact that solves the problem.
4) Demonstration	*Demonstrate the use of the artifact.* Prove that the artifact works by solving one or more instances of the problem.	Knowledge of how to use the artifact to solve the problem.
5) Evaluation	*How well does the artifact work?* Observe and measure how well the artifact supports a solution to the problem by comparing the objectives with observed results.	Knowledge of relevant metrics and evaluation techniques.
6) Communication	*Communicate the problem*, its solution, and the utility, novelty, and effectiveness of the solution to researchers and other relevant audiences.	Knowledge of disciplinary culture.

Table 1: Design Science Research Methodology (DSRM)

[27] Hevner et al. , 2004
[28] Peffers et al. , 2008

2.3 Process-audits in the production

To understand the concept of process-audits better, both words will be elucidated shortly. The Oxford English Dictionary states a process as: "*A process is a series of actions or steps taken in order to achieve a particular end. This includes a systematic series of mechanized or chemical operations that are performed in order to produce something.*"[29] The Cambridge dictionary explains a process as: "*A method of producing goods in a factory by treating natural substances.*"[30] The meaning of the word audit is defined by the Cambridge Dictionary as: "*An official examination of the quality or condition of something.*"[31] The ISO 19011 defines an audit as: "*systematic, independent and documented process for obtaining audit evidence and evaluating it objectively to determine the extent to which the audit criteria are fulfilled.*"[32]

After both words were explained separately, a definition of the combination of both will be given. According to the VDA 6.3, a process-audit is: "*A process audit is a method for impartial analysis and evaluation of the product development and realization as well as the effectiveness of the defined product. The goal of the process audit is to check the conformity of the process/ process steps with the requirements and specifications. Any deviations that are detected are documented as audit findings and evaluated based on the product risk and/ or the process risk within the audited organization or in the supply chain. The evaluation must consider what the resulting risks would be if the findings indicate non-compliant products can be expected.*"[33]

Auditing is hence always a manner of comparing something against an ideal or measure how similar they are. Process auditing can therefore be described as a measurement of how conforms a certain process is running and producing parts. The aim is to determine the extent to which the audit criteria are fulfilled.[34] The importance of measuring within audits will be elucidated by a quotation of H. James Harrington:

"*Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it.*"[35]

In the title of this thesis, the term "Quality Audit" Process is used, which describes the procedure with the individual steps, necessary to conduct conform process-audits. It specifies a proceeding to conduct conform and uniform process-audits.

[29] Oxford English Dictionary, 2011
[30] www.dictionary.cambridge.org
[31] www.dictionary.cambridge.org
[32] ISO 19011:2017, p. 8
[33] VDA 6.3, 2016, p.13
[34] DIN ISO 9000, 2015
[35] H. James Harrington, CIO (Sep 1999), p. 19

Before amplifying the term of process-audit further, other audits will be elucidated, to better understand the difference between the different audits types. Furthermore, the reference object of a process-audit, the production process will be explained in detail, which should help to understand better where to focus during a process-audit.

Firstly, audits can be divided into internal and external audits[36]. The difference lies in the interrelationship among the participants of the audit. Internal audits are performed by internals, employees of the organization. External audits are performed by externals, outside agents. This thesis addresses internal audits, hence what internal audits are should be highlighted. The main goal of internal audits is to provide independent assurance that the tasks of an organization are fulfilled effectively. They provide the management with assurance that everything is done as intended and can also be called first-party audits. Furthermore, it is always better to find failures on your own, instead that a customer detects them. The IIA's described an internal audit in 2013 as:

"*Internal auditing is an independent, objective assurance and consulting activity designed to add value and improve an organization's operations. It helps an organization accomplish its objectives by bringing a systematic, disciplined approach to evaluate and improve the effectiveness of risk management, control and governance processes.*"[37]

External audits can be divided into second-party audits, where the audit is done by customers who examine their suppliers, to check if they are fulfilling the needed requirements and third-party audits, where the audits are conducted by external independent auditors[38].

Secondly, there are three different types of internal audits, product audits, process-audits and system audits. A product audits is an examination of a particular product with the aim to evaluate whether it conforms to the given requirements. A process-audit is a verification that processes are working with established limits. It evaluates an operation or method against predetermined instructions or standards to measure the effectiveness of the instructions and the conformance to the given standards. A system audit is conducted in order to audit a management system. It is a documented activity to verify, by examination and evaluation of objective evidence, that applicable elements of the systems are appropriate and effective, the same as have been developed, documented, and implemented in accordance and conjunction with specified requirements. It evaluates the whole system. It is mainly important, to understand, the difference between a product audit and a process-audit. The overall goal of process-audits is to improve the quality of the products through control of the

[36] G. Gietl et al. , 2016
[37] IIA, 2013
[38] J. Brauweiler et al., 2015

production processes. It controls how products are made and doesn't inspect finished products[39].

In this thesis, the process-audits are production process-audits, which compare the production processes (e.g. printing, pressing, lasing, etc.) against predetermined standards. So, a single process-audit will not assess the overall efficiency and performance of an organization, but simple grade how conforms a single production process is currently running. The later developed maturity model will assess the overall efficiency and performance of the process-audits of an organization.

By its very nature, process auditing implies an action such as transforming inputs into outputs. Logically, it is also necessary to have an overview over the production process, if the interest is to improve the process auditing.

The figure below shows a flow chart diagram of a production process. It consists of a starting point (Input) and end point (output). The figure is based on the idea that a production process consists of different so-called elements. Those elements are: Man, Machine, Material, Method, Environment and Measurement[40]. Together, all these elements describe the different activities within the production process.

- **Man**: summarizes all the aspects concerning the people who are concerned within the production process
- **Machine**: sums up all the tools and equipment which are used to complete a production task
- **Material**: merges raw material, components, supplies used for production and general materials, it covers issues coming into the process
- **Method**: concentrates the production and support processes which are used
- **Environment**: integrates all factors within the production area (e.g. light, noise, etc.) and environmental issues
- **Measurement**: combines physical measurement, automatic sensor readings, and inspections

The different process elements represent the used resources (machine, material, man) to transform the inputs into outputs, the environment, the followed methods (procedures and instructions) and the measurements collected to determine the process performance. Supplementary to the usage of those 6 process elements, an auditor who conducts a process-audit should use process techniques which verifies conformance to the required sequential steps from input to output. For this purpose, simple flow charts, process maps or process flow diagrams can be used. Those help the auditor to easily understand the different steps of the process he is verifying and allows additionally to survey the production process in a more global view, as one

[39] J.P. Russell, 2013
[40] J.P. Russell, 2006

unit. They add supplementary value by considering the dynamic nature of a process and the linkages between requirements.

One last important aspect of the production process diagram is the feedback loop, which has an important role within this thesis. For every control system, the existence of a feedback information loop from the process output is important. This feedback information will be used to check the setup and adjust the process or make decisions about the output. Statistical techniques can help to better understand what changes need to be made to the process to ensure that output objectives are achieved. Within the feedback information loop, the most critical parameters can be monitored to ensure the process is running correctly[41].

The following figure summarizes the before mentioned information and is based on the ideas of Russell[42].

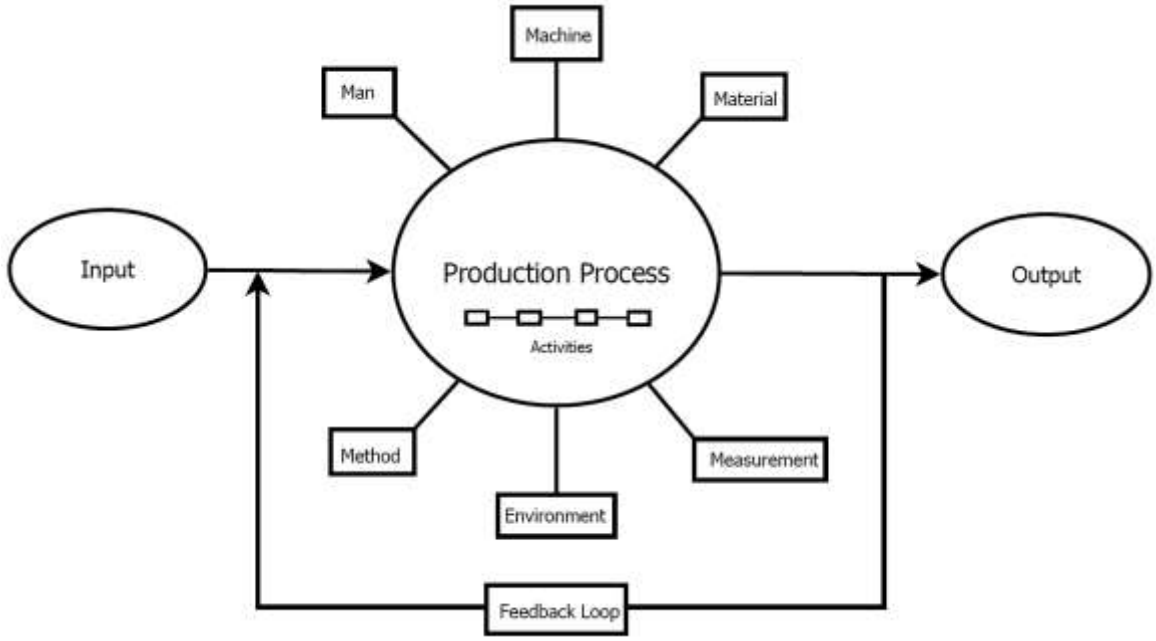


Figure 6: Production Process Diagram with Feedback Loop

This section should help to clearly define the term of what a process-audit is. It is important to have a fairly accurate image of what a process-audit represents, to be able to understand the development of the new maturity model. The different steps which are necessary to conduct conform and uniform process-audits are unfortunately not clearly defined in the available literature. Therefore, they will be elaborated at a later moment within this thesis, by conducting a systematic literature review.

The following section will deal with maturity models and give a comprehensive introduction on what a maturity model is, and which different forms exists.

[41] J.P. Russell, 2009
[42] J.P. Russell, 2006

2.4 Maturity Models (MM)

To start the theoretical foundations concerning maturity models, its word composition will be elucidated in a first step. Afterwards, the main characteristics of maturity model the same as distinctions within different maturity models will be elaborated.

There are a lot of different explications for the word maturity. The literal meaning is 'ripeness', which describes the development from some initial state to some more advanced state[43]. The Oxford English Dictionary defines 'maturity' as: "*The state of being mature, fullness or perfection of development or growth*"[44]. For immaterial things it is described as: "*The state of being complete, perfect or ready*"[45]. From a linguistic perspective, the definition of 'maturity' outlines the conditions, when certain examined objects reach the perfect state for their intended purpose. Maturity in combination with industry development signifies full development or perfection[46]. All in all, maturity can be defined as the final stage which requires a certain development to reach, an evolutionary progress.

A model represents a formal description of "*some aspects of the physical or social reality for the purpose of understanding and communicating*"[47]. However, a model reflects one state of a particular application domain whether it is the exact description of the current situation or a suggestion for a more efficient or ideal target state. Methods are used "*to perform a systems development project, based on a specific way of thinking, consisting of directions and rules, structured in a systematic way in development activities with corresponding development products*"[48]. Consequently, methods are systematic, goal-oriented and repeatable. The differentiation between models and methods is, that for models the reproduction of state descriptions of the ideal solution is the ultimate objective of the design work (what) whereas methods rather focus on the specification of activities to reach the ideal solution (how). Maturity models combine state descriptions with a number of key practices. Therefore, in the word composition 'Maturity Model' the word 'model' is somehow in between models and methods[49].

The main idea of maturity models is the idea of stages building on each other. This idea emerged out of quality management and was introduced by Crosby in 1979 in his so-called *quality management process maturity grid*. It defines five maturity stages and the last stage, called 'Certainty' describes a complete or perfect state[50]. Maturity models can be defined as: "*A maturity model is a structured collection of*

[43] P. Fraser et al. , 2002
[44] J. A. Simpson et al. , 1989
[45] J. A. Simpson et al. , 1989
[46] J. Oleskow-Szlapka et al. , 2018
[47] J. Mylopoulos, 1992, p. 3
[48] S. Brinkkemper, 1996, p. 275-276
[49] T. Mettler et al., 2009
[50] R Wendler, 2012

elements that describe the characteristics of effective processes at different stages of development. It also suggests points of demarcation between stages and methods of transitioning from one stage to another"[51]. More easily expressed, they pretend a clear guidance for companies by giving them indicators as well as guidance to analyze and subsequently improve their processes. Furthermore, they indicate when or at which stage a firm should implement which ideas for improvement[52]. Another definition for maturity models can be defined as a group of elements that describe processes at different levels of development, including delimitation boundaries between levels and how to evolve from one to the next. A maturity model can be presented as a guide to help organizations identifying their current state and additionally recommendations to improve the current progress to a more advanced maturity level are offered[53]. An important fact is, that for maturity models, the main focus is an improvement of the processes with a sustainable background[54].

Using a Top-Down approach, a fixed number of maturity levels get specified and afterwards confirmed with characteristics.[55] Applying a Bottom-Up approach, first the characteristics are determined before they are directed into maturity levels.

Maturity models can be divided into three basic groups: maturity grids, CMM-like models and Likert-like questionnaires[56].

- **Maturity grids** include text descriptions for each activity at each maturity level. The typical behavior or position exhibited by a firm at several levels of maturity is described in a few phrases.
- **CMM-like models** have a more formal architecture, where the different process areas are arranged by common features which contain a number of key practices. There is a global description of every maturity level, however no individual descriptions for each activity at each maturity level.
- **Likert-like questionnaire** can be considered as a simple form of maturity model. The respondent of the questions scores the relative performance of the organization on a scale from 1 to n. If only the characteristics of the top level are described, the Likert-like questionnaire is equivalent to a maturity grid and if n=2, this form of instrument becomes a checklist[57].

[51] W. Pullen, 2007
[52] J. Oleskow-Szlapka et al. , 2018
[53] Uriarte et al. , 2017
[54] Dr. H. Schlingloff, 2013
[55] Becker et al. , 2009
[56] G. Lahrmann et al. , 2011
[57] P. Fraser et al. , 2002

Furthermore, maturity models can be descriptive, prescriptive or comparative in nature. The descriptive model captures the state-as-it-is and has no interest in improving the maturity or performance of a model. This model is best to determine the as-is situation. The prescriptive model offers road-maps for approaching maturity improvement by correlating the state-as-it-is with business performance. The main goal is to affect business value positively. Comparative models aim to compare the maturity of practices across an organization within a certain industry while detecting that similar levels of maturity do not translate directly to business performance. At a first glance, these three different model types can be seen as distinct, whereat they can actually be seen as an evolutionary phase of a model's lifecycle. During the introduction of a new maturity model, in a first phase, the model will be descriptive, to achieve a better understanding of the as-is domain situation. At a second stage, the model can then be emerged into being prescriptive, since only through a proper understanding of the current situation, considerable and repeatable improvements can be achieved. The final stage in the evolution of a maturity model will be a comparative phase. This is necessary to compare different organizations of a same domain. Accordingly, it must be applied in a wide range of organizations in order to attain sufficient data to enable valid comparison[58].

One last interesting term to cite is, *Process Maturity*. The concept of process maturity originates from Total-Quality-Management (TQM). Here, the application of statistical process control techniques showed that improving maturity of any technical and business process ideally leads to a reduction of variability inherent in the process, and thus an improvement in the mean performance of the process[59].

The following figure depicts the different stages of maturity models.

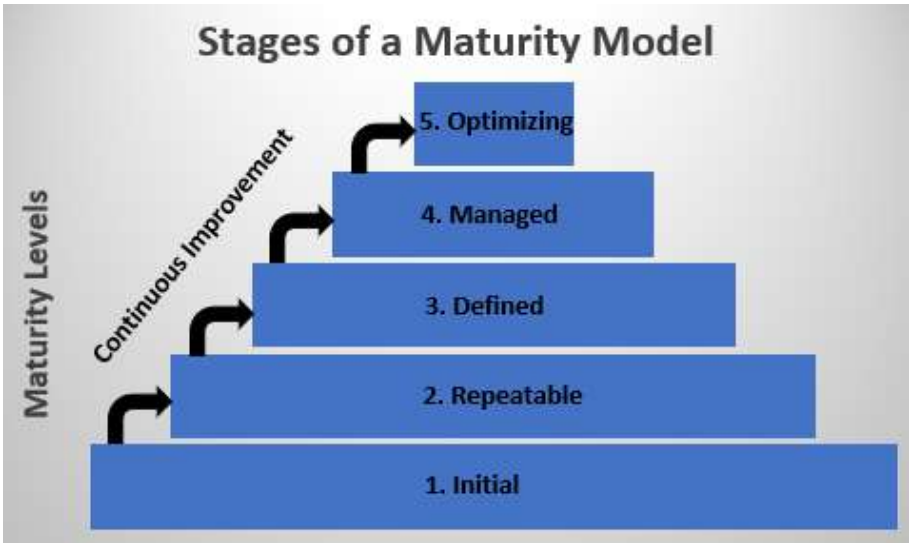


Figure 7: Representation of the structure of a Maturity Model

[58] De Bruin et al. , 2005
[59] Maier et al. , 2009

2.4.1 Capability Maturity Model (CMM)

The first precursor of the CMM was released in 1979 by Philip B. Crosby, named Quality Management Maturity Grid (QMMG)[60]. Later, in 1984, the US Defense Department formed the Software Engineering Institute at Carnegie Mellon University to establish standards of excellence for software engineering and to accelerate the transition of advanced technology and methods into practice. The goal was to characterize the capabilities of software development organizations. The result was the Capability Maturity Model (CMM), which was published in 1988 by Watts S. Humphrey. This is a framework which can be used by any software organization to rate its own capabilities and identify the most important areas for improvement[61].

The CMM defines software process maturity as: "*the extent to which a specific process is explicitly defined, managed, measured, controlled, and effective.*"[62] However, CMM takes a mildly different approach than the quality grid, by identifying a cumulative set of 'key process areas' (KPAs) which all needs to be enclosed to pass to the next maturity level. This representation is defined as 'staged' and conducts to the assignment of a single level for maturity in the range of 1 to 5[63]. The five stages are defined as: 'Initial', 'Repeatable', 'Defined', 'Managed' and 'Optimizing'.

The following figure shows the five levels of process maturity with the process evolution as defined by Humphrey.

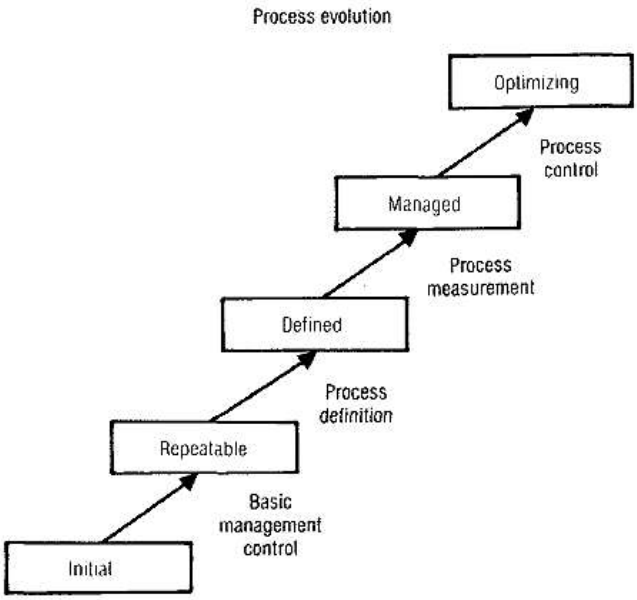


Figure 8: The five levels of process maturity[64]

[60] P. Fraser et al. , 2002
[61] W. S. Humphrey, 1988
[62] P. Fraser et al. , 2002, p. 1
[63] P. Fraser et al. , 2002
[64] (W. S. Humphrey, 1988, p. 74)

To have more diverse uses of the CMM, it must be decomposed in sufficient detail. The maturity level is the first part, from where the further decompositions start. A maturity level is a well-defined evolutionary plateau, towards achieving a mature software process. A maturity level indicates the process capabilities, which illustrate a range of expected results achieved by following the software process. Furthermore, a maturity level contains key process areas. They indicate where an organization should focus on and help to identify the issues that must be directed to achieve a certain maturity level. CMM only describes the process areas which are considered necessary for achieving a certain maturity level. This is implemented through the word 'key'. KPAs should achieve a set of goals. Goals sum up the key practices of a KPA. The scope, boundaries and intent of each KPA is indicated by the goals. They determine if an organization has effectively implemented the KPAs. The practices that characterize the KPAs are organized by common features. They are attributes that indicate whether the institutionalization and implementation of KPAs are effective, lasting and repeatable. There are five common features which are: ability to perform, activities performed, commitment to perform, measurement and analysis and verifying implementation. The common features contain key practices which describe the infrastructure and activities needed to effectively implement and institutionalize a KPA[65 66].

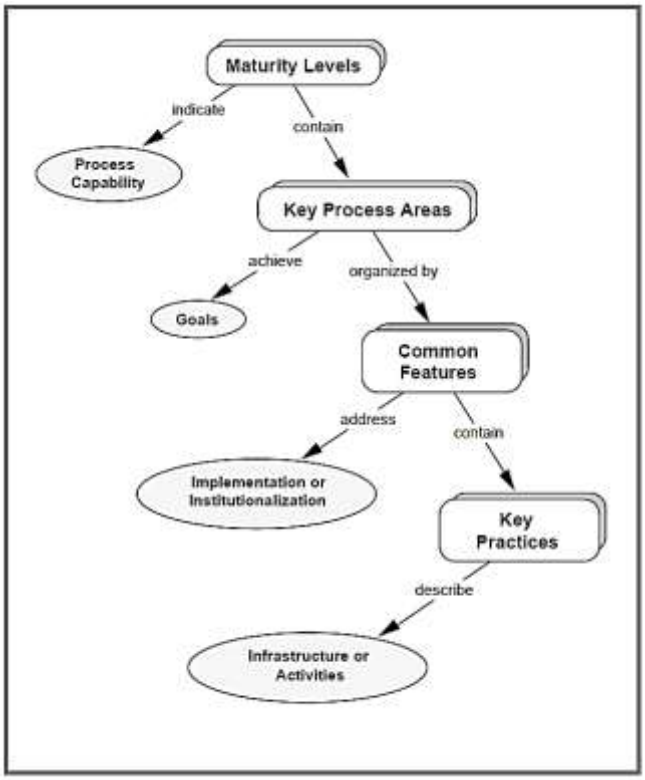


Figure 9: The Structure of CMM[67]

[65] M. C. Paulk et al. , 2000
[66] E. Biberoglu et al. 2002
[67] (M. C. Paulk et al. , 2000, p. 15)

To introduce an effective software process, some basic principles are important. The first is that the development process is under statistical control. If the process is under no statistical control, constant progress is not possible until statistical control is introduced. To have a statistical control, measurements are important. To be able to know something about what you speak, you need to be able to measure it and to express it in numbers. Furthermore, Humphrey indicated five steps which organizations need to follow to improve their software capabilities. Firstly, they need to understand the current status of their development process. Secondly, they need to develop a vision of the desired process. Thirdly, they need to improve a list of required process improvement actions in order of priority before producing a plan to accomplish these actions in a forth step. The final step is to commit the resources to execute the plan[68]. A more detailed description of the different Maturity Levels with their KPAs can be seen in Table 1.

Capability Maturity Model-CMM			
Level	*Maturity*	*Description (Humphrey, 1998)*	*Key Process Areas (M. C. Paulk et al, 2000)*
1	Initial	No regulated progress in process improvement is possible as long as the process is under no statistical control. The Initial Process is often chaotic and can be called ad hoc. At this stage, organizations normally operate without formalized procedures, cost estimates and project plans. If they have formal procedures for project control, there is management mechanism to ensure they	At level 1, no Key Process Areas exists.
2	Repeatable	A stable process is achieved by an organization through a repeatable level of statistical control by initiating rigorous project management of commitments, cost, schedule and changes. The Repeatable Process provides commitment control, thus organizations at this level face major risks when they are presented with new challenges.	Software configuration management, Software quality assurance, Software subcontract management, Software project tracking and oversight, Software project planning, Requirements management
3	Defined	The process is defined by an organization to ensure consistent implementation and provide a basis for a better understanding of the process. Moreover, advanced technology can be usefully introduced. At this level, an organization has achieved the foundation for major and continuing progress. However, the Defined Process is only qualitative, which means that there is little data to indicate what is going on or how effective the	Peer reviews, Intergroup coordination, Software product engineering, Integrated software management, Training program, Organization process definition, Organization process focus
4	Managed	At this level, the most significant quality improvements begin, due to comprehensive process measurements initiated by an organization. These goes beyond those of cost and schedule performance. The main potential problem with the Managed Process is the cost of gathering data and to maintain data.	Software quality management, Qualitative process management
5	Optimizing	A foundation for continued improvement and optimization of the process is included in an organization. The main difference at this level is that up to this point, the focus lied mainly on the products itself and only data that directly relates to product improvement has been gathered and analyzed. In the Optimizing Process, the data is available to adjust the process itself.	Process change management, Technology change management, Defect prevention

Table 2: Capability Maturity Model

[68] W. S. Humphrey, 1988

2.4.2 Capability Maturity Model Integration (CMMI)

The Capability Maturity Model Integration (CMMI) was officially introduced in 2002. This was caused by the capacious number of developed CMMs since 1991. Some of the most important models included software engineering, systems engineering, software acquisition etc. All these models have proven useful to many organizations in different industries; however the use of multiple models was problematic. The goal of many organizations was to span their improvement efforts over different groups within the organization. Nonetheless, the differences among the discipline-specific models were too huge, so that organizations had limited capabilities to broaden their improvements successfully[69].

To combine different CMMs into a single improvement framework, for the use of enterprise-wide process improvement, the CMMI was launched. In addition, to keep up with the increasingly and competing demand of software, many organizations have inherited the CMMI level instead of the simpler CMM level. CMMI offers the same as CMM, five maturity levels that can only be reached one after the other. The CMM has 18 KPAs compared to 23 KPAs for the CMMI, which will be elaborated afterwards[70].

The CMMI project was constructed to build an initial set of integrated models and to provide a structured view of process improvements across an organization. It helps with the development of products and services, since it consists of best practices that address development and maintenance activities that cover the product lifecycle from conception through delivery and maintenance. CMMI expresses process improvement experience and lesson learned from other industries and includes a wealth of processes and best practices for software engineering, system engineering and learning, unified in a single framework. CMMI has replaced CMM, which is no longer supported[71].

CMMI can be divided into a continuous representation and into a staged representation. Continuous CMMIs have six different capability levels, from 0 to 5, which are labelled as follow: Incomplete, Performed, Managed, Defined, Quantitatively Managed and Optimizing. Continuous CMMIs can be applied to an organization's process improvement achievement in individual KPAs[72]. Here, the levels are instruments for incrementally improving the processes corresponding to a given process area[73]. This allows an organization to improve different processes at different rates. It is meant to be used if you know the processes that need to be improved and understand the dependencies among the process areas described in

[69] Carnegie Mellon – Software Engineering Institute, 2006
[70] S. Mahmood, 2015
[71] S. Mahmood, 2015
[72] S. Mahmood, 2015
[73] Carnegie Mellon – Software Engineering Institute, 2006

CMMI[74]. The staged model has five maturity levels, the same as the CMM, which are labelled as followed: Initial, Repeatable, Defined, Managed and Optimizing. These different levels with their corresponding KPAs will be clarified in a later table. Staged CMMI are used to measure the maturity of an organization's software process and for evaluating its software process capability across multiple process areas[75]. These levels are instruments of predicting the general outcomes of the next project undertaken[76].

The following table summarizes the different names of the two representations.

Level	Description	Continuous	Staged
0	Not performed	Incomplete	/
1	Individual Learning	Performed	Initial
2	Project Learning	Managed	Repeatable
3	Organizational Learning	Defined	Defined
4	Quantitative Learning and Decision Making	Quantitatively Managed	Managed
5	Agile, Adaptive Learning	Optimizing	Optimizing

Table 3: Comparison between Continuous and Staged Representation

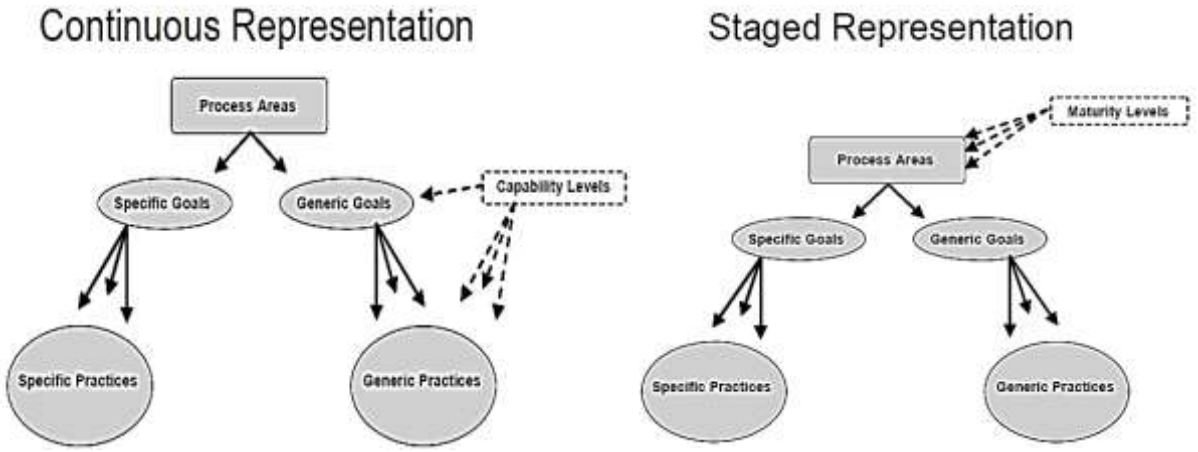


Figure 10: Continuous Representation & Staged Representation[77]

The differences between the continuous and staged representation are slight but significant. The continuous representation uses capability levels to characterize the state of the organization's processes relatively to an individual process area, whereas the staged representation uses maturity levels to characterize the overall state of the organization's process relative to the model as a whole[78].

In a next step, first the different capabilities levels of the continuous representation will be elaborated in detail, before the different maturity levels of the staged representation will be listed precisely.

[74] Carnegie Mellon – Software Engineering Institute, 2006
[75] S. Mahmood, 2015
[76] Carnegie Mellon – Software Engineering Institute, 2006
[77] (Carnegie Mellon – Software Engineering Institute, 2006, p. 30)
[78] E. Weigl, 2010

Continuous Representation:

A capability level consists of a generic goal and its generic practices, which can improve the organization's processes related to that process area.

Level	**Description (Carnegie Mellon - Software Engineering Institute, 2006)**
Level 0 - Incomplete	An 'incomplete process' is not performed or partially performed. Specific goals of the process area are not complied, and no generic goals exist.
Level 1 - Performed	A 'performed process' is a process which complies the specific goals of the process area and enables the work needed to produce work products. Despite that capability level 1 result in important improvements, no institutionalization is performed and hence all those improvements can be lost over time. The application of institutionalization helps to ensure that improvements are maintained.
Level 2 - Managed	A 'managed process' is a performed process that has the basic infrastructure in place to support the process. It is planned and executed in accordance with policy, is monitored, controlled, and reviewed. It ensures that existing practices are retained during time of stress. However, the standards may be quite different in each specific instance of the process.
Level 3 – Defined	A 'defined process' is a managed process, that is tailored from the organization's set of standard processes according to the organization's tailoring guidelines, and contributes work products, measures, and other process improvement information to the organizational process assets. The critical distinction between level 2 and 3 is the scope of standards, process description, and procedures. At level 3, the standards, process descriptions, and procedures for a project are tailored from the organization's set of standard processes to suit a particular project or organizational unit and are therefore more consistent.
Level 4 – Quantitatively Managed	A 'quantitatively managed process' is a defined process, that is controlled using statistical and other quantitative techniques. Quantitative objectives for quality and process performance are established and used as criteria in managing the process.
Level 5 - Optimizing	An 'optimizing process' is a quantitatively managed process that is improved based on an understanding of the common causes of variation inherent the in the process. The focus lies on continuous improvement in the range of process performance through both incremental and innovative improvements.

Table 4: Level description of the continuous representation

Staged Representation:

A maturity level consists of related specific and generic practices for a predefined set of process areas that improve the organization's overall performance.

Capability Maturity Model Integration – CMMI (Staged Representation)		
Level	**Description (Carnegie Mellon – Software Engineering Institue, 2006)**	**Key Process Areas (S. Mahmood, 2015)**
Level 1 – Initial	Processes at maturity level 1 are usually ad hoc and chaotic. There is no stable environment provided by the organization to support the processes. The success within an organization depends on the competences of the people in the organization and not on the use of proven processes. Organizations with maturity level 1 often produce products and services that work, but they often do not meet their schedules and exceed their budgets. They are symbolized by a tendency to over commit, abandonment of processes in a time of crises and the inability to repeat their successes.	At level 1, no KPAs exist.
Level 2 – Repeatable	The processes of an organization at maturity level 2 have assured that processes are planned and executed in accordance with policy, the projects employ skilled people who have adequate resources to produce controlled outputs and furthermore, projects are monitored, controlled and reviewed. At maturity level 2, it is important, that existing practices are retained during times of stress. If these practices are in place, projects are performed and managed according to their documented plans. At maturity level 2, it is possible for the management to view the status of work products and the delivery of services at defined points.	Requirements Management, Project Planning, Project Monitoring and Control, Supplier Agreement Management, Measurement and Analysis, Process and Product Quality Assurance, Configuration Management
Level 3 – Defined	Processes at maturity level 3 are well characterized and understood and are described in standards, procedures, tools and methods. The organization's set of standard processes is established and improved over time. These standard processes are used to establish durability across the organization. Projects establish their defined processes by adapting the organization's set of standard processes according to conforming guidelines. At maturity level 3, the organization must ripen further the maturity level 2 process areas and address generic practices which were not addressed at maturity level 2. Processes are typically qualitatively predictable.	Requirements Development, Technical Solution, Product Integration, Verification, Validation, Organizational Process Focus, Organizational Process Definition, Organizational Training, Integrated Project Management, Risk Management, Decision Analysis and Resolution, Integrated Teaming, Organization Environment for Integration, Integrated Supplier Management
Level 4 – Managed	At maturity level 4, the organization and projects establish quantitative objectives for process and quality performance and use them as criteria in managing processes. Quantitative objectives are based on different key aspects, like the needs of the customer, the end users, the process implementers and the organization. Quality and process performance is understood in statistical terms and is managed throughout the life of the processes. An important improvement at maturity level 4 is the predictability of process performance. The performance of processes is controlled using statistical and other quantitative techniques and is quantitatively predictable. The organization is concerned with addressing special causes of process variation and providing statistical predictability of the results.	Organizational Process Performance, Quantitative Project Management
Level 5 – Optimizing	At the final maturity level, an organization continually ameliorates its processes based on a quantitative understanding of the common causes of variation inherent in processes. The main focus lies on a continual improvement of process performance through incremental and innovative process and technological improvements. Quantitative process improvement objectives for the organization are established, continually revised to reflect changing business objectives and used as a criterion in managing process improvement. At maturity level 5, the organization is anxious with addressing common causes of process variation and changing the process to improve process performance and to achieve the established quantitative process improvement objectives.	Organizational Innovation and Deployment, Causal Analysis and Resolution

Table 5: Level Description of the staged representation

2.4.3 Structure of the CMMI - Continuous Representation

A first important aspect which needs to be clarified is, that the later model shows what to do, however not how to do it or who does it. The model indicates which goals need to be fulfilled to reach a certain level but doesn't indicate how to implement those goals. This is an important point, which needed to be clarified.

The continuous representation provides a maximum of flexibility for focusing on specific process areas according to business goals and objectives. The figure below shows the structure of the CMMI for the continuous representation. This figure shows clearly the difference between generic goals and practices on the vertical axis, which correspond to a certain capability level and specific goals and practices on the horizontal axis, which correspond to a certain process area[79]. Generic goals and practices are hence required to reach a certain capability level and are consecutive, which means that it is not possible to reach level three without fulfilling all the required generic goals of level two. The same generic goal statement applies to multiple process areas. Specific goals and practices are dependent to a certain process area and address the unique characteristics which describe what must be implemented to satisfy a certain process area. For this reason, specific goals and practices will hence be elaborated later within this thesis.

The following figure visualizes the continuous representation.

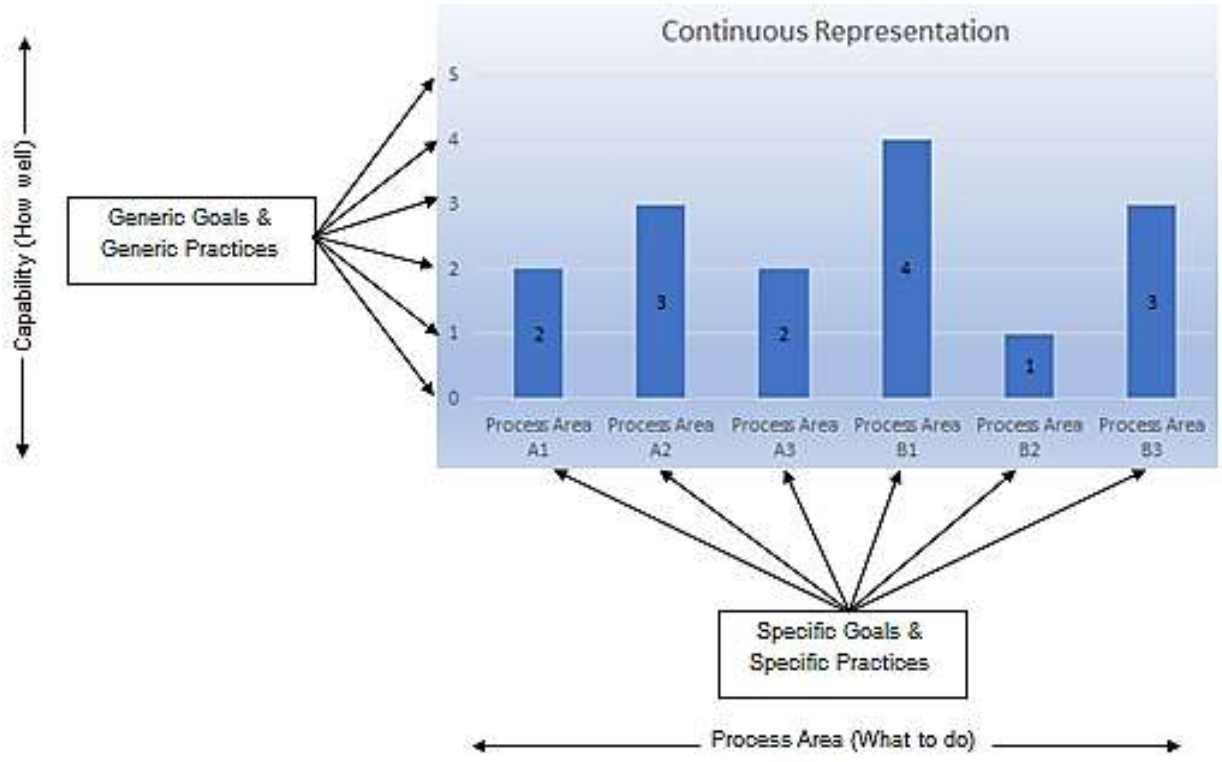


Figure 11: Structure of the CMMI Continuous Representation

[79] T. Rout et al. , 2005

One of the reasons to use generic goals and practices from the CMMI is to establish consistency and compatibility with the international standard for process assessment[80]. For this purpose, the generic goals and practices are summarized in the following table[81] and elaborated in detail afterwards. GG stands for generic goal and GP means generic practice. Every capability level consists out of one generic goal and several generic practices.

GG 1	**Achieve Specific Goals**
GP 1.1	Perform Specific Practices
GG 2	**Institutionalize a Managed Process**
GP 2.1	Establish an Organizational Policy
GP 2.2	Plan the Process
GP 2.3	Provide Resources
GP 2.4	Assign Responsibility
GP 2.5	Train People
GP 2.6	Manage Configurations
GP 2.7	Identify and Involve Relevant Stakeholders
GP 2.8	Monitor and Control the Process
GP 2.9	Objectively Evaluate Adherence
GP 2.10	Review Status with Higher Level Management
GG 3	**Institutionalize a Defined Process**
GP 3.1	Establish a Defined Process
GP 3.2	Collect Improvement Information
GG 4	**Institutionalize a Quantitatively Managed Process**
GP 4.1	Establish Quantitative Objectives for the Process
GP 4.2	Stabilize Subprocess Performance
GG 5	**Institutionalize an Optimizing Process**
GP 5.1	Ensure Continuous Process Improvement
GP 5.2	Correct Root Causes of Problems

Table 6: Generic Goals and Generic Practices

Before elaborating the different generic goals and practices, the word ‘institutionalization’ will be clarified. Institutionalization is an important concept in process improvement. Whenever used within the description of the generic goals and practices, it implies that the process is ingrained in a way that the work is performed and there is commitment and consistency to perform the process. An institutionalized process is more likely to be retained during times of stress[82].

The generic goals and practices are elaborated in detail in the following section.

[80] T. Rout, A. Tuffley, 2005
[81] Carnegie Mellon, 2006
[82] Carnegie Mellon, 2006

GG 1: Achieve Specific Goals

The achievement of specific goals of the process area implies the process of transforming identifiable input work products to produce identifiable output work products.

GP 1.1: Perform Specific Practices

The performance of specific practices of the process area is to develop work products and provide services to achieve the specific goals of the process area. The purpose of the first generic practice is to produce the work products and deliver the services that are expected to perform the process. However, these practices may be done informally, without following a plan or documented process description. The accuracy of these practices depends mainly on the individual managing and performing skills of the worker and hence may vary considerably.

GG 2: Institutionalize a Managed Process

The process is institutionalized as a managed process.

GP 2.1: Establish an Organizational Policy

The aim of an organizational policy is to establish and maintain a guideline for planning and performing the process. This means that organizational expectations for the process are defined and visible for those in the organization who are affected. What is important is that appropriate organizational directions are available. Normally, the senior management is responsible for establishing and communicating these guiding principles.

GP 2.2: Plan the Process

The aim of planning the process is to establish and maintain the actual plan to perform the process. This means to determine what is needed to perform the process. This implies to achieve established objectives, to prepare a plan for performing the process, to prepare a process description, and to get agreement on the plan from relevant stakeholders.

For this generic practice, it has to be mentioned, that the practical implications of applying a generic practice vary for each process area. E.G. for project monitoring, this generic practice sets as expectation that a plan exists to plan the project monitoring itself. For the process area of project planning, this generic practice implies that the planning process itself is planned. Therefore, this generic practice may either reinforce expectations set elsewhere or set new expectations that should be addressed.

Sub-practices of this generic practice are:

1. Define and document the plan for performing the process.
2. Define and document the process description.
3. Review the plan with relevant stakeholders and get their agreement.
4. Revise the plan as necessary.

GP 2.3: Provide Resources

The aim of this generic practice is to provide adequate resources for performing the process, developing the work products, and providing the services of the process. This ensures that the needed resources to perform the process, which were defined by the plan, are actually available. The resources include an adequate funding, appropriate physical facilities, skilled people, and appropriate tools.

GP 2.4: Assign responsibility

The aim of this generic practice is to assign responsibility and authority to perform the process, develop the work products, and provide the service of the process. This means that accountability of the process is assigned to the responsible people and that they have the needed authority to perform the assigned responsibilities. This can be done through detailed job description or within living documents. Another way is dynamic assignment of responsibility, where the assignment and acceptance of responsibility are ensured throughout the life of the process.

Sub-practices of this generic practice are:

1. Assign overall responsibility and authority for performing the process.
2. Assign responsibility and authority for performing the specific task of the process.
3. Confirm that the people assigned to the responsibilities and authorities understand and accept them.

GP 2.5: Train People

The aim of this generic practice is, to train all the people who perform or support the process as much as needed. This implies that the responsible people have all the necessary skills and expertise to perform or support the process. Training supports the successful performance of the process by establishing a common understanding of the process and by imparting the skills and knowledge needed to perform the process

GP 2.6: Manage Configurations

The aim of this generic practice is to place designated work products of the process under appropriate levels of control. This implies to establish and maintain the integrity of the designated work products of the process throughout their useful life. The designated work products are specifically identified in the plan for performing the process, the same as with a specification of the appropriate level of control. Different levels of control are appropriate for different work products and different points in time.

GP 2.7: Identify and Involve Relevant Stakeholders

The aim of this generic practice is to identify and involve the relevant stakeholders of the process as planned. This means to establish and maintain the expected involvement of stakeholders during the execution of the process. They can be involved in activities such as: Planning, Decisions, Commitments, Communications, Coordination, Reviews, Appraisals, Requirements definitions, Resolution of problems/ issues. It ensures that interactions necessary to the process are accomplished, while not allowing excessive numbers of affected groups and individuals to hamper the process execution.

Sub-practices of this generic practice are:

1. Identify stakeholders relevant to this process and their appropriate involvement.
2. Share these identifications with the project planners or other planners as appropriate.
3. Involve relevant stakeholders as planned.

GP 2.8: Monitor and Control the Process

The aim of this generic practice is to monitor and control the process against the plan for performing the process and take appropriate corrective action. This means to perform a direct day-to-day monitoring and controlling of the process. It maintains appropriate visibility into the process and hence corrective actions can be taken if necessary. Furthermore, it implies measuring appropriate attributes of the process.

Sub-practices of this generic practice are:

1. Measure actual performance against the plan for performing the process.
2. Review accomplishments and results of the process against the plan for performing the process.
3. Review activities, results, and status of the process with the direct level of management responsible for the process and identified issues. This provides appropriate visibility into the process.

4. Identify and evaluate the effects of significant deviations from the plan for performing the process.
5. Identify problems in the plan for performing the process and in the execution of the process.
6. Take corrective action when requirements and objectives are not satisfied, when issues are identified, or when progress differs significantly from the plan for performing the process.

   Corrective action can include:

   - Taking remedial action to repair defective work products or services
   - Changing the plan for performing the process
   - Adjusting resources, including people, tools, and other resources
   - Negotiating changes to the established commitments
   - Securing change to the requirements and objectives that must be satisfied
   - Terminating the effort

7. Track corrective action to closure.

GP 2.9: Objectively Evaluate Adherence

The aim of this generic practice is to objectively evaluate adherence of the process against its process description, standards, and procedures, and address noncompliance. This means to supply credible assurance that the process is implemented as planned and adheres to its process description, standards, and procedures. Adherence is typically evaluated by people within the organization, however external to the process.

GP 2.10: Review Status with Higher Level Management

The aim of this generic practice is to review the activities, status, and results of the process with higher level management and resolve issues. This means, that appropriate visibility into the process needs to be furnished to the higher-level management. Here, higher level management comprises those levels of management in the organization above the immediate level of management responsible for the process. These reviews are for managers who provide the policy and overall guidance for the process, and not for those who perform the direct day-to-day monitoring and controlling of the process. Different managers have different needs for information about the process.

GG 3: Institutionalize a Defined Process

The process is institutionalized as a defined process.

GP 3.1: Establish a defined Process

The aim of this generic practice is to establish and maintain the description of a defined process. This means that a description of the process that is tailored from the organization's set of standard processes to address the needs of a specific instantiation is established and maintained. An organization should have standard processes that cover the process area, as well as have guidelines for tailoring these standard processes to meet the needs of a project or organizational function. While introducing a defined process helps to reduce variability in how a process is performed across an organization and hence process assets, data, and learning can be effectively shared.

Sub-practices of this generic practice are:

1. Select from the organization's set of standard processes those processes that cover the process area and best meet the needs of the project or organizational function.
2. Establish the defined processes by tailoring the selected processes according to the organization's tailoring guidelines.
3. Ensure that the organization's process objectives are appropriately addressed in the defined process.
4. Document the defined process and the records of the tailoring.
5. Revise the description of the defined process as necessary.

GP 3.2: Collect Improvement Information

The aim of this generic practice is to collect work products, measures, measurement results, and improvement information derived from planning and performing the process to support the future use and improvement of the organization's processes and process assets. This generic practice is performed so that the information and artifacts can be included in the organizational process assets and made available for those who are planning and performing the same or similar processes. All of this information is saved in the organization's measurement repository and the organization's process asset library.

Sub-practices of this generic practice are:

1. Store process and product measures in the organization's measurement repository.
2. Submit documentation for inclusion in the organization's process asset library.
3. Document lessons learned from the process for inclusion in the organization's process asset library.
4. Propose improvements to the organizational process assets.

GG 4: Institutionalize a Quantitatively Managed Process

The process is institutionalized as a quantitatively managed process.

GP 4.1: Establish Quantitative Objectives for the Process

The aim of this generic practice is to establish and maintain quantitative objectives for the process, which address quality and process performance, based on customer needs and business objectives. It is important to determine and obtain agreement from the relevant stakeholders about specific quantitative objectives for the process. They can be expressed in terms of product quality, service quality, and process performance. These quantitative objectives are criteria which are used to judge whether the products, services, and process performance will satisfy the customers, end users, organizational management, and process implementers.

Sub-practices of this generic practice are:

1. Establish the quantitative objectives that pertain to the process.
2. Allocate the quantitative objectives to the process or its subprocesses.

GP 4.2: Stabilize Subprocess Performance

The aim of this generic practice is to stabilize the performance of one or more subprocesses to determine the ability of the process to achieve the established quantitative quality and process-performance objectives. These are mainly critical subprocesses for the overall performance, using appropriate statistical and other quantitative techniques. These support predicting the ability of the process to achieve the established quantitative quality and process-performance objectives. Stable subprocesses show no significant indications of special causes of process variation and are predictable within the limits established by the natural bounds of the subprocesses. Predicting the ability of the process to achieve the established quantitative objectives requires a quantitative understanding of the contributions of the subprocesses that are critical to achieving these objectives.

Sub-practices of this generic practice are:

1. Statistically manage the performance of one or more subprocesses that are critical contributors to the overall performance of the process.
2. Predict the ability of the process to achieve its established quantitative objectives considering the performance of the statistically managed subprocesses.
3. Incorporate selected process-performance measurements into the organization's process-performance baselines.

GG 5: Institutionalize an Optimizing Process

The process is institutionalized as an optimizing process.

GP 5.1: Ensure Continuous Process Improvement

The aim of this generic practice is to ensure continuous improvement of the process in fulfilling the relevant business objectives of the organization. This means to select and systematically deploy process and technology improvements that contribute to meeting established quality and process-performance objectives. Depending on the participation of an empowered workforce connected to the business values and objectives of an organization, processes that are agile and innovative will be optimized. The organization's ability to rapidly respond to changes and opportunities is enhanced by finding ways to accelerate and share learning.

Sub-practices of this generic practice are:

1. Establish and maintain quantitative process improvement objectives that support the organization's business objectives.
2. Identify process improvements that would result in measurable improvements to process performance.
3. Define strategies and manage deployment of selected process improvements based on the quantified expected benefits, the estimated costs and impacts, and the measured change to process performance.

GP 5.2: Correct Root Causes of Problems

The aim of the last generic practice is to identify and correct the root causes of defects and other problems in the process, which were encountered in a quantitatively managed process. This corrects the root causes of these types of defects and problems and hence prevents these defects and problems from occurring in the future.

As reference literature, the 'CMMI for Development, Version 1.2' from the Carnegie Mellon-Software Engineering Institute (2006) was used.

2.4.4 Examples of staged maturity models

The following two staged representations are elucidated, since the later continuous representation will be a maturity model for process-audits. So, some parts from the first example, the audit maturity model and some parts from the second example, the industrial process maturity model will be included.

Audit Maturity Model (AMM)[83]

In today's world, it gets more and more important for organizations to improve their quality management. To prevent delivery outages and to achieve business excellence, quality management functions and its processes need to be made more mature, through reviews and auditing capability. The Audit Maturity Model (AMM) will provide organizations with a tool to measure their maturity in quality management in the perspective of process auditing, along with recommendations for preventing delivery outage and identifying risks to achieve business excellence. Herewith, organizations can reach higher maturity levels and identify their gaps easily. AMM envisages a new auditing model, which represents a guide for an organization to achieve higher maturity levels and therewith a better quality. The new maturity model should however focus on the audits of production processes.

For any world class organization, quality compliance to its standard software process is considered as a basic hygiene factor. ISO[84] and CMMI[85] are official certifications for this which each business unit must ensure. In today's business scenario, traditional compliance related aspects don't suffice anymore, but must be elevated towards more value-added services to justify its presence to meet business objectives. The audit function needs to be more matured to prevent delivery outage and to achieve business excellence to survive and prove oneself best in class in today's industry. By strengthening process maturity and quality of data, the prevention of delivery outage can be achieved through proactive identification of the risks associated with delivery management, product quality and process adherence.

The different maturity levels will be illustrated in the following section. The bottom level is called *Initial*, similar than in the CMM. For organizations at this level, audit activities are informal, chaotic and ad hoc. Audits are carried out mainly on reactive basis to understand and correct critical project issues. However, the main problem is that the success of the audits mainly depends on the skill of the people conducting the audits. Supplementary, there is no Software Quality Assurance (SQA) group defined to assess the audit process and there is no formal auditing team to meet the basic objective. The second level is called *Managed*. Here, localized standards of

[83] B. Uttam et al. , 2013
[84] Levine D. et al. , 2010
[85] Carnegie Mellon, 2006

audits have been recognized, best practices different audits are identified, and a software quality assurance group is formed to make it more manageable. The audits at this level are much more disciplined and meet all basic needs for setting up a standard process. With the help of the existing SQA team, the objective of the audits is to ensure verbatim compliance to meet all basic hygiene. This type of audit can be called 'Disciplined Audit' and are carried out by the members of the SQA team. The third level is called *Compliant* and the audit activities at this level are completely standardized and consistent. The audits are more conform/compliant to many international standards and the audit function now focuses on process maturity through repeatable results and increasing scope of audits. The auditing activities are now formal by establishing sets of well-defined and documented standard processes. The main objective of the audits at this level is to ensure process maturity and the audits itself are carried out by experienced members of the SQA team. The forth level is called *Matured* and the focus of the audits shifts to proactive risk identification to ensure product quality and maturity. To prevent delivery outage at this level, it is important to have a delivery management with a stable product quality and process adherences. The audits are carried out by senior members of the SQA team along with seasoned project and delivery managers. The top level is called *Optimizing* and there is a paradigm shift. Here, the audits focus on business excellence rather than process maturity or delivery maturity. The main objective at this level is the acescent of business risks in finance, customer relations, employee, infrastructure and security. The audits at this level are carried out by senior management team members.

The evaluation of the maturity audit activities is an examination of different goals defined at different levels by a trained team using Audit Maturity Model framework as a basis for determining strengths and weaknesses of an organization. This will help to determine gaps at different levels in the framework. Weaknesses can be analyzed, and it is possible to implement proper action items to close the gaps and therewith achieve a higher maturity level.

The use of the AMM has many benefits. While using a maturity model, a ratting assessment of quality assurance function in the perspective of auditing capability will be available. Furthermore, after reaching the second maturity level, basic hygiene factors like ISO and CMMI are achieved. AMM helps to describe and find the strengths and weaknesses of an organization. An evaluation database in quality assurance area can be used to monitor the quality assurance process improvement progress and to support future appraisals. And finally, a proactive risk identification and mitigation for all projects of the organization in delivery management, process, product and business area is available.

However, the implementation of an AMM framework will also include some challenges. The input from higher management, which is required for conducting level 5 audits, will be a key challenge as they need to understand the maturity assessment value addition. Another challenge will be to identify each aspect of the audit checklist for each level. And a last challenge will be the identified findings or risks, which need to be synchronized to meet future business objectives.

The following table should resume the different maturity levels.

Audit Maturity Model (AMM)		
Level	**Description (Bhattacharya Uttam et al., 2013)**	**Key Process Areas ()**
Level 1 - Initial	At the *Initial* maturity level, no Software Quality Assurance (SQA) group exists, the audits are informal, ad hoc & chaotic. To reach the next maturity level, audits need to get disciplined.	At level 1, no KPAs exist.
Level 2 - Managed	At the *Managed* maturity level, a Software Quality Assurance (SQA) group exists and the objective of the audits is to ensure compliance. Here, focusing on process maturity and data quality through desktop audits is necessary. To reach the next maturity level, audits need to get standardized and consistent.	desktop audit
Level 3 - Compliant	At the *Compliant* maturity level, formal audits exist, and the objective is to ensure process maturity by focusing on the quality of deliverables by identifying risks of product quality. To reach the next level, audits need to get proactive risk focused.	process, work product & delivery audits
Level 4 - Matured	At the *Matured* maturity level, the objective is to ensure product quality and maturity by identifying proactive risks of delivery management to prevent delivery outage. To reach the final level, audits need to get business focused.	execution maturity audit
Level 5 - Optimizing	At the final maturity level, the *Optimizing* level, the objective is to enable business excellence. The final level reinforces client expectations by identifying and mitigating business risks in the area of finance, customer relations, employee, infrastructure and security.	engagement maturity model

Table 7: Audit Maturity Model (AMM)

Since there is an absence of significant prior experience in the field of AMM and nearly all the information is from one resource, the literature review is only considered sufficient in providing a theoretical starting point and other means of identification are necessary[86].

These so called 'other means' may be interviewing a panel of experts to detect process areas. To have a departure to define the KPAs, understanding and recognizing organizational process goals can be an effective tool. A possible procedure could be the following: first, define associated goals, which are considered necessary to achieve the organization's overall objective and then, from these goals, the KPAs can be derived[87].

[86] A. Maier et al. , 2009
[87] A. Maier et al. , 2009

Industrial Process Maturity Model (IPMM)

Since the traditional Total Quality Management doesn't provide any explicit tools to simplify production and operations process improvement initiatives, organizations must consider other models as tools to guide through which evolutionary industrial process improvements are possible. Here, the Industrial Process Maturity Model (IPMM) can be of avail. The IPMM provides a framework that supports processes from their inception, maturation, evaluation and implementation[88]. The framework of the IPMM can be derived from the traditional CMM architecture. The basic framework of the CMM and the developed IPMM exhibit a lot of similarities the same as some differences. The different maturity levels of the IPMM correlate with the maturity levels of the traditional CMM. However, within the different levels, it exits major differences. The specifications of the tenets and attributes for every level differ, the same as for the KPAs[89]. CMM suffers shortcomings when applied to organizational functions which are not directly linked with software development. Therefore, within CMM doesn't exist KPA requirements which can be directly addressed to unrelated issues[90]. IPMM is a tool, which helps production and operations managers to gild process improvement initiatives using a standardized framework that adds KPA tenets discretely attuned to the needs of industrial environments. Moreover, IPMM not only accomplishes the requirements of continuous improvement of the TQM, but also contributes the necessary framework for addressing process-related concerns from a maturation and evolutionary perspective[91].

Since IPMM has its roots in maturity models, the IPMM implements a unique perspective of process improvement based on process maturity and evolution, instead of only supporting improvement initiatives from a quantitative aspect of efficiency and effectiveness. Furthermore, IPMM can be a tool through which operations and production managers could execute benchmarking tests to incite greater process efficiency while not compromising process effectiveness. Another positive effect is, that IPMM can support streamlining activities included within industrial environments, the same as recommend process evolution and maturity. Processes evolve and get optimized through the stages and wasteful process activities are eliminated. The proposed IPMM includes feedback and piloting tenets through which measurements of customer satisfaction and pursuit of corporate objectives may be expressed quantitatively. Additionally, operations and production managers could address legislative issues and ISO initiatives through IPMM within industrial environment and could influence the outcomes of related process via

[88] D. Adrian Doss et al. , 2006, 2
[89] D. Adrian Doss et al. , 2006, 1
[90] D. Adrian Doss et al. , 2006, 4
[91] D. Adrian Doss et al. , 2006, 2

process maturation and evolution. This will play a major role for the latter link with the Audit Maturity Model[92].

A few examples of common features of IPMM and KPAs of the PS-Organization should be elucidated in the following section[93]. A first example area is the 'commitment to perform'. This area is described by Soganich[94] as followed: "*actions the organization must take to ensure that the process is established and will endure. Involves establishing organizational policies and leadership*". The second example is the 'ability to perform': The prerequisites necessary to implement industrial management processes competently. Involves "*resources, organizational structures, and training*"[95]. The third example are the 'activities performed': "*activities, roles, and procedures necessary to implement a KPA*" and "*establishing plans and procedures, performing work, tracking it, and taking corrective actions*"[96]. The final example is the 'measurement/ analysis': "*practices that are necessary to determine status related to the process*"[97].

The following table illustrates the different maturity levels of the IPMM, which could be found in the literature. Since most of the information is from the same resource and no other literature was available, this resource was stated as insufficient.

Industrial Process Maturity Model (IPMM)		
Level	**Description (D. Adrian Doss et al., 2006, 185-190)**	**Key Process Areas ()**
Level 1 - Initial	Industrial management process may be informal; undefined; and unstructured.	currently, no literature concerning the KPAs was found
Level 2 - Repeatable	Basic industrial management processes are settled to track cost, schedule and functionality. The necessary process discipline is in place to repeat earlier industrial management success with similar functions.	
Level 3 - Defined	Industrial management processes activities are documented, standardized, and intergrated into a standard process for the organization. Industrial management initiatives use an approved, tailored version of the organization's standard industrial management process for developing, implementing and maintaining industrial activities.	
Level 4 - Managed	Detailed measures of industrial management processes are collected. Industrial management processes and activities are quantitatively understood and controlled.	
Level 5 - Optimizing	Industrial management process improvement is enabled by quantitative feedback from processes and from piloting innovative ideas and technologies.	

Table 8: Industrial Process Maturity Model (IPMM)

[92] D. Adrian Doss et al. , 2006, 2
[93] D. Adrian Doss et al. , 2006, 4
[94] M. Soganich, 1994
[95] M. Soganich, 1994
[96] M. Soganich, 1994
[97] M. Soganich, 1994

2.5 World-Class (WC) and Best-Practice (BP)

A main aim of the PS-Organization is to achieve World-Class-Manufacturing (WCM). WCM is a management concept, which can be understood as a production on a global level. It means that the highest achievable level of organization and management are performed at a company. The basics are:

- Reduce wastage and losses
- Improve the standards and methods
- Involve all employees in the process of continuous improvement

Since no process is perfect and it is always place for improvement, WCM is based on the principles of Kaizen (continuous improvement), Total Quality Management and Lean Manufacturing[98]. WCM is composed out of ten pillars and one of them is 'Quality Control', which is important for this work.

To include WCM in the branch of 'Quality Control', the ideas of it should be considered within the new maturity model for process-audits. To have a better overview, two brief definitions of World-Class and Best-Practice will be given.

As a definition for World-Class, the following explication from the BusinessDictionary was found as most suitable: "*Goods, services, and processes that are ranked by customers and industry-experts to be among the best of the best. This designation denotes standard-setting excellence in terms of design, performance, quality, and customer satisfaction and value when compared with all similar items from anywhere in the world.*"[99]

As a definition for Best-Practice, a definition from Techopedia was identified as convenient: "*A best practice is an industry-wide agreement that standardizes the most efficient and effective way to accomplish a desired outcome. A best practice generally consists of a technique, method, or process. The concept implies that if an organization follows best practices, a delivered outcome with minimal problems or complications will be ensured. Best practices are often used for benchmarking and represent an outcome of repeated and contextual user actions.*"[100]

To be able to stay always up-to-date, the new maturity model needs to be updated continuously and be compared to World-Class and Best-Practice available at the market. The last level, Optimizing, will be equal to operate at world-class.

[98] Lyp-Wronska K., 2016
[99] http://www.businessdictionary.com/definition/world-class.html
[100] https://www.techopedia.com/definition/14269/best-practice

2.6 Layered Process Audits (LPA)

The surest way to identify and measure process variation is to examine whether standard processes and work instructions are being followed consistently regardless of the operator or the shift. Unlike product inspections, process verification examines resources (equipment, materials and people), the environment, the process itself and the methods followed by the operator. LPA represents a significant enhancement to typical process-audits. Instead of relying on a single auditor or audit team, LPAs require the involvement of multiple levels, here called layers, normally from level 1 to level 3[101]. In this case, level 1 represents the worker-level, where the audit is executed by a so called 'Quality Inspector' and should be performed several times per week. Level 2 is one layer higher in the structure of an organization. LPAs at level 2 are carried out by engineers of the concerning areas, once or twice per week, and always by different ones. Level 3 represents, in this scenario the final level, so the top-management, like the plant manager and should be performed once per month. LPAs are one way to involve the top leadership in verifying that the system they assume are in place and are effective. Another positive feature for the higher layers is, that the responsible engineers, the same as the management know that the processes are running correctly because they were able to personally verify them[102]. LPAs can include only pass/fail or Likert-scale questions[103].

Some of the quality norms of the automotive suppliers, like e. g. IATF 16949 even require the implementation of an LPA[104]. An LPA is nothing more, than an ongoing chain of simple verification checks. It is a disciplined way to verify that work is done the way it was intended. Only the most needed areas are included, like safety and quality of the processes and should be mainly performed on conditions that vary daily. Since LPAs are performed by different layers, it is necessary, that every question includes a short description of the specific requirement, in order to support people who are unfamiliar with a certain process[105]. LPAs should be kept relatively short with 10 to 15 questions and focus where they will be most effective[106].

Summarizing, it can be said, that LPAs are a quality technique that focuses on observing and validating how products are made, rather than inspecting finished products, and involves different layers in doing so. LPAs make sure, that audits and quality in general are taken seriously and will no longer be only a concern of the quality department, but to the whole organization.

[101] EASE, 2017
[102] Murray et al., 2007
[103] EASE, 2017
[104] IATF 16949, 2017
[105] Murray et al., 2007
[106] Automotive Industry Action Group, 2005

3 Systematic Literature Review – Process-audit procedure

The importance of literature in scientific works can be illustrated by the transition from ‘existing knowledge’ towards the ‘production of new knowledge’. In between are the activities of reading, learning and reflection. There are two different approaches for the usage of literature. The first is reviewing literature as a self-educative reason and the second one is the literature review, which informs an audience of what is happening in a certain field[107]. However, in the frame of this work, the systematic literature review will not only be used for scientific reasons, but also as an instrument which allows the PS-Organization to stay always on the newest state of knowledge.

Literature review is a process of collecting, checking and (re)analyzing data from existing literature with a particular search question in mind. It can have various purposes in science, like 1) defining a specific issue, concept, phenomena, 2) gathering published literature on a topic, 3) summarizing critical points of current knowledge about a specific topic/ problem and 4) unveiling a research gap[108].

A systematic literature review is a more structured process of collecting and selecting data and material for the review. The systematic literature review is an optional solution for controlling the incomplete and possibly unbalanced reports of traditional reviews. If a proper and well-structured construct for a systematic literature research is build, a continuous up-to-date procedure is easily applicable. This ensures that the selection and construction of the different process area is based on a scientific background. This is important, since no standardized process-audit procedure could be found in a first literature review

Fink (2005) defines a literature review as a: “*systematic, explicit, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners*.”[109]

Furthermore, it can be stated, that before a systematic literature review, the researcher starts from an early state of ‘personal/ individual’ knowledge of the problem, also called “‘MY’ Current State of the problem”. At the end of the process, the knowledge of the problem moves to a universal state, also called “‘THE’ Current State of the problem”[110].

[107] E. Gallardo, 2016
[108] E. Strukelj, 2018
[109] E. Gallardo, 2016, p. 4
[110] P. V. Torres-Carrion et al. , 2018

3.1 The need for a systematic literature review in this thesis

No maturity model, which corresponds to the needs to define and measure the quality and compliance of process-audits, could be found in the available literature. Therefore, the different dimensions and sub-dimensions of the new maturity model needs to be defined through different available literature models. In order to not miss any important aspects, the same as not to devious too much from the main focus, a systematic literature review was found to be the best method. This should help to get a better structure into the literature research.

Since different sources, like research articles, automotive and quality norms will be used to define the different steps to conduct conform and uniform process-audits. A traditional literature review would only lead to a lot of inconvenient information and was thus perceived as inappropriate.

3.2 Structure of the systematic literature review of this thesis

The structure of the systematic literature review is orientated on the "*Methodology for Systematic Literature Review applied to Engineering and Education*" from Pablo Vicente Torres-Carrion et al.[111]. This method leads the researcher from "My" to "The" current state of the problem and is an adaptation of the method by Kitchenham and Bacca. The process of Kitchenham and Bacca is divided into three sub-parts: 1) Planning, 2) Conducting, 3) Reporting results. The structure of the adapted method from Pablo Vicente Torres-Carrion et al. can be seen in the figure below.

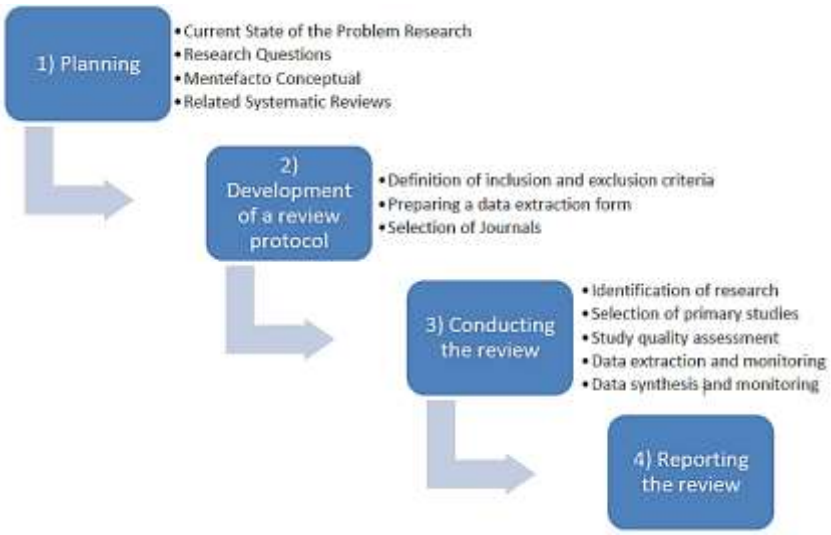
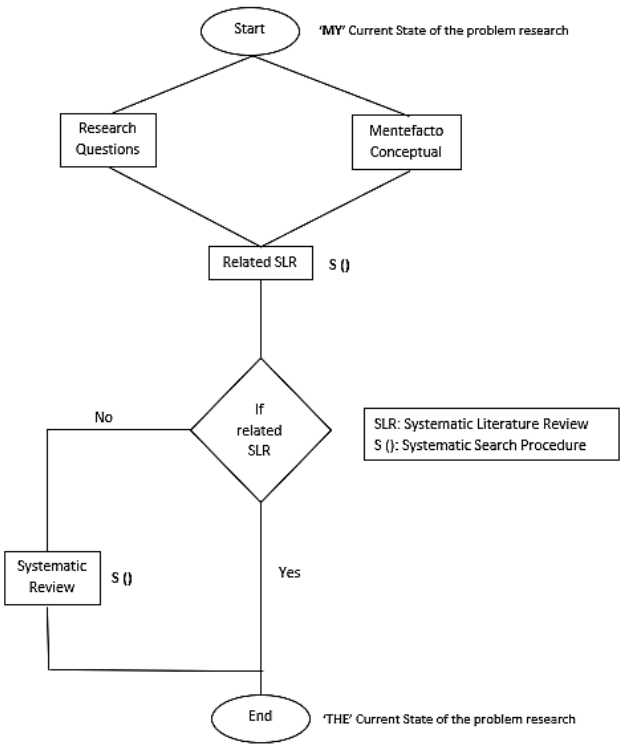


Figure 12: Structure of the systematic literature review

[111] P. V. Torres Carrion et al. , 2018

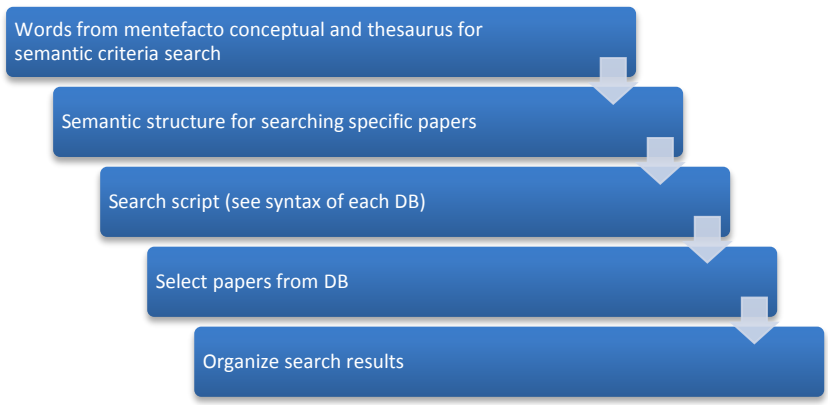
Before starting the systematic literature review, a preliminary conceptual analysis process needs to be performed. It is developed to form a link between an early approach to the general research problem and refers to the conceptual mind, designed by De Zubiria[112]. Here, the researcher starts from an early state of "personal/ individual" knowledge of the problem, which is represented as "'MY' Current State of the problem" and should end after the conceptual analysis at a universal state, called "'THE' Current State of the problem".



Only the fact of knowledge about the specific problem is not considered sufficient, but the researcher should at least write the research questions and draw the mentefacto conceptual before starting with the actual research. From this base, a first systematic search is done, to determine the existence of systematic reviews conducted on the subject in particular. Only, if no systematic review, which answers the research questions has been found, a systematic review will be carried out. The accompanying figure illustrates the mentioned steps.

Figure 13: Procedure to get from 'MY' to 'THE' current state of the problem research

The Systematic Search Procedure **S()** requires several sub-stages, which are listed in the following figure.



Unfortunately, it is not a linear process, but several processes need to be done iterative and take place in a continuous circle until the goals of each phase and sub-phase are completed.

Figure 14: Systematic Search Procedure S()

[112] De Zubiria, 1996

In the following section, the different phases from Structure of the systematic literature review will be explained more clearly.

The first phase is 'Planning'. In this place, the first sub-phase is 'Current State of the Problem Research', which represents the research problem and is the starting point of all scientific process. It is mainly important, that the researcher has clarity about the problem, because the input here affects all the other phases. The second sub-phase is the 'Research Questions'. Kitchenham recommends writing between 3 and 5 research questions, to keep a balance between the coverage of the research and the depth of the answer required by each question. These research questions are very important, because they will guide the whole process and needs to be precise and explain the reason for their formulation. The third sub-phase is the 'Mentefacto Conceptual', which was designed by De Zubiria[113] as a necessary instrument to make a good reading and learning and in order to represent concepts. It is an ideogram or graphic sketch that assumes a complex idea and conceptualizes it.

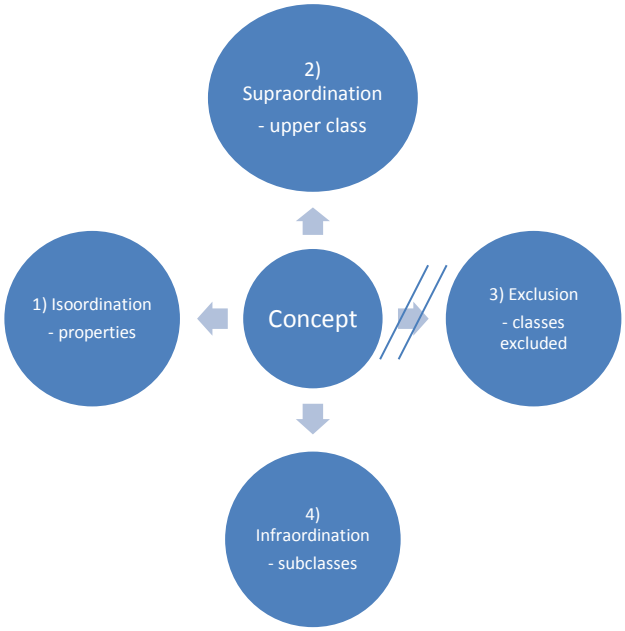


Figure 15: Mentefacto Conceptual

Four questions need to be answered: 1) What is characterized in essence? 2) Which group of things includes it? 3) What are the differences with similar objects? 4) Are there subtypes? From these four questions, the basis for the concept is assembled by four groups: 1) Isoordination, which shows the essentialities, 2) Supraordination, which includes the concept, 3) Exclusion, which points out the excluded classes and 4) Infraordination, which specifies the classes and subtypes of the concept.

In this ideogram, from the left side (Isoordination) and partly from the bottom (Infraordination), the search words can be deviated. Details from the inclusion and exclusion criteria can be deduced from Supraordination and Exclusion. The fourth sub-phase is 'Related Systematic Reviews', where the first systematic search is performed by the listed steps from the figure 12 (Systematic Search Procedure S()). The search words are taken from the mentefacto conceptual and are related to the thesaurus of the area of science. An adapted script for each DB will be made and the resulting papers are organized into three categories: valid, referents and response. If the literature review found has answers to the research questions, the study is taken

[113] De Zubiria, 1996

as the basis to support the research proposal. If not, the unanswered research questions will be specified, by labeling them in a way that a structured follow-up of the bibliographic research can be launched.

The second phase is ‘Development of a review protocol’. Here, the first sub-phase is ‘Definition of inclusion and exclusion criteria’, which is detailing general, specific and additional criteria, considering the research questions. The mentefacto conceptual diagram should also be taken into account for this sub-phase. The result of this sub-phase is a list of the specific inclusion and exclusion criteria, which is applicable to all the resulting papers. The second sub-phase is ‘Preparing a data extraction form, where the results can be classified and codified in a bibliography management tool. The third sub-phase is ‘Selection of Journals’ with as goal to select those journals with the highest impact factor. This filter helps to focus the attention on the databases and journals that are of real interest to our area of research, like only journals that are associated to the area of the study.

The third phase is ‘Conducting the review’, where the actual review starts. This phase relies on the results from the previous phase, inclusion and exclusion criteria and consists of five sub-phases. The first sub-phase is ‘Identification of research’ and completes in some way the protocol exposed in the previous phase. It involves activities like establishing search strategies, publication bias, bibliography management, document retrieval and documenting the search. The second sub-phase is ‘Selection of primary studies’, where the full articles of the studies need to be obtained. To reduce the likelihood of bias, the selection criteria are decided during the protocol definition and will be used in this sub-stage to guide the entire process. This makes a main difference between systematic and traditional review. Furthermore, final inclusion/ exclusion decisions should be made after the full articles have been reviewed. Each paper must be labeled, downloaded and placed in the repository, which was already previously created for this purpose. The third sub-phase is ‘Study quality assessment’, where the focus lies on the “quality” of the primary papers. Here, criteria like the relevance of the study, the quality of the bibliographic sources, the relevance and academic prestige of the authors and the impact factor of the journal are taken in consideration. The fourth sub-phase is ‘Data extraction and monitoring’, where the objective is to design data extraction forms to accurately record the information the researchers obtain from the primary studies, like name of review, date of data extraction, title, authors or journal. The last and fifth sub-phase is ‘Data synthesis and monitoring’, where the quality of the systematic review is defined.

The last phase is ‘Reporting the review’, with the goal to communicate the results to the scientific community to receive feedback.

3.3 Application of the systematic literature review for this thesis

3.3.1 Planning

The first step of the systematic literature research is ‘Planning’. The first sub category is ‘Current State of the Problem Research’. To fulfil this first category, it is necessary to move from ‘MY’ to ‘THE’ current state of the problem research. As guidance, the figure ‘Procedure to get from ‘MY’ to ‘THE’ current state of the problem research’ will be used. The first step is to develop 3 to 5 research questions, which will guide the further process of the systematic literature research, the same as to create a mentefacto conceptual.

To make sure that the later literature review focuses on the accurate areas, the research questions and the mentefacto conceptual were composed after having revised several Process-FMEAs of the PS-Organization and divers’ significant exchanges with my intern supervisor. Concerning the ‘Action Research Methodology’, it is important to assemble the review in a way that it can be used several times. This ensures that a scientific standard is fulfilled, the same as that an organization can use the framework later on to stay always up-to-date.

The following 4 research questions were developed:

Research Questions:

1) Which steps are necessary to conduct conform process-audits?
2) How can comparability of consecutive process-audits be guaranteed?
3) What are the focus areas of process-audits?
4) Do other maturity models of process-audits or any other audit procedure exist?
5) How does continuous improvement can be pursued for a process-audit procedure?

Mentefacto Conceptual:

The mentefacto conceptual is an ideogram that assumes a complex idea and conceptualizes it. The below model was elaborated to have a first view over the focused areas for the literature research.

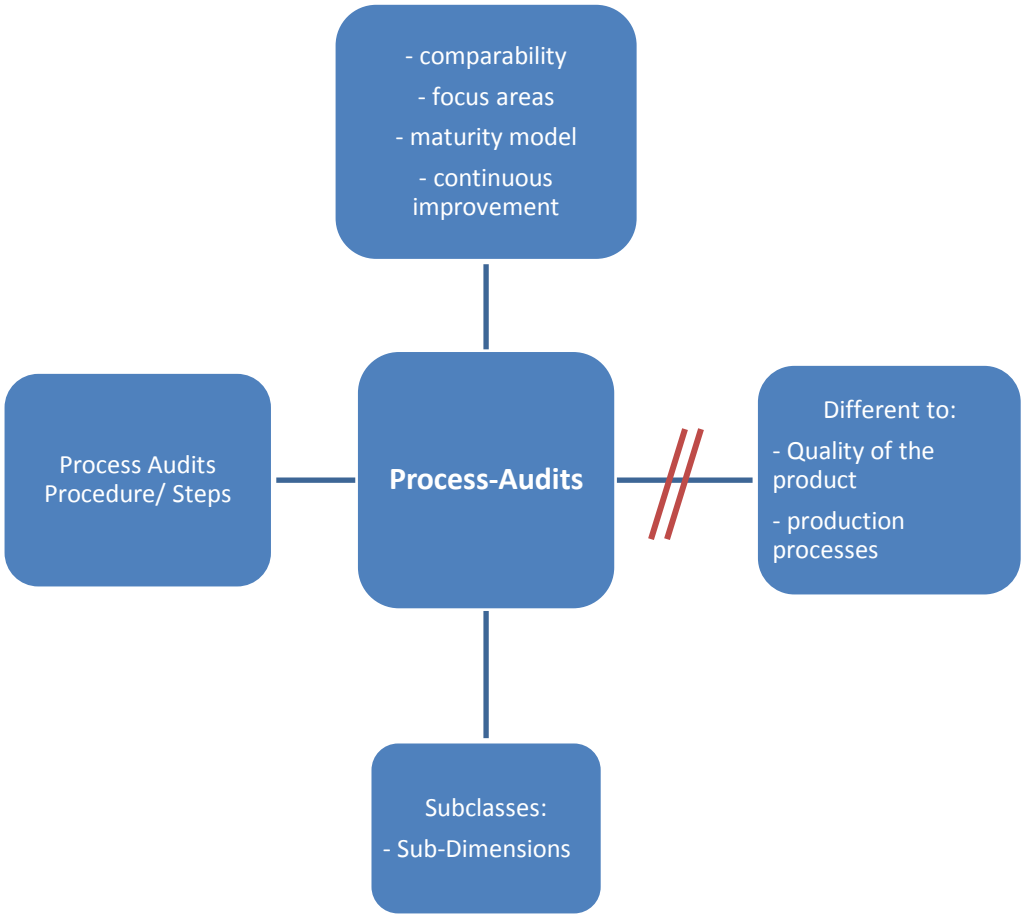


Figure 16: Mentefacto Conceptual - Production Process

Related Systematic Literature Review:

The first systematic search was conducted by following the steps of the 'Systematic Search Procedure S()'. This first search proved that literature concerning the individual themes is available; however the needed links are not clearly visible. In total, 123 articles were found, while conducting a first literature search. Supplementary to those articles, the international standards of 'VDA 6.3: Process Audit', 'IATF 16949', 'ISO 9000/ 9001' and some intern FMEAs were used.

As search engines, the available tools from the TU Wien library were used. This contains one search engine to scan all the available articles at the TU Wien library (CatalogPlus), the same as ScienceDirect, SpringerLink, one search engine for Austrian thesis's and Google Scholar. To find supplementary information about some themes, ResearchGate was used at a later time. No articles older than ten years should be considered (year >= 2008), the same as only articles and conference journals. For the first related systematic literature review, books were not considered. Here, the number of resulting papers will be mentioned, for the later Systematic research review, the resulting papers are categorized into valid/ reference/ resulting (val/ ref/ res).

The following filters were used for the first systematic search:

DB	Syntax	Resulting papers
CatalogPlus	Process Audit (title) AND (steps OR procedure); Topic: Internal Auditing AND Auditors AND Auditing AND Audits	34
ScienceDirect	Process Audit (title) AND (steps OR procedure); Article types: Review articles, Research articles, Book chapters	31
SpringerLink	Process Audit (Title) AND (steps OR procedure)	3
Österreichische Dissertationsdatenbank	Process (title) AND Audit (title)	14
Google Scholar	(steps OR procedure) AND allintitle: Process Audit	41
Total		**123**

Table 9: Related Systematic Literature Review

3.3.2 Development of a review protocol

Definition of inclusion and exclusion criteria:

In this part, several general and specific inclusion and exclusion criteria are defined. After having completed the first systematic research, the first version of the mentefacto conceptual, the same as the research questions have been adjusted. Furthermore, the first search helped to get a first overview for important inclusion and exclusion criteria. The results are listed in the following table.

Inclusion	Exclusion	Category groups	Period
• process • audit • steps • procedure	• product quality	• Engineering • Manufacturing • Quality Management/ Control • Auditing	2008-2018

Table 10: Criteria for the Systematic Literature Review

The above table shows a summary of all the gathered criteria. In a first step, they will all be inserted to the mentioned search engines and if needed slightly adjusted for every search engine.

Preparing a data extraction form:

At this point of the research, a bibliography management tool called Zotero was prepared, to organize and facilitate the analysis. All the applicable papers and other documents will be saved within Zotero, with all necessary information. This will simplify the later establishment of the references, the same as to have a structured order within all the resulting papers.

Selection of Journals:

In this sub-stage of the research, it is important to detect those journals with the highest impact factor that deal with production process in the field of automotive suppliers. This criterion is used to reduce the number of papers from reference to valid. Since the number of suitable articles is restricted, also articles referring to other audits will be retained.

3.3.3 Conducting the review

Identification of research:

In this part of the research, the hard search is performed, with the defined criteria. In a first step, the inclusion and exclusion criteria were used for the different search engines to reduce the number of results towards a reasonable number. In a second step, the titles and abstracts of these articles have been analyzed and only interesting and fitting articles were retained. In a third and last step, only articles with useful information were maintained.

Selection of primary studies:

This sub-stage and the above sub-stage were partially conducted in parallel, mainly for the third step. Once the reference lists have been finalized, it is important to obtain the full articles of selected studies. After they are downloaded, they will be saved within Zotero. The study selection criteria are intended to identify those primary studies that provide direct evidence about the research question. Furthermore, final inclusion and exclusion decisions are made after having reviewed the full texts.

Study quality assessment:

Supplementary to the previous sub-stage, this part takes care, that the “quality” of primary papers is given. This takes mainly in consideration, the relevance and the academic prestige of the authors. Here, all the valid articles were checked, if the so called “quality” of the articles corresponds to the needed academic standards for a master’s thesis.

Data extraction and monitoring:

The objective of this stage is to design data extraction forms to accurately record the information obtained from the primary studies. This task was fulfilled by Zotero.

The following table shows the different stages of literature retain. As already mentioned before, the resulting papers are categorized into valid/ reference/ resulting (val/ ref/ res).

DB	Syntax	Resulting papers (val/ ref/ res)
CatalogPlus	Process Audit (title) AND (steps OR procedure) AND quality; Topic: Internal Auditing AND Auditors AND Auditing AND Audits AND Audit Process	29/ 11/ 6
ScienceDirect	Process Audit (title) AND (steps OR procedure) AND quality; Article types: Review articles, Research articles, Book chapters	27/ 4/ 1
SpringerLink	Process Audit (Title) AND (steps OR procedure)	3/ 1/ 0
Österreichische Dissertationsdatenbank	Process (title) AND Audit (title)	10/ 3/ 0
Google Scholar	(steps OR procedure) AND allintitle: Process Audit	38/ 3/ 1
Total:		107/ 22/ 8

Table 11: Systematic Literature Research

In addition, the search engine google was browsed to receive supplementary information on which methods and technologies are currently available on the marked. Within this search, 7 additional results were detected. They can be found in the appendix of this thesis.

Data synthesis and monitoring:

The last sub-stage defines the quality of the systematic review. Since all the used articles correspond to a certain academic level, the same as no doubtful research engines were used, the quality of the literature resources can be stated as a high academic level. Deduced from these facts, the global quality of the systematic literature research can be stated as adequate for a master's thesis.

The following table summarizes the resulting articles.

DB	Author (Year)	Title
CatalogPlus	J.P. Russell (2006)	Process Auditing and Techniques
CatalogPlus	J.P. Russell (2009)	Process Auditing Techniques
CatalogPlus	M. Popa (2011)	Techniques and Methods to Improve the Audit Process of the Distributed Informatics Systems Based on Metric System
CatalogPlus	S. – A. Pitt (2014)	Internal Audit Quality – Developing a Quality Assurance and Improvement Program
CatalogPlus	S. Rao Vallabhaneni (2014)	Conducting Internal Audit Engagements – Audit Tools and Techniques

CatalogPlus	R. Underdown et al. (2012)	The Process of Internal Audits as a Catalyst for Continuous Improvement
ScienceDirect	J. Kettunen (2011)	External and internal quality audits in higher education
Google Scholar	Ciafrani et al. (2013)	Auditing Process-based Quality Management Systems
Norm	DIN ISO 9001 (2015)	Quality management systems - Requirements
Norm	DIN ISO 19011 (2017)	Guidelines for auditing management systems

Table 12: Resulting articles from the Systematic Literature Research

All the listed articles were used at least once to help to define the different dimensions or sub-dimensions of the new maturity model.

3.3.4 Reporting the review

After having conducted the systematic literature review, it is important to receive a certain feedback. Since this work is a master thesis with cooperation with an organization, the review was done with the supervisor of the PS-Organization.

3.4 Results of the systematic literature review

At this point, the discovered steps or procedures which were perceived as suitable are listed. To decide whether they are suitable or not, many rigorous discussions and analysis with the supervisor of the PS-Organization were conducted. The retained steps, which are necessary to conduct conform process-audits are:

- ➔ Planning and preparing
- ➔ Demonstrate ability of quality
- ➔ Risk determination
- ➔ Collection of information
- ➔ Standardized assistance form
- ➔ Execution
- ➔ Reporting
- ➔ Monitoring
- ➔ Analysis
- ➔ Corrective Actions
- ➔ Follow-Up

In addition, the Plan-Do-Check-Act cycle was determined as suitable to regroup and order the different steps. A summary of the different steps and integration into the PDCA-cycle can be found in the following section 4.4.1.

4 Methodical approach to develop the new Maturity Model - DSRM

4.1 Approach to develop the new Maturity Model

Before starting to elaborate the different activities of the development of the new maturity model, the connection and relation between the different activities will be elucidated by the PVF. The different tasks of every activity refer to the DSRM.

The figure below summarizes the different activities in form of the Libby boxes from the PVF with the respectively activity for each box.

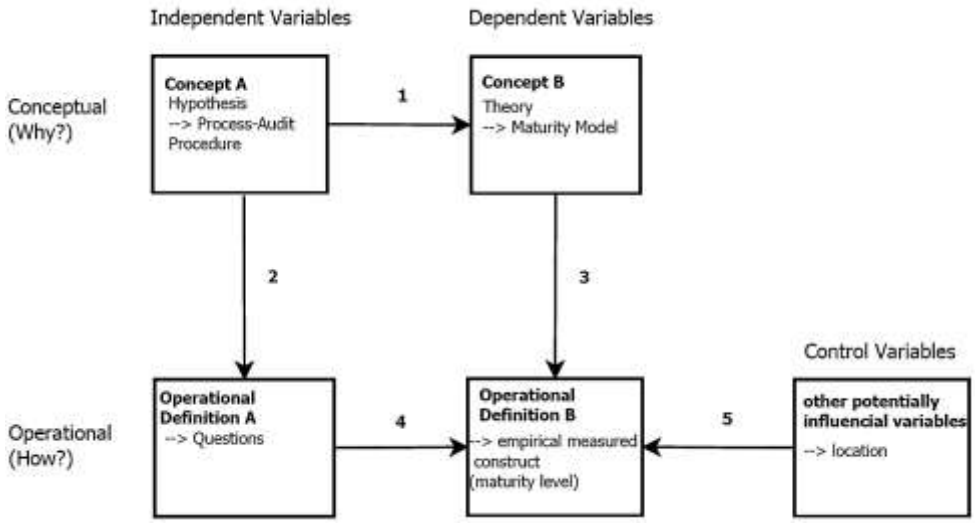


Figure 17: Different steps of the development through the PVF

The first box represents the construct of interest, in this case the ‘Process-Audit Procedure’. The second box specifies the meaning of the first box, in this case the ‘Maturity Model’. The first link, in between the first two boxes, illustrates the theory which represents the expected relationships between the identified constructs. The third and fourth boxes represent the independent and dependent variables which were operationalized during the experiment. To operationalize the ‘Process-Audit Procedure’, ‘Questions’ based on the generic goals and generic practices from the CMMI were developed. To operationalize the ‘Maturity Model’, different ‘Maturity Levels’ based on the CMMI were developed. The second and third link, make the transmission between conceptual and operational and translate constructs into operational variables that measure the variability associated with constructs. Since it is not possible for a researcher to directly test the relationship between two concepts (Link 1), one needs to test the theory by assessing the relationship between the operational definitions of the dependent and independent variables (link 4). The fifth

box represents other/ extraneous potentially influential variables which could affect the dependent variable, in this case the 'Location'. They are captured by the fifth link.

This is a very important aspect which needs to be understood. It is impossible to assess the different process-audit steps directly since they are immeasurable parameters. They can't be measured the same way than for example a distance between point a and b. For this purpose, it is necessary to use the PVF in order to convert immeasurable parameters into measurable parameters.

It must be ensured, that the assumptions that the relations between the concepts and the operational definitions (Link 2 and 3) need to be valid and other factors which might affect the dependent variable (Link 5) have either been controlled or have no effect. If those points are respected, the evaluation of the validity of a study is a function of the appraisal of the Links 1, 2, 3 and 5. So, if it has been determined once, that a logically consistent theoretical framework is being employed (Link 1), the evaluator should look closely at the ways in which variables are operationalized (Links 2 and 3) and how other factors are controlled (Link 5).

To guarantee, a problem-solving paradigm[114], which goal is to develop knowledge that the professionals of the discipline in question can use to design solutions for their field problems[115], the different activities refer to the DSRM[116]:

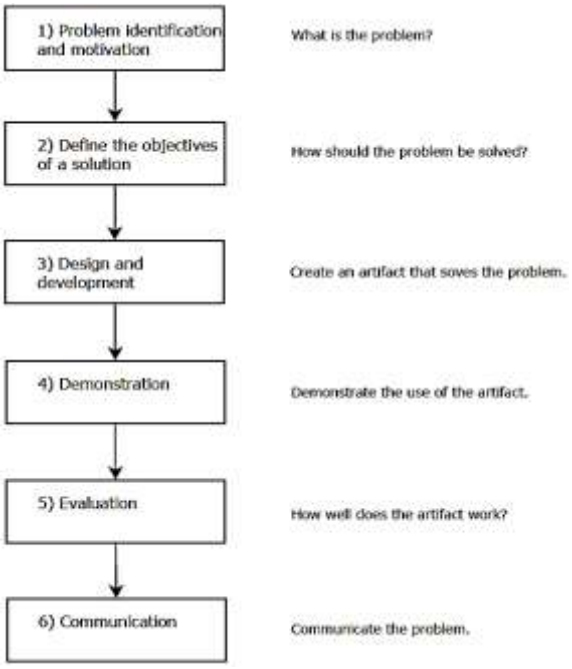


Figure 18: Sequence of the different activities to develop the new maturity model

The third activity, the design and development will however be divided once again into the different parts from the PVF.

[114] Hevner et al. , 2004
[115] Van Aken, 2005
[116] Geerts, 2011

4.2 Problem identification and motivation

The aim of the first activity is to define what the problem is[117]. So, before starting with the elaboration of the new maturity model, the need for a new maturity model should be elucidated. This serves as problem identification and motivation. On the one hand for the world of science, and on the other hand for the PS-Organization. It should answer the question: What is the problem?

Even if this task is already mainly answered in the introduction, the main points will be briefly summarized at this point.

Firstly, referring to science, the amount of information concerning process-audits is limited, mainly for the different steps which are necessary to conduct process-audits. There are specifications as to which steps should be included in an audit in general, however only vague specifications exist which steps process-audits should include. Furthermore, there isn't any assessment model, which allows evaluating the current stage of conformity of the different steps of process-audits. Hence, it is not possible to determine weak points within the process-audits of an organization. These are the two main identifications for the world of science.

Secondly, referring to the problem detection at the PS-Organization, a need for improving the overall process-audit procedure was detected. Currently, process-audits are conducted and also some promising improvements like Layered Process Audits (LPAs) were already introduced, however the overall results of process-audits aren't fulfilling the given expectations, mainly at level 1. To be able to improve, it is important to know where the problems are and to know how severe they are, before being able to improve. Hence, the idea of an assessment model was coming up.

4.3 Define the objectives of a solution

The aim of this activity is to define how the problem should be solved[118]. Combining both problems, the development of a new maturity model for process-audits was found as most suitable. To be able to combine the different needs, the dimensions of the maturity model represent the different processes or steps which are necessary to conduct process-audits. These processes are not the production processes, but the steps necessary to conduct audits in order to check the conformity of production processes. As reference model, the detailed steps from JP Russell with Process Auditing Techniques[119] were taken and underlaid or completed by different other authors. One other author worth to mentioning at this point is Sally-Anne Pitt with

[117] Geerts, 2011
[118] Geerts, 2011
[119] JP Russell, 2009

Internal Audit Quality[120], which provided many suiting ideas. The ISO 9001[121] served as basis for the PDCA-Cycle. Most articles represented a first step in the right direction, however individually they were not covering all the listed requirements, for the world of science, the same as for the PS-Organization. Due to this insufficiency, they were only taken as reference and a new model was developed. The following figure shows the different process auditing steps from JP Russell.

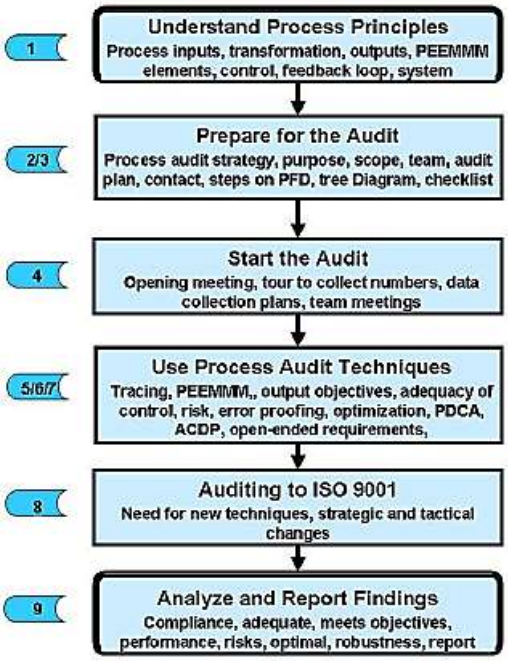


Figure 19: Process Auditing Detailed Steps[122]

All the references are the result of the systematic literature review. They combine necessary steps of audits in general, which were found suitable, and steps listed as process-audit phases. Combined, this generates a logical sequence of the different dimensions and creates a process-audit procedure. The different dimensions are inspired by the PDCA-cycle, to induce continual improvement. To be able to detect problems more precisely, the different dimensions are again divided into different sub-dimensions, which represent one specific process.

The available literature was used to determine the different process areas, here named as process-audit steps, and the generic goals and practices from the CMMI[123] were used to define the different levels.

To prevent any misunderstandings, it must be clarified, that with the help of the maturity model, the weak points of the process-audits can be detected and assessed. However, the improvement, and hence the rise of maturity levels for the different sub-

[120] S.-A. Pitt, 2014
[121] ISO 9001, 2015
[122] (JP Russell, 2009, p.5)
[123] Carnegie Mellon – Software Engineering Institute, 2006

dimensions, will be conducted by other methods. So, the main aim of this model is to assess the current problems and support the improvement by giving guidance on what is needed to ameliorate the current status. How this improvement is achieved, isn't included within the maturity model.

To be able to improve a process or a system in its overall, it is important to concentrate on the weakest areas. To clarify this statement, Eliyahu M. Goldratt gave an interesting illustration, where he links systems to chains. A summary of the statement is the following: The goal of a chain is to transmit force from one end to the other. As soon as you introduce a force into the chain and keep on increasing this force, the chain will break exactly at its weakest point. So, if you want to increase the resistance of a chain, you need to improve the chain at the weakest point. An enforcement of the weakest point will increase the whole chain[124]. The same applies for systems, or in this case for process-audits. If you want to increase the quality and reliability of the process-audits, one needs to start to reinforce at the weakest joint. To be able to do so, first the weakest point needs to be detected.

The following figure shows the different dimensions with the corresponding sub-dimensions, which are necessary to complete process-audits and represents a process-audit procedure. The PDCA-Cycle integration can also be seen in this figure.

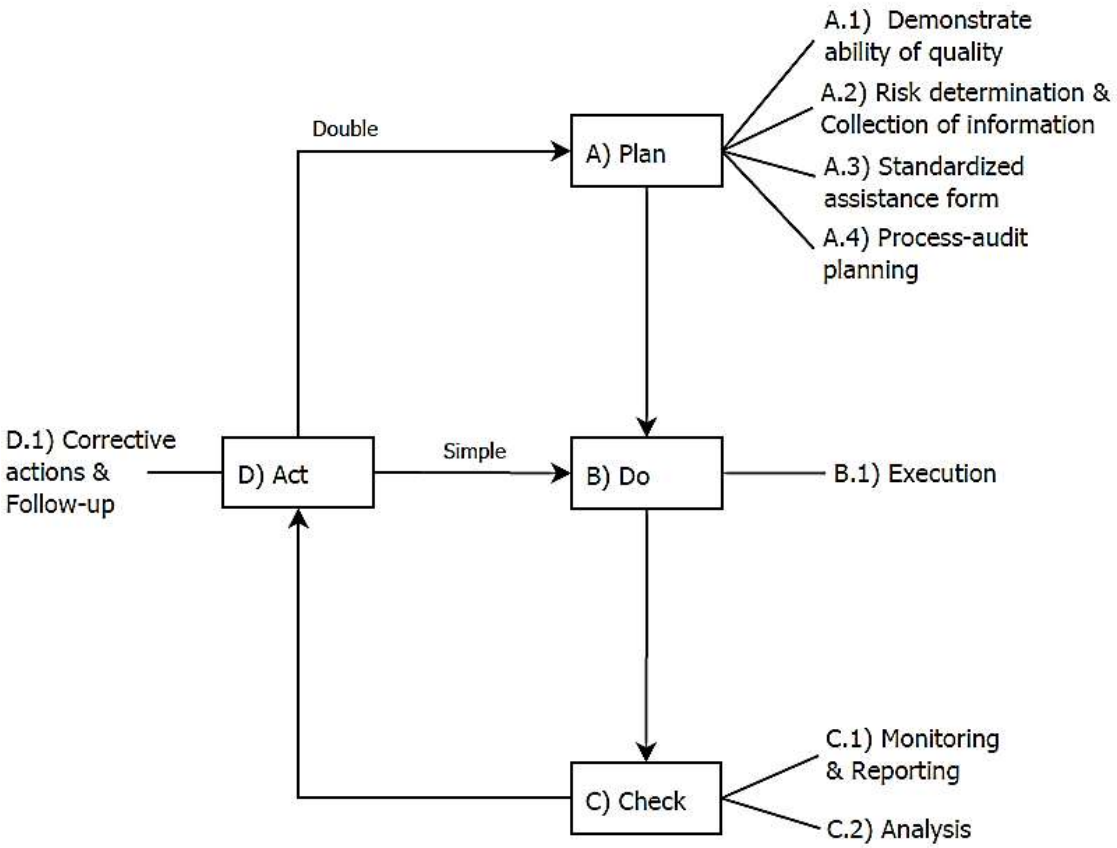


Figure 20: Process-Audit Procedure with dimensions and sub-dimensions

[124] Dettmer H Willian, 1998

4.4 Design and development

4.4.1 Definition of the different Dimensions and Sub-Dimensions

The aim of this activity is to create an artifact that solves the problem[125]. The above figure summarizes the different dimensions with their respective sub-dimensions. This so-called process-audit procedure ensures that uniform audits throughout the company are achieved, since an approach on how to perform process-audits is given, from the beginning to the end[126]. They are as already mentioned, composed out of different literatures, since no suitable model was found. To simplify the understanding and to include continual improvement within the procedure, the different dimensions are constructed on the PDCA-Cycle and named accordingly: Plan, Do, Check, Act. Each dimension represents a self-contained audit section with a clear structure and is divided into sub-dimensions. Combined, they lay out a complete audit sequence, ensuring that all necessary audit activities are performed. The intent is to use this sequence as a process-audit procedure for standard process-audits and thus ensure the achievement of an intended outcome. The procedure helps to visualize the sequence and defines important milestones. The purpose is, that a standard for carrying out process-audits is set, which simplifies the fact to compare different audits among each other. Standards establish a professional framework for undertaking internal audit engagements and builds excellence into process-audit engagements[127].

At this point, a brief explication about the PDCA-Cycle and risk-based thinking will be given. The PDCA-Cycle is an iterative four-step method, which enables an organization to ensure that its processes are adequately resourced and managed, and that opportunities for improvement are determined and acted on. Risk-based thinking enables an organization to determine the factors that could cause its processes and its quality management systems to deviate from the planned results[128]. The first phase, the Plan-phase comprises the identification of amelioration, analysis of the current state and definition of targets. The second phase, the Do-phase, which represents the enactment of the previous planning. In the third phase, the Check-phase, the gathered information from the do-phase gets compared to the expected outcomes. The last phase, the Act-phase closes the loop and creates the link towards the first phase (double) or second phase (simple). In this phase, adjustments are carried out and hence a process is improved. In a simple PDCA-Cycle, the act-phase gives input for the do-phase and in a double

[125] Geerts, 2011
[126] H. Kagermann et al. , 2008
[127] S.-A. Pitt, 2014
[128] ISO 9001, 2015

PDCA-Cycle, the act-phase gives input for the plan-phase. This illustrates, that for a functioning continuous improvement, feedback is important at various stages.

To have a more structured approach to list and elaborate the different dimensions and sub-dimensions, the listing with their explications will follow a structure. First a small explication of what the dimension represents will be given, before every sub-dimension will be defined in detail, with always one main identification question at the end. The expression 'process' will be used to describe the process area.

A) <u>Plan-Phase:</u>

The Plan-phase defines the vision and purpose of the audits. It establishes the objectives of its system, determines the resources needed to deliver results in accordance with customers' requirements and the organization's policies and identifies and addresses risks and opportunities[129]. The aim is to establish the organization's purpose and to determine the nature of the contribution it intends to make while predefining choices that will shape decisions and actions.[130] It sets the conditions for an audit and thus defines the framework of the process-audits[131]. Since the PDCA-Cycle is an iterating procedure, which always starts with the plan-phase, this first dimension is of great importance and need to be adjustable to new necessities. This is an important fact, to always be able to adjust to new situations. Therefore, this dimension has the most sub-dimensions, to ensure that a secure framework for the later dimensions is set. A statement of Winston Churchill should help to reflect the importance of planning:

"*Failing to plan is planning to fail.*"[132]

The plan dimension is divided into four sub-dimensions:

[129] ISO 9001, 2015
[130] S.-A. Pitt, 2014
[131] J. Kettunen, 2011
[132] Winston Churchill

A1) Demonstrate ability of quality

To be willing to do something, an organization needs a reason to do so. So, this first sub-dimension is about why an organization should conduct process-audits? Process-audits are checking how conform a certain process is running and can thus determine the quality of a process. Process-audits are a possibility to measure the quality of processes, and in this case of production processes. Consequently, the answer to the question is to demonstrate their ability of quality. This purpose can be for external or internal purpose. The external purpose can be to match different norms and specifications of the market. Conducting process-audits is even one requirement which needs to be fulfilled to be admitted producing within the automotive field[133]. Through process-audits, a production plant can prove that their processes are running as expected and provide evidence that their quality is equivalent to the regulations. This is like a confirmation, to increases the confidence of customers and attire new customers. The internal purpose is to verify how conform the different productions processes are running, to detect problems, before they occur. An internal knowledge what process-audits are and why they are performed needs to be available. Additionally, new requirements from the act-phase will feed into this sub-dimension.

So, the first process which is necessary to conduct conform process-audits is the commitment to conduct and improve them and the fact to demonstrate the ability of quality of a production plant. In today's world, a constant up-to-date on which quality requirements are asked from the market and the ability to demonstrate quality gets more and more important, this is guaranteed by a higher maturity level. As main identification question, the following question can be stated: *Does the commitment to conduct and improve process-audits in order to demonstrate an organization's ability of quality, fulfils the following requirements?*

A2) Risk determination & Collection of information

To be able to detect problems within a production process, it is important to refer to critical characteristics and elements of the processes, and to not miss any subject. To identify and address risks is one of the main focuses within the IATF 16949[134] for the plan-phase. Risk-based thinking is essential for achieving an effective quality management system, and to conform to the requirements of the IATF 16949 and ISO 9001, an organization needs to plan and implement actions to address risks[135]. This is one of the main pillars for the process-audit procedure and is for this purpose included within the plan-phase. It is important to focus on the right subjects.

[133] IATF 16949, 2015
[134] IATF 16949, 2016
[135] ISO 9001., 2015

To be able to detect risks, it is important to have a process which indicates how all the needed information to conduct a later audit gets gathered and how risk areas get detected[136]. All the needed data needs to be gathered from available sources, like the intern documents[137]. The aim is to assess key risks of process-audits themselves the same as how critical and significant characteristics of processes get identified[138]. This is important to prevent any production downtime during the execution of process-audits, the same as to capture and verify the most critical and significant characteristics of a process during the audits. Furthermore, transparency within this process is important, to always know which are the currently known risks and to pass on potential new risks. A high maturity level ensures that an organization is aware of eventual risks and can focus the audits on these characteristics, the same as ensure that the process-audits don't interrupt any production processes. A higher maturity level will make sure that risk determination is institutionalized within an organization and continually improved. As main identification question, the following question can be stated: *Does the process to gather production process relevant information, fulfils the following requirements?*

A3) Standardized assistance form

Another important process within the first dimension is to transform all the available information into a standardized assistance form, which is used as aid during the execution of the process-audits[139]. The aim is to provide an additional support to the auditors, which allows indicating a certain direction to process-audits and ensuring a later comparability and uniform analysis of the process-audits.

The actual form of the assistance form is not considered within this sub-dimension, since there exists different opportunities and everyone has its pros and cons[140]. Furthermore, the aim is not to prevent methods on how to improve a certain process, but only what a standardized assistance needs to fulfil to reach a certain level. A reliable assistance form needs to ensure that all the relevant characteristics are checked the same as that different audits are comparable among each other. They need to be arranged in a logical manner to expedite both their review and knowledge sharing[141]. The different levels of the maturity model will mainly deal with the problem on how these standardized assistance forms are established and assessed. While, advancing through the different levels, it will display that the standardized forms focus on the relevant characteristics, are standardized and are updated automatically. In this sub-dimension, it is crucial to obtain constant feedback from the do-phase, to be able to improve them continuously. The creation of the standardized

[136] JP Russell, 2009
[137] M. Popa, 2011
[138] S.-A. Pitt, 2014
[139] S.-A. Pitt, 2014
[140] S. Rao Vallabhaneni, 2014
[141] S.-A. Pitt, 2014

assistance form deals as well with an assessment method on how to rate the findings. As main identification question, the following question can be stated: *Does the process to create standardized assistance forms, fulfils the following requirements?*

A4) Process-audit planning

An effective and efficient audit planning sets the foundation for a stable quality audit[142]. It allows to identify the areas in which the process-audits will focus its effort, determines the goals, the same as by who and when an audit gets conducted. Hence, it is a highly important process, to ensure a proper sequence of the process-audits[143]. It represents the actual planning of the plan dimension.

The different tasks of this process will be elucidated separately. The first task is to identify the areas which need to be audited within a production plant. An organization needs to be clear on its own existing areas and unities and determine which are worth to be checked on a regularly basis, how often and which not at all. The second task is to determine the goals of the process-audits. Clear and concise objectives are critical to the success of an engagement[144]. It is important to set clear goals for the quality of an organization[145], which is synonymic with defining goals for the process-audits. These goals need to be in accordance with given norms and customer specification from the first sub-dimension (demonstrate ability of quality). The third task can be summarized as scheduling. It determines where the process-audits take place, at which time and who is conducting the process-audits[146]. A structured and reliable scheduling of the process-audits helps an organization to verify that every area is checked in a required frequency, the same as it can save time by ensuring that everyone knows when and where they need to conduct the audits. This can be improved in a way that more critical production processes will be audited more often than less critical production processes. To be able to do so, it needs a strong linkage with the second sub-dimension, risk determination & collection of information. The advancement in the maturity model helps an organization ensure that every area was checked as often as needed and save time through an accurate scheduling. As main identification question, the following question can be stated: *Does the process to plan the execution of the process-audits, fulfils the following requirements?*

This is the last sub-dimension of the plan-phase. If all these processes are implemented and matured over time, a structured and accurate plan-phase is guaranteed. This simplifies the comparability of previous and future audits.

[142] S.-A. Pitt, 2014
[143] JP Russell, 2009
[144] S.-A. Pitt, 2014
[145] ISO 9001, 2015
[146] VDA 6.3, 2016

B) Do-Phase

The Do-phase consists in the implementation of the previous defined plan and represents the second dimension. It consists simply in implementing what was planned before[147]. All the gathered information of the previous dimension was already summarized and at this point, an organization is ready to perform the actual audit. It is the start of the actual process-audit[148]. However, it should be mentioned that it will not represent an immediate ideal state, no matter how accurate the previous planning was. For this purpose, it will be piecemeal improved with every execution of the PDCA-Cycle and hence need constant adjustments. This is only possible through a precise information flow from the previous dimension. Since this statement already describes most of the tasks of this dimension, the Do-phase consists out of only one sub-dimension, the execution of the process-audits.

B1) Execution

As already mentioned, this sub-dimension consists of the execution of the process-audits. Without this process in place, the others are worthless, since all the other processes are planning, checking or acting on this sub-dimension. It handles every aspect of the execution itself[149].

The so-called fieldwork should be undertaken in accordance with the before elaborated specifications. It starts when the auditor gets the assignment to conduct the audits and ends the moment, when the auditor completes the check of the process. The aim is that the auditors collect enough evidence to make an informed opinion against the audit objective[150]. The evidence needs to be credible, authoritative, accurate and fairly represent a particular condition. All audit evidence should meet the three standards of audit evidence. The first standard is sufficiency, the evidence need to be convincing, the second is competence, the evidence needs to be reliable, and the third is relevance, the evidence needs to be logical[151]. Moreover, it is important that auditors take nothing for granted, but question and critically assess everything they see[152]. A higher maturity level is equal to a better effectiveness and efficiency, which are of major importance within this sub-dimension. An accurate execution can increase the effectiveness and efficiency of the overall process-audit procedure and hence save a lot of resources. As main identification question, the following question can be stated: *Does the process to collect evidence to make an informed opinion against the process-audit objectives, fulfils the following requirements?*

[147] ISO 9001, 2015
[148] JP Russell, 2009
[149] H. Kagermann et al. , 2008
[150] JP Russell, 2009
[151] S. Rao Vallabhaneni, 2014
[152] S.-A. Pitt, 2014

C) Check-Phase

The Check-phase consists of controlling if the do-phase was executed according to the determined specifications in the plan-phase. The aim is to monitor and measure processes and resulting products and services against policies, objectives, requirements and planned activities and report the results[153]. This is of major importance for the targeted continuous improvement. Within this dimension, two processes were detected as crucial and will be elaborated in detail. The first sub-dimension is about how the control is done and the second sub-dimension is about how these results are evaluated later. Both are important processes to take care during the process-audit procedure. They control the accordance of the previous dimensions and pave the way for the following dimension.

C1) Monitoring & Reporting

The first sub-dimension consists of summarizing and documenting all the gathered information during the audits[154] and reports them against the strategy and quality determined in the first dimension[155]. The term information is used, because this dimension doesn't limit itself to a specific kind of data, but various data, like for example the number and type of findings, the completeness of the results, who conducted the audit at which time and where, etc. It must be ensured, that the reporting is complete, truthful, and clear. Another task of this sub-dimension is the monitoring of the results, where the transparency is of major importance.

Furthermore, the speed of the reporting and monitoring is important within this sub-dimension. The gathered information needs to be optimized and afterwards the reports need to be available as quickly as possible. The transmission of the information and the assurance to not lose any during the transfer between different parties is respected in this sub-dimension. A higher maturity level guarantees a better accuracy, transparency and reporting. As main identification question, the following question can be stated: *Does the process to summarize and check the gathered information against its specifications, fulfils the following requirements?*

[153] ISO 9001, 2015
[154] H. Kagermann et al. , 2008
[155] S.-A. Pitt, 2014

C2) Analysis

The analysis process deals with the problem on how to treat findings and prepare the later corrective actions. It is important to solve problems at its roots, to be able to prevent future occurrences of the same issue and not only solve problems temporarily[156]. To be able to do so, it is necessary to analyze the received results and try to understand why the issues occurred.

The analysis sub-dimension doesn't solve the issues but tries to detect the roots and reasons why the issues occurred. However, within this process not only negative findings should be considered, but also positives. The idea behind this statement is, what benefits can be taken out of audits, where no findings were detected? Is this because the production processes are running faultlessly or because the process-audits are referring to the wrong parameters? An accurate analysis guarantees a reliable finding evaluation and initiates the later solving of the problems at its roots. They must be presented in a clear and convincing manner, to convince the other people to implement corrective actions during the next dimension. A higher maturity model implicates a more profound institutionalization, and hence importance to the analyzation process within an organization. As main identification question, the following question can be stated: *Does the process to analyze the information, fulfils the following requirements?*

[156] S.-A. Pitt, 2014

D) Act-Phase

The Act-phase is an important final step to finish the PDCA-Cycle and launch continual improvement. It consists of initialing improvement measures and the inspections of the effectiveness and efficiency of the countermeasures[157]. Actions to improve the performance, as necessary, need to be carried out[158]. At this point it is important to react to the previous detected problems and create a link to the first dimension, the plan phase. Without this linkage, continual improvement is not possible. Hence, after fulfilling this dimension, it needs to be able to adapt the plan-phase towards the knowledge gained and introduce lessons learned. For this dimension only one sub-dimension was considered important.

D1) *Corrective actions & Follow-up*

Initiating Corrective Actions and Following-Up is the final step of this process-audit procedure[159]. The aim is to take care of the corrective actions and make sure that similar issues will be avoided in the future. This is an important step to improve a specific issue. However, to be able to introduce continual improvement, it is important to follow-up all the conducted actions and gathered information to adapt the first dimension, the plan-phase adequately.

Corrective actions correct the observed condition and prevent them from reoccurring[160]. In this sub-dimension, the identified corrective actions are implemented[161]. A corrective action is however always problem-specific and will only be a solution for this specific issue and will not solve other problems. Nonetheless, it is possible to learn from these corrective actions, the same as it is important to verify the consequences of the corrective actions. For this purpose, a following-up needs to be introduced, which may be understood as monitoring of the corrective actions[162]. This ensures effectiveness and helps to prevent recurrence. This process is important to solve the previously detected issues by undertaking corrective actions and following-up. A higher maturity level provides the needed resources and institutionalization to ensure a proper launch of corrective actions and a following-up within an organization. Furthermore, it ensures that a valuable link towards the plan-phase is ensured. As main identification question, the following question can be stated: *Does the process to initiate corrective actions and following the process-audits up, fulfills the following requirements?*

[157] H. Kagermann et al. , 2008
[158] ISO 9001, 2015
[159] S.-A. Pitt, 2014
[160] S.-A. Pitt, 2014
[161] R. Underdown et al. , 2012
[162] S.-A. Pitt, 2014

4.4.2 Definition of the Levels

The different capability levels have the same names as the CMMI. There are six capabilities levels, whereas a higher level-number indicates higher capability and hence a higher maturity. The levels are building on each other, reaching a higher level automatically includes the maturity-capabilities of the lower level. Every level consists of a generic goal and its related generic practices related to a process area. In the following, first how an advancing through the different capability levels looks like is shown, before respectively a specific advancement through the different capability levels is shown.

This should serve as illustration, to better understand how an improvement looks like, before the actual requirements to achieve a certain capability level will be listed in form of a questionnaire.

Level	Description	Examples
Level 0 - Incomplete	Level 0 is called “Incomplete” and means that a process is either **not performed** or only partially performed.	• work is not performed • process is unpredictable
Level 1 - Performed	Reaching Level 1 “Performed” means that specific goals of that process area are satisfied and enables the work needed to produce work products. However, no institutionalization is performed, which ensures that improvements are maintained over time. Processes at this level are **performed but ad hoc and chaotic**.	• work is performed • work is dependent on individual practitioner
Level 2 - Managed	Reaching Level 2 “Managed” means that the **basic infrastructure** is in place to support the process, the same as that the process is monitored, controlled and reviewed. This ensures that existing practices are retained during time of stress. However, standards may be quite different in each specific instance of the process.	• process is planned • process performance is managed against a plan • corrective actions are taken when necessary • process is retained during times of stress
Level 3 - Defined	Reaching Level 3 “Defined” assumes that an **organizational standard** process exists associated with that process area, which can be tailored to the needs of the project. Process activities are documented, standardized and integrated and are hence more consistent.	• organizational standards exist • process is qualitatively understood
Level 4 – Quantitatively Managed	Reaching Level 4 “Quantitatively Managed” assumes that this process area is a key business driver that an organization wants to manage using **quantitative and statistical techniques to measure** the process area’s performance. This analysis gives the organization more visibility into the performance of selected process areas that will make it more competitive in the marketplace and provide a predictability of process performance.	• process performance is measured • process is stable
Level 5 - Optimizing	Reaching the ultimate Level 5 “Optimizing” assumes that selected process areas are stabilized and that the common causes of variation within that process are reduced. The focus lies on **continuous improvement** in the range of process performance through incremental and innovative improvements. Furthermore, there is quantitative feedback.	• defects are prevented • improvements are proactive • innovations are inserted and deployed • change is expected, not feared

Table 13: Summary Table - Understanding Capability Levels

A) Plan

A1) Demonstrate ability of quality

Level	Description
Level 0 - Incomplete	At level 0, an organization is not interested in demonstrating their ability of quality. If process-audits are conducted, the commitment to conduct process-audits is not based on the will to demonstrate their ability of quality.
Level 1 - Performed	At level 1, the commitment to conduct and improve process-audits the same as to demonstrate the ability of quality is ad hoc and chaotic. The success depends on the competences of certain people within the organization and there is no institutionalization which ensures future success. At this level, the aim of process-audits is not defined and only unstructured attempts to improve are launched.
Level 2 - Managed	The main difference between level 1 and 2 is that at level 2 basic infrastructures exist, to support the demonstration of quality. The ability of quality gets monitored, or in other words, shown that an organization fulfils a certain norm or specification. However, it doesn't exist any standard how to demonstrate the ability of quality in a conform and uniform way. A commitment to conduct and improve is noticeable.
Level 3 - Defined	At level 3, an organization has a standard procedure to demonstrate their ability of quality. Their ability of quality is documented, standardized and integrated. This means, that there is a predefined procedure how to handle a fulfilment of norms and specifications to confident customers and thus demonstrate their ability of quality. Additionally, reaching this level implies that new internal requirements from the act-phase will feed into this sub-dimension.
Level 4 – Quantitatively Managed	At level 4, an organization is using quantitative methods to demonstrate their ability of quality. The specified requirements to an organization are quantitatively determined and demonstrated. This is done for external and internal requirements and an organization at this level can easily demonstrate their quality. Reaching this level means that this process area is a key business driver and is only considered valuable if an organization can deliver the expected quality.
Level 5 - Optimizing	At the ultimate level, the focus lies on continuous improvement. Here, the current existing quantitative norms are constantly ameliorated to work with higher conformance and faster. An organization at this level is constantly searching for technological improvements, which are more performant and they are a member of committees which determine new norms. This ensures that they can easily attract new markets and customers, since they can easily prove that they are on the newest status of the existing norms and specifications.

Table 14: Level Definition – Demonstrate ability of quality

A2) Risk determination & Collection of information

Level	Description
Level 0 - Incomplete	At level 0, an organization doesn't have any risk determination referred to process-audits the same as for identifying critical and significant characteristics of a process. Every part of a process is treated equivalent and no further attention is given to more important parts.
Level 1 - Performed	At level 1, a risk determination exists, however the collection of information is ad hoc and chaotic and only routinely. Besides, there is no institutionalization, which means that the determined risks can get lost over time and that the proceeding is dependent on the responsible people.
Level 2 - Managed	At level 2, an organization provides basic infrastructure to monitor, control and review risks. This is important to maintain the detected risks even during a time of stress. The main problem at this level is that risks aren't determined following a standardized procedure. This is problematic since the risk determination isn't done in the same way for every process. Furthermore, at this level it isn't guaranteed, that the collected information gets forwarded to all the required people and are later on used to audit the different processes.
Level 3 - Defined	At level 3, an organization has a standardized procedure to determine risks. Risks, the same as the collection of all the needed information are documented, standardized and integrated. This is an important step to ensure that the risk determination is concluded in the same way for every process, which facilitates the risk determination for new processes dramatically. Furthermore, at this level it is ensured, that the risk determination is completely integrated into the planning of process-audits and thus a standardized gathering of relevant process information is guaranteed.
Level 4 – Quantitatively Managed	At level 4, an organization uses quantitative methods to determine risks and thus collect relevant information. This allows determining new risks partly automatically and integrating risk predictability. This is important in order to have a better overview over the different risks and value better how important and which consequences a certain risk has for a process or even the whole organization. Reaching level four implies that the risk determination and the collection of information are key business driver of an organization.
Level 5 - Optimizing	At level 5, an organization tries to continuously improve their risk determination and gathering of production process relevant information. Correspondingly, they are always looking for new technologies to ameliorate their current method. Quantitative feedback becomes more and more important and an organization at this level is operating at World-Class level.

Table 15: Level Definition – Risk determination & Collection of information

A3) Standardized assistance form

Level	Description
Level 0 - Incomplete	At level 0, an organization doesn't have any assistance form to conduct process-audits. If audits are conducted, it was not invested any time or resource in preparing assistance tools for the auditor.
Level 1 - Performed	At level 1, an organization generates some kind of an assistance form to support the auditor during the later audit. The creation of this assistance tool is ad hoc and chaotic, and no institutionalization exists. This could be under form of some random written questions or notes, which are different for every audit and can get lost over time. Furthermore, it isn't ensured, that the content of the process-audits is focusing on important subjects.
Level 2 - Managed	At level 2, an organization provides basic infrastructures to generate an assistance form. The generating is monitored, controlled and reviewed and the existing practices are retained during a time of stress. However, there are no standards to ensure that this assistance form looks the same for every instance. At this level, a standardized assistance tool with aimless questions is the result.
Level 3 - Defined	At level 3, standards exist on how to generate a standardized assistance form. These assistance forms are completed and appropriately reviewed for all engagements. Every activity to generate an assistance form is documented, standardized and integrated. This ensures that every assistance form is according to the organization's guidelines and every new assistance form gets generated following a standardized procedure. To reach this level, an organization needs a standard for creating a standardized assistance tool for a random production process.
Level 4 – Quantitatively Managed	At level 4, quantitative assistance tools are used to generate and ameliorate the assistance forms. New forms get generated automatically and already existing forms get up-dated automatically. This means that ineffective and inefficient questions and controls get partly automatically removed from the assistance tool. Reaching level four implies that the creation of a standardized assistance form is a key business driver of an organization and is partially interactive.
Level 5 - Optimizing	At level 5, standardized assistance forms get continually improved and an organization is constantly looking for new technologies to improve their current procedure. Currently this means, that questionnaires or checklists get automatically generated and updated. An organization at this level is operating at World-Class and therefor they are also reconsidering their current procedure and looking for better solutions.

Table 16: Level Definition - Standardized assistance form

A4) Process-audit planning

Level	Description
Level 0 - Incomplete	At level 0, an organization doesn't have any process-audit planning to conduct audits at all. If audits are conducted, every auditor decides randomly where and when they conduct an audit. The problem is, that it isn't ensured, that every area or process is audited as often as needed and time is lost since it isn't ensured, that the chosen process is even running.
Level 1 - Performed	At level 1, an organization executes a process-audit planning. However, it is done ad hoc and chaotic, and no institutionalization is available. This means that the planning isn't retained during a time of stress and thus can be lost, the same as improvements aren't retained.
Level 2 - Managed	At level 2, an organization has basic infrastructures to perform the planning of process-audits and it is controlled, monitored, and reviewed. The existing planning will be retained during a time of stress. Nonetheless, it can differ over a longer period of time without any reason. This is caused by a missing standard procedure. At this level, planning exists, but it mainly focuses on the fact that a certain quantity of audits is performed and not on an efficient and effective scheduling. Furthermore, how often and which areas get audited isn't standardized.
Level 3 - Defined	At level 3, an organization owns a standard procedure to perform the planning. The planning is documented, standardized and integrated. This ensures that the planning stays identical over time and that every area and process is audited as often as necessary the same as different opinions are retained, since it is assured, that different auditors conduct the audits. At this level, efficiency and effectiveness is integrated into the process-audit planning.
Level 4 – Quantitatively Managed	At level 4, the planning is done with quantitative techniques. This allows a certain predictability of the planning. Hereby, the planning can be done automatically, since all the needed information is already available. This can save a lot of time and resources and ensure that everything is audited as often as needed. At this level, all the responsible people get automatic notifications and entries in their calendars, the same as an automatically schedule is possible. Reaching level four implies that the process-audit planning is a key business driver of an organization.
Level 5 - Optimizing	At level 5, an organization is conducting its planning on a World-Class level. At this level, continuous improvement plays a crucial role and hence the constant search for new technologies is important to maintain this level. The planning at this level is active and can easily adjust itself to changes or incidents.

Table 17: Level Definition – Process-audit planning

B) Do

B1) Execution

Level	Description
Level 0 - Incomplete	Since this sub-dimension consists of the execution of the process-audits itself, most of the other sub-dimensions can only be performed if this one reaches at least level 1. Level 0 for this sub-dimension would mean that the process-audits are not conducted at all. If an organization hasn't conducted any process-audits and wants to implement process-audits within their organizational structures, this is the first sub-dimension where they need to improve.
Level 1 - Performed	At level 1, an organization conducts process-audits. However, they are ad hoc and chaotic the same as no institutionalization exists to maintain the conducting procedure over time. This means that the execution of the audits doesn't follow any structure and only depends on the abilities of the auditor.
Level 2 - Managed	At level 2, an organization provides a basic infrastructure to conduct audits. The execution is monitored, controlled and reviewed and existing methods to conduct an audit are retained during a time of stress. A problem consists, that the conduction of different areas and processes isn't following any standards and therefore the conduction can differ for different processes. At this level, no standardized work instruction exists on how process-audits need to be conducted and the results need to be registered manually.
Level 3 - Defined	At level 3, an organization has a set of standards to conduct process-audits. They are conducted following the 3 standards of evidence and hence they are similar and better comparable latter on. At this level, it is ensured that the actual fieldwork is undertaken in accordance to the before elaborated specifications and is documented, standardized and integrated. At this level, an organization provides work instructions on how every process needs to be audited.
Level 4 – Quantitatively Managed	At level 4, an organization uses quantitative techniques to conduct process-audits. For this purpose, the usage of certain technologies is necessary and the transmit of the registered parameters is automatically. Reaching level four implies that the execution of process-audits is a key business driver of an organization.
Level 5 - Optimizing	At level 5, am organization operates at a World-Class level. Continuous improvement plays a major role and thus the search for new technologies is crucial to stay at this level. At this level, process-audits are performed partly automatically and constant feedback to the responsible people is given. This means that the necessary parameters are controlled automatically, and a warning signal and notification gets provided as soon as a deviation is found.

Table 18: Level Definition – Execution

C) Check

D1) Monitoring & Reporting

Level	Description
Level 0 - Incomplete	At level 0, an organization doesn't summarize and document the conducted process-audits, neither report them against the strategy determined in the first dimension. Consequentially, findings of process-audits aren't taken seriously. At this level, process-audits are worthless, since no additional information or input is taken out of the process-audits.
Level 1 - Performed	At level 1, an organization starts to summarize, document and report the conducted process-audits. The proceeding itself is however ad hoc and chaotic and no institutionalization exists which ensures that the proceeding isn't lost over time. At this level, the results are mainly dependent on the abilities of the working people.
Level 2 - Managed	At level 2, an organization provides basic infrastructures to report and monitor the gathered information during the process-audits. All the information is monitored, controlled, and reviewed, which ensures that the existing practices are retained during a time of stress. The main problem at level 2 is that no strict standards exist on how to ensure a consistent reporting and monitoring of process-audits. This complicates a comparison between different process-audits.
Level 3 - Defined	At level 3, an organization introduces a set of standards, to ensure that every report is done according to these standards and allows a consistent monitoring. The whole proceeding is documented, standardized and integrated. At this level the reporting is accurate, objective, clear, concise, constructive, complete, and the monitoring timely.
Level 4 – Quantitatively Managed	At level 4, an organization is using quantitative techniques to report and monitor all the gathered information from the execution. Through the introduction of quantitative techniques, the reporting and monitoring can be accelerated, and unnecessary faults can be avoided. This increases the transparency of the process-audits and allows a sharing with a more widely group of people. Reaching level four implies that the reporting and monitoring of process-audits are key business drivers of an organization.
Level 5 - Optimizing	At level 5, an organization is operating at World-Class level and is hence always interested in continuous improvement. To be able to stay at this level, new technologies are of crucial importance. The reporting and monitoring at this level is done automatically, what reduces the needed resources (time and people) and increases the speed.

Table 19: Level Definition –Monitoring & Reporting

C2) Analysis

Level	Description
Level 0 - Incomplete	At level 0, an organization isn't doing any analysis of the gathered information from the execution. At this level, an organization isn't interested in solving the detected problems and weaknesses.
Level 1 - Performed	At level 1, an organization is doing an ad hoc and chaotic analysis of the gathered information. At this level, the knowledge and will within an organization to solve problems and detect weaknesses is present. However, no concrete measures were induced to do so. Furthermore, an institutionalization which maintains any improvements over time is missing.
Level 2 - Managed	At level 2, an organization provides basic infrastructures to analyze the gathered information. The analysis is monitored, controlled, and reviewed and existing practices are retained during a time of stress. The major problem at level 2 is that an organization at this level is missing standards, which ensures that the analysis, the same as a possible root-cause-analysis is always following the same structured procedure. At this level, an organization is trying to solve problems at its roots. Nonetheless, the needed standards to learn from previous experiences are missing.
Level 3 - Defined	At level 3, an organization has a set of standards which ensures, that every analysis of the gathered information is following the same scheme. This enables a better comparison between the different induced root-cause-analyses. At this level, every analysis is documented, standardized and integrated. Herewith, an organization is always able to access previous analysis and use these as reference. The root-cause-analysis is completely integrated and is an important part of the process-audit procedure. To reach this level, an organization needs to make sure, that it has built in a constant feedback loop, to analyze the execution, the same as the reporting and monitoring.
Level 4 – Quantitatively Managed	At level 4, an organization is using quantitative techniques to analyze the gathered information from the execution. The result is a partially automatic analysis, with a partially automatic root-cause-analysis. To reach this level, an organization needs to count on new technologies. Reaching level four implies that the analysis of process-audits is a key business driver of an organization.
Level 5 - Optimizing	At level 5, an organization is doing the analysis of the gathered information at World-Class level, which means that they are operating with the current Best-Practice available worldwide. At this level, continuous improvement of the current methods is crucial and constant feedback to improve the analysis need to be available.

Table 20: Level Definition - Analysis

D) Act

D1) Corrective actions & Follow-Up

Level	Description
Level 0 - Incomplete	At level 0, an organization isn't interested in continuous improvement and is satisfied with the current process-audits. For this purpose, an organization at this level is not introducing any corrective actions, neither doing any follow-up. However, this last sub-dimension is an important last step, to close the PDCA-cycle and improve the process-audit procedure continually over time.
Level 1 - Performed	At level 1, an organization is aware and willing to launch corrective actions, the same as to do a follow-up of the whole procedure. However, the used methods are ad hoc and chaotic. Furthermore, no institutionalization is in place to save the executed corrective actions over time. Improvements are only considered for the current time or current problem and aren't focusing enough on continual improvement.
Level 2 - Managed	At level 2, an organization has a basic infrastructure to ensure that corrective actions the same as a later follow-up are executed. At this level, corrective actions are monitored, controlled, and reviewed. This guarantee, that the improvements are retained during a time of stress. However, no standard procedures are defined, to guarantee that corrective actions are executed uniformly for every occurring problem.
Level 3 - Defined	At level 3, an organization has introduced a set of standard procedures to guarantee that corrective actions and the follow-up is performed in a uniformly manner. This is a very important step, which makes sure that corrective actions are facing the roots of the problems. This requires a strong link with the analysis sub-dimension.
Level 4 – Quantitatively Managed	At level 4, an organization is using quantitative techniques to introduce corrective actions and to do the later follow-up. This is important to introduce corrective actions faster and enables certain predictability. Reaching level four implies that corrective actions and a later follow-up are key business drivers of an organization.
Level 5 - Optimizing	At level 5, an organization is operating at a World-Class level and hence is investing a lot of resources to develop new technologies to introduce automatic introduction of corrective actions. Furthermore, the follow-up is done automatically and only needs to be revised by responsible people.

Table 21: Level Definition – Corrective actions & Follow-up

4.4.3 Summary of the Maturity Model

Process Areas		Capability Levels				
	Generic Goals	1. Performed	2. Managed	3. Defined	4. Quantitatively Managed	5. Optimizing
		GG1: Achieve Specific Goals	GG2: Institutionalize a Managed Process	GG3: Institutionalize a Defined Process	GG4: Institutionalize a Quantitatively Managed Process	GG5: Institutionalize an Optimizing Process
A. Plan	Generic Practices	• Perform Specific Practices	• Establish an Organizational Policy • Plan the Process • Provide Resources • Assign Responsibility • Train People • Manage Configurations • Identify and Involve Relevant Stakeholders • Monitor and Control the Process • Objectively Evaluate Adherence • Review Status with Higher Level Management	• Establish a Defined Process • Collect Improvement Information	• Establish Quantitative Objectives for the Process • Stabilize Subprocess Performance	• Ensure Continuous Process Improvement • Correct Root Causes of Problems
A1: Demonstrate ability of quality						
A2: Risk determination & Collection of information						
A3: Standardized assistance form						
A4: Process-audit planning						
B. Do						
B1: Execution						
C. Check						
C1: Monitoring & Reporting						
C2: Analysis						
D. Act						
D1: Corrective actions & Follow-up						

4.4.4 Definition of the Questions

The following figure represents the decision tree, which is used to determine at which level an organization is currently operating. This decision tree is used for every sub-dimension and determines herewith the current level.

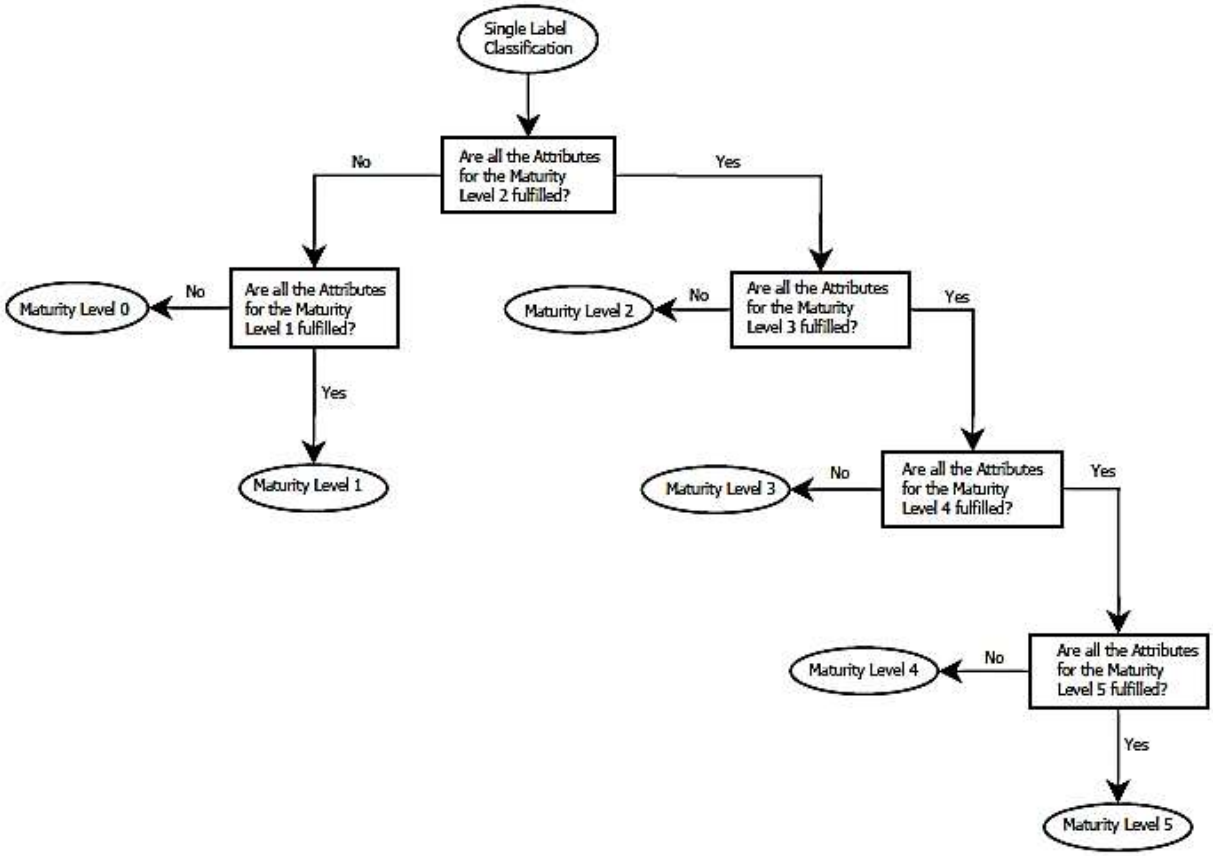


Figure 21: Decision tree for level assessment

To be able to use this decision tree, explicit questions need to be generated. These questions need to be clear, so that no doubts are left open to determine the current level of an organization. Only, if every question and hence requirement to fulfil a certain level is achieved, an organization can reach the next level.

The questions themselves are derivate from the generic goals and practices from the CMMI[163]. Within Excel, a questionnaire was created, to easily assess the capability level of the different processes. These questions were however adapted, because it was not possible to ask a matching question for every generic practice. The different sub-questions need all to be answered positively, to have a positive main question (e.g. 4.1.1 & 4.1.2 need a positive answer to fulfil the question 4.2)

The established questions will be listed hereinafter, the demonstration and evaluation of the new maturity model will be done in the ensuing sections.

[163] Carnegie Mellon, 2006

These are elaborated questions from the generic practices. In order to simplify the questionnaire, the actual questionnaire differs slightly from these questions.

Level 1: Performed - Achieve Specific Goals

GP 1.1: Are the specific practices of this process area performed?

Level 2: Managed – Institutionalize a Managed Process

GP 2.1: Is an organizational guideline for planning and performing the process available?

GP 2.2: Is a plan available to establish and maintain the process?

- ➔ GP 2.2.1: Is the plan for performing the process defined and documented?
- ➔ GP 2.2.2: Is the process description defined and documented?
- ➔ GP 2.2.3: Is the plan reviewed with relevant stakeholders and got their agreement?
- ➔ GP 2.2.4: Is the plan revised as necessary?

GP 2.3: Are adequate resources available to perform the process?

GP 2.4: Are responsibilities and authority to perform the process assigned?

- ➔ GP 2.4.1: Is the overall responsibility and authority to perform the process assigned?
- ➔ GP 2.4.2: Are responsibilities and authority for performing specific task of the process assigned?
  GP 2.4.3: Do the assigned people understand and accept their responsibilities?

GP 2.5: Do the responsible people have all the necessary skills and expertise to perform and support the process?

GP 2.6: Are designated work products of the process under appropriate levels of control?

GP 2.7: Are relevant stakeholders identified and involved in the process? (insures necessary interaction)

- ➔ GP 2.7.1: Are relevant stakeholders to this process identified?
- ➔ GP 2.7.2: Are these identifications shared with the process planners?
- ➔ GP 2.7.3: Are relevant stakeholders involved as planned?

GP 2.8: Is the process monitored and controlled against the plan for performing?

- ➔ GP 2.8.1: Is the actual performance measured against the plan for performing the process?
- ➔ GP 2.8.2: Are the accomplishments and results of the process reviewed against the plan for performing the process?
- ➔ GP 2.8.3: Are the activities, results, and status of the process reviewed with the immediate level of management responsible for the process?
- ➔ GP 2.8.4: Are effects of significant deviations from the plan for performing the process identified and evaluated?
- ➔ GP 2.8.5: Are problems in the plan for performing the process and in the execution of the process identified?
- ➔ GP 2.8.6: Are corrective actions taken when: requirements and objectives are not satisfied, when issues are identified, or when progress differs significantly from the plan for performing the process?
- ➔ GP 2.8.7: Are corrective actions tracked until closure?

GP 2.9: Is credible assurance available that the process is implemented as planned and adheres to its process description, standards, and procedures?

GP 2.10: Are the activities, status, and results of the process reviewed with higher level management and issues resolved?

Level 3: Defined – Institutionalize a Defined Process

GP 3.1: Is a defined process established and maintained for the process?

- ➔ GP 3.1.1: Are the processes that cover the process area and best meet the needs of the project or organizational function selected from the organization's set of standard processes?
- ➔ GP 3.1.2: Is the defined process established by tailoring the selected processes according to the organization's tailoring guidelines?
- ➔ GP 3.1.3: Is ensured, that the organization's process objectives are appropriately addressed in the defined process?
- ➔ GP 3.1.4: Is the defined process documented?
- ➔ GP 3.1.5: Is the description of the defined process revised as necessary?

GP 3.2: Are work products, measures, measurement results, and improvement information derived from the planning and performing of the process to support future use and improvement of the organization's processes and process assets?

- ➔ GP 3.2.1: Are processes and product measures stored?
- ➔ GP 3.2.2: Is the documentation for inclusion in the organization's process asset library submitted?

- ➔ GP 3.2.3: Are lessons learned from the process for inclusion in the organization's process asset library documented?
- ➔ GP 3.2.4: Are improvements to the organizational process assets proposed?

Level 4: Quantitatively Managed – Institutionalize a Quantitatively Managed Process

GP 4.1: Are quantitative objectives for the process established and maintained?

- ➔ GP 4.1.1: Are quantitative objectives that pertain to the process established?
- ➔ GP 4.1.2: Are quantitative objectives to the process or its subprocesses allocated?

GP 4.2: Is the performance of one or more subprocesses stabilized, to determine the ability of the process to achieve the established quantitative quality and process-performance objectives?

- ➔ GP 4.2.1: Is the performance of one or more subprocesses that are critical contributors to the overall performance of the process statistically managed?
- ➔ GP 4.2.2: Is the ability of the process to achieve its established quantitative objectives considering the performance of the statistically managed subprocesses predicted?
- ➔ GP 4.2.3: Are selected process-performance measurements into the organization's process-performance baselines incorporated?

Level 5: Optimizing – Institutionalize an Optimizing Process

GP 5.1: Is continuous improvement of the process in fulfilling the relevant business objectives of the organization ensured?

- ➔ GP 5.1.1: Are quantitative process improvement objectives that support the organization's business objectives established and maintained?
- ➔ GP 5.1.2: Are process improvements that would result in measurable improvements to the process performance identified?
- ➔ GP 5.1.3: Are strategies defined and deployment of selected process improvements based on quantified expected benefits, the estimated costs and impacts, and the measured change to the process performance managed?

GP 5.2: Are root causes or defects and other problems in the process, which were encountered in the quantitatively managed process identified and corrected?

4.5 Demonstration

The aim of this activity is to demonstrate the use of the elaborated artifact and prove that the artifact works by solving one or more instances of the problem[164].

To be able to do so, the new maturity model was applied within the PS-Organization, to assess the quality of their currently used process-audit procedure. After having done so, the results were analyzed and suggestions for improvements were given.

The assessment of the new maturity model within the PS-Organization was done independently by my intern supervisor in absence of me. This has two positive impacts. Firstly, she has excellent knowledge about the currently used process-audit procedure and secondly, the fact that the assessment was done independently and in absence of myself, assured the demonstration. If a person who has excellent knowledge about their process-audit procedure and as assessment information only the definition of the different dimensions and sub-dimensions the same as the questionnaire itself, is able to complete the questionnaire, the demonstration activity in the course of this master's thesis is validated. To be able to ensure the validation and demonstration of the new assessment model further, additional assessments in other organizations need to be done. This exceeds however the expense of this master's thesis.

During the completion of the first assessment, some weaknesses of the new maturity model were discovered, and some adjustments were performed. This was due to the fact, that unlike initially planned, it was not possible to ask the entire questionnaire to every sub-dimension. Regarding this fact, some adaptions within the definition of the different sub-dimensions were performed, the same as some questions will not be asked for certain sub-dimensions. After these minor adaptions, it was possible to complete the questionnaire.

Performing this demonstration proved the initial intend, that it is possible to assess the quality of the different sub-steps of a process-audit procedure with this new maturity model. The results, which will be elaborated in the next section, clearly illustrate the weaknesses of the currently used process-audit procedure. Knowing exactly where the weaknesses are, it is easily possible to improve them and thus improve the whole procedure. This saves resources, because it is not necessary to improve the whole procedure at once but it is possible to start the improvement at its weakest points.

In the following section, the results of the demonstration, the case study itself, will be elaborated in detail.

[164] Geerts, 2011

4.6 Evaluation

The aim of this activity is to show how well the artifact works[165]. This section is divided as follow: first a short introduction will be given to understand how the questionnaire needs to be read with additional information concerning the actual assessment process. Secondly, the filled questionnaire is listed before lastly the individual sub-dimensions will be discussed.

The Excel-sheet is structured in a way that the different requirements which need to be fulfilled to reach a certain level, are listed on the left side. On top, the different dimensions and sub-dimensions with their respective identification question are listed. These so-called identification questions should help to fill out the questionnaire by gathering the most important aspect of a sub-dimension in one precise question. Addressed alone, this identification question is not enough and therefore the different dimensions and sub-dimensions are described more precisely in the section 4.4.1 and the different requirements are described accurately in section 2.4.3. The cells beneath are meant to register a response to the asked question and the respective requirement. The entry of a 0 indicates that the sub-dimension does not fulfill the respective requirement (negative answer). The entry of 1 indicates that the sub-dimension does fulfill the respective requirement (positive answer). The row which states 'Fulfillment (%)', calculates automatically the percentage of positive requirements for a certain level. The row which states 'Reached Level x?', indicates if a certain level is reached or not. To reach level x, it is necessary to completely fulfill the requirements of level x and additionally, the level x-1 needs to be successfully completed. At the very end, and additional 'Total Fulfillment (%)' is calculated, which indicates the total percentage of accomplished requirements.

The figure below shows an example of how the display within Excel looks like.

Dimension:		Plan			
Sub-dimension:		Demonstrate ability of quality	Risk determination & Collection of information	Standardized assistance form	Process-audit planning
Identification Question:		Does the commitment to conduct and improve process audits , fulfils the following requirements?	Does the process to gather production process relevant information, fulfils the following requirements?	Does the process to create standardized assistance forms, fulfils the following requirements?	Does the process to plan the execution of the process audits, fulfils the following requirements?
Level 1: Achelve Specific Goals					
GP 1.1	*Achieve Specific Goals* (process needs to exist)	1	1	1	1
Fulfillment (%):		100%	100%	100%	100%
Reached Level 1?		1	1	1	1
Level 2: Institutionalize a Managed Process					
GP 2.1	*Establish an Organizational Policy* (guideline to perform the process needs to exist)	1	1	1	1
GP 2.2	*Plan the Process* (establish and maintain the actual plan to perform the process)	1	1	0.25	0
GP 2.2.1	Define and document the plan for performing the process	1	1	0	0
GP 2.2.2	Define and document the process description	1	1	0	0
GP 2.2.3	Review the plan with relevant stakeholders and get their agreement	1	1	0	0
GP 2.2.4	Revise the plan as necessary	1	1	1	0

Figure 22: Display of the questionnaire within Excel

[165] Geerts, 2011

Assessment of the Maturity level for every Process-Area

To determine the maturity level of every process area, according to the generic goals and practices of the CMMI, the following questionnaire was determined. (0: negative answer; 1: positive answer, Answers to questions with sub-questions will be calculated automatically e.g. 2.2)
Dimension:
Sub-dimension:
Identification Question:

Level 1: Acheive Specific Goals	
GP 1.1	***Achieve Specific Goals*** **(process needs to exist)**
Fulfillment (%):	
Reached Level 1?	
Level 2: Institutionalize a Managed Process	
GP 2.1	***Establish an Organizational Policy*** **(guideline to perform the process needs to exist)**
GP 2.2	***Plan the Process*** **(establish and maintain the actual plan to perform the process)**
GP 2.2.1	Define and document the plan for performing the process
GP 2.2.2	Define and document the process description
GP 2.2.3	Review the plan with relevant stakeholders and get their agreement
GP 2.2.4	Revise the plan as necessary
GP 2.3	***Provide Ressources*** **(adequate ressources need to be available to perform the process)**
GP 2.4	***Assign responsibility*** **(responsibilities need to be assigned to perform the process)**
GP 2.4.1	Assign overall responsibility and authority for performing the process
GP 2.4.2	Assign responsibility and authority for performing the specific task of the process
GP 2.4.3	Confirm that the people assigned to the responsibilities understand and accept them
GP 2.5	***Train people (*** **responsible people of the process need appropriated trainings)**
GP 2.6	***Manage Configurations*** **(designated components of the process need be placed under appropriate control)**
GP 2.7	***Identify and Involve Relevant Stakeholders*** **(necessary interactions of the process need to be regulated)**
GP 2.7.1	Identify stakeholders relevant to this process and their appropriate involvement
GP 2.7.2	Share these identifications with the process planners
GP 2.7.3	Involve relevant stakeholders as planned
GP 2.8	***Objectively Evaluate Adherence (supply credible assurance that the process is implemented as planned - by internal people which are however external to the process)***
GP 2.9	***Review Status with Higher Level Management*** **(the status of the process needs to be revised with a higher level management)**
Fulfillment (%):	
Reached Level 2?	

Level 3: Institutionalize a Defined Process	
GP 3.1	***Esatblish a Defined Process*** **(standard to perform the process needs to exist)**
GP 3.1.1	Establish an organizational standard
GP 3.1.2	Ensure that the organization's process objectives are appropriately addressed in the defined process
GP 3.1.3	Document the defined process and the records of the tailoring
GP 3.1.4	Revise the description of the defined process as necessary
GP 3.2	***Collect Improvement Information*** **(work products, measurements and improvement information of the process need to be collected)**
GP 3.2.1	Store process and product measures in the organization's measurement repository
GP 3.2.2	Submit documentation for inclusion in the organization's process asset library
GP 3.2.3	Document lessons learned from the process for inclusion in the organization's process asset library
GP 3.2.4	Propose improvements to the organizationa process assets
Fulfillment (%):	
Reached Level 3?	
Level 4: Institutionalize a Quantitatively Managed Process	
GP 4.1	***Establish Quantitative Objectives for the Process*** **(obtain agreement from relevant stakeholders about specific quantitative ojectives for the process)**
GP 4.1.1	Establish the quantitative objectives that pertain to the process
GP 4.1.2	Allocate the quantitative objectives to the process or its subprocesses
GP 4.2	***Stabilize Subprocess Performance*** **(stabilize the performance of one or more subprocesses to determine the ability of the process to achieve the established quantitative quality)**
GP 4.2.1	Manage KPIs of one or more subprocesses
GP 4.2.2	Predict the ability of the process to achieve its established quantitative objectives
GP 4.2.3	Incorporate selected process-performance measurements into the organization's process-performance baselines
Fulfillment (%):	
Reached Level 4?	
Level 5: Institutionalize an Optimizing Process	
GP 5.1	***Ensure Continuous Process Improvement*** **(select and systematically deploy process and technology improvements)**
GP 5.1.1	Establish and maintain quantitative process improvement objectives that support the organization's business objectives
GP 5.1.2	Identify process improvements that would result in measurable improvements to process performance
GP 5.1.3	Define strategies and manage deployement of selected process improvements
Fulfillment (%):	
Reached Level 5?	

Total Fulfillment (%)

Plan			
Demonstrate ability of quality	**Risk determination & Collection of information**	**Standardized assistance form**	**Process-audit planning**
Does the commitment to conduct and improve process audits , fulfils the following requirements?	Does the process to gather production process relevant information, fulfils the following requirements?	Does the process to create standardized assistance forms, fulfils the following requirements?	Does the process to plan the execution of the process audits, fulfils the following requirements?

1	1	1	1
100%	**100%**	**100%**	**100%**
1	1	1	1
1	1	1	1
1	1	0.25	0
1	1	0	0
1	1	0	0
1	1	0	0
1	1	1	0
1	1	1	1
1	0.67	1	0.67
1	1	1	1
1	1	1	1
1	0	1	0
1	0	1	1
	1	0	0
1	1	0.67	1
1	1	1	1
1	1	1	1
1	1	0	1
1	1	1	1
1	1	1	1
100%	**85%**	**77%**	**74%**
1	0	0	0

1	1	0.5	0
1	1	1	0
1	1	0	0
1	1	1	0
1	1	0	0
1	0.75	0.75	0
1	1	1	0
1	1	1	0
1	0	0	0
1	1	1	0
100%	**88%**	**63%**	**0%**
1	0	0	0
1	1	0.5	0.5
1	1	1	1
1	1	0	0
1	1	0	0
1	1	0	0
1	1	0	0
1	1	0	0
100%	**100%**	**25%**	**25%**
1	0	0	0
0.67	0.33	0.33	0.33
1	0	0	1
0	1	1	0
1	0	0	0
67%	**33%**	**33%**	**33%**
0	0	0	0

98%	**85%**	**67%**	**57%**

Do	Check		Act
Execution	**Monitoring & Reporting**	**Analysis**	**Corrective Actions & Follow-up**
Does the process to collect evidence, fulfils the following requirements?	Does the process to summarize and check the gathered information, fulfils the following requirements?	Does the process to analyze the information, fulfils the following requirements?	Does the process of following the process audits up, fulfills the following requirements?

1	1	1	1
100%	**100%**	**100%**	**100%**
1	1	1	1
1	1	1	1
0	0.75	0	0
0	1	0	0
0	1	0	0
0	1	0	0
0	0	0	0
0	1	1	1
0.67	1	0.67	0.67
1	1	1	1
1	1	1	1
0	1	0	0
0	0	0	1
1	1	1	0
0.67	0	1	0
1	0	1	0
1	0	1	0
0	0	1	0
1	0	0	0
0	0	0	1
48%	**53%**	**52%**	**52%**
0	0	0	0

0.25	1	0.5	0.5
1	1	0	1
0	1	0	0
0	1	1	1
0	1	1	0
0.5	1	0.75	0.75
0	1	1	1
1	1	1	1
1	1	1	1
0	1	0	0
38%	**100%**	**63%**	**63%**
0	0	0	0
0.5	0	0	0
1	0	0	0
0	0	0	0
0	1	0.67	0
0	1	1	0
0	1	1	0
0	1	0	0
25%	**50%**	**33%**	**0%**
0	0	0	0
0	0	0.67	0
0	0	1	0
0	0	1	0
0	0	0	0
0%	**0%**	**67%**	**0%**
0	0	0	0

44%	**58%**	**55%**	**46%**

After having presented the completed questionnaire, this section discusses the results of the different sub-dimensions.

The completion of the questionnaire was done by my supervisor at the PS-Organization, which is also responsible for the process-audits at the PS-Organization. The completion of the questionnaire took a bit more than one hour and was completed without any additional help from my site. This was due to the fact to test if it is possible to complete the questionnaire autonomously. After a first test, some adjustments were done to simplify the model, before completing a second definitive questionnaire. Further, the questionnaire was completed by me, to see if both of us have different perceptions, concerning their currently used process-audit procedure. In total, we had some minor discrepancies, but both of us assessed the same level to every sub-dimension. For this purpose, we discussed the discrepancies together and the shown questionnaire is the result. The discrepancies were not due to a different conception of the questions and requirements, but due to a lack of knowledge from my part. It is comprehensive, that it was impossible from my site to get the different internal processes know in the same way than my supervisor . This had however no consequences on the feasibility of the developed questionnaire, since all the questions and requirements were understood in the same way.

If we first have a look on the 'Total Fulfillment (%)', we note that most of the sub-dimensions are fulfilling more than 50%, however except the first sub-dimension, no other sub-dimension was able to reach at least level 2. This means that a lot of useful applications are already used at the PS-Organization, but in-between, important connections are missing. This issue can be stated already as their main problem, the missing connections within their procedure. Hereinafter, the individual problem for every sub-dimension will be listed. This is important, since only the diagram of the reached levels is not significant enough.

The figure below summarizes the level completion of the different sub-dimensions.

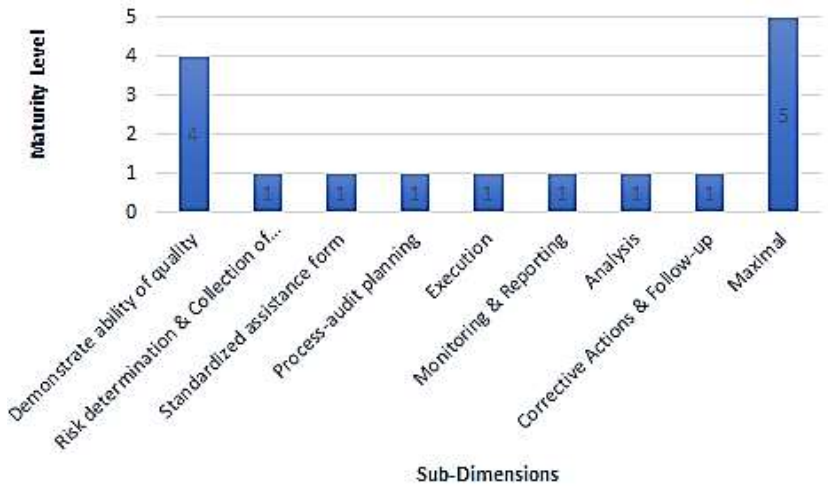


Figure 23: Assessment of the current maturity levels

The first dimension, the plan-phase consists of four sub-dimensions. Concerning the first, not much need to be said. The fact that this thesis is established in cooperation with the PS-Organization shows their strong willingness to conduct and improve their currently used process-audits. Accordingly, they reach level 4 for this sub-dimension.

For the second sub-dimension, the assessment showed a very interesting constellation. The overall assessment is only level 1, but level 2 and 3 are respectively complied for 85% and 87%, with one or two requirements missing to reach a higher level. Furthermore, all the requirements from level 4 are already successfully in place. If we now have a look at the different missing requirements, we find out that all the information needed to create a valuable assistance form are available at the PS-Organization, however they get not transferred correctly to the responsible people of the process-audits. One example is that P-FMEAs for every process are done and well maintained, but the responsible people for the process-audits have no access to this information. By sensitizing the responsible people about this problem, it is easily possible to reach level 4 within this sub-dimension.

The third sub-dimension reached as expected only level 1. To handle this problem was one of the tasks, given to me by the PS-Organization. It is interesting to see, that standardized checklists (requirement level 3), which are the same within every plant of the PS-Organization exists; however the composition of these checklists is not determined at all. The result is 25 different checklists, which are the same for every plant, but some are focusing on processes, some on products and some others on a production area. Concerning this purpose, a work-instruction was established on how to create a conform checklist for a random production process, based on the six elements. While doing so, it is possible to reach level 3.

The last sub-dimension of the DO-Phase proved an already known problem at the PS-Organization and thus only reaches level 1. Currently, no real planning of process-audits exists at the PS-Organization. The available checklists are printed out and classified in a folder, and whenever a quality inspector has time, he simply takes out one checklist and does the audit for this production process. One improvement, which will also have consequences for other sub-dimensions, is a digitalization of their process-audit checklists. While doing so, an automatic and independent planning procedure is possible. This ensures that every production process is audited as often as necessary and that the responsible people all know when they must audit which area. If the digitalization gets introduced the way it was prescribed, this sub-dimension will reach at least level 3.

The third and fourth sub-dimensions will only reach level 3, since it is not necessary to incorporate selected process-performance measurements of these processes into the PS-Organization’s process performance baselines. This does not represent a weak point but doing so would only waste resources while being useless.

The second dimension, the do-phase, only consists of one sub-dimension, the execution of the process-audits, which again reached level 1. In total, this sub-dimension has the lowest fulfillment rate of only 44%. This is mainly due to the fact, that no guideline on how the execution needs to be performed exists. The quality inspectors are supposed to fill out the checklists with a pen and have as answer possibility ‘ok’ and ‘not ok’. Since the questions of the checklists are not always process relevant, it is thus difficult for the quality inspectors to collect enough evidence to make an informed opinion against the process-audit objectives. With the aspired digitalization, they will be equipped with a tablet. Benefits are that only relevant questions will be asked, a supplementary commentary section exists, failure catalogues are easily accessible and it is possible to take pictures of detected issues. This way, quality inspectors can collect enough evidence and thus it is possible that this sub-dimension reaches level 4.

The third dimension, the check-phase, consists of two sub-dimensions and both depicted similar results and will therefore be discussed together. For both, my assessment differed with the assessment of my supervisor. This was due to the fact, that I was deceived by the advantages of their currently used web-based issue tracker, and didn’t recognize the missing connections. My personal perception was that within this web-based issue tracker, the monitoring & reporting the same as the analysis was handled in a structured way, with as only negative point the fact, that the findings were entered manually. Discussing these discrepancies with my supervisor, it became clear to me that this web-based issue tracker is a very valuable tool; however it is not used and understood correctly concerning level one, the quality inspectors. For both sub-dimensions, the needed tool to reach a higher level is available, but it is not used correctly. While completing the questionnaire, the weaknesses were depicted clearly. So, if these weaknesses get solved, it is possible to reach level 4 without investing any additional money for supplementary tools. It is only important to make it clear to the people who are working with the existing tool, how they need to use this one. The working procedure for both sub-dimensions needs to be specified more clearly for the quality inspectors, to guarantee a smooth running. In addition, an integration of the digitalization and the web-based issue tracker will allow an automatic monitoring and reporting.

The last dimension, the act-phase, consists of one sub-dimension, the initiation of corrective actions & follow-up of the process-audits has similar problems than the two previous sub-dimensions. Here, the same as before, the web-based issue tracker is used to initiate a following-up of the process-audits. Again, with a linkage to the previous sub-dimensions, the tool itself is available, how to work properly with the available tool is however not specified for level 1, the quality inspectors. Again, if a clear guidance how to work with the available tool is given, it is possible to reach level 4 without investing any additional money.

Before treating the last activity, the evaluation activity will be summarized and some points will be clarified.

The evaluation activity proved the applicability of the new maturity model within the PS-Organization. With this newly developed model, we were able to assess the quality of their currently used process-audit procedure in a detailed and viewable way. It was possible to detect weaknesses clearly and analyze those individually. Herewith, it was possible to suggest and implement individual improvements for the PS-Organization. The possible level improvements can be seen in the figure below and the detailed filled questionnaire can be found in the annex.

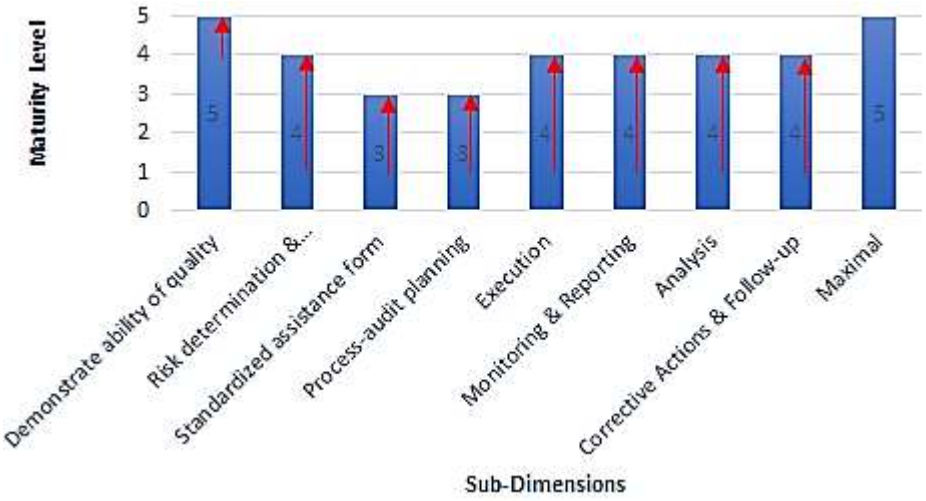


Figure 24: Assessment of the possible maturity levels

At this point it should be clarified once again, that this newly developed maturity model assesses the current state of conformity of the different process-audit steps and thus it is possible to detect weaknesses. Furthermore, the model indicates what is necessary to further evolve and improve the currently used process-audit procedure, but it does not indicate how these improvements can be implemented. For example it indicates that to reach level 3 is necessary to have an organization wide standard, how to create or implement such a standard is nevertheless not indicated within this new maturity model. So it indicates what is necessary to improve, however not how to do so.

All in all the assessment for the PS-Organization was a success and it clearly depicted the weaknesses. Even if some of these were already known before, it was important to confirm those with an independent model and outline these illustratively. This is important to get granted the needed resources from the management, to be able to implement the suggested improvements. Referring to this point, the model can as well be used to justify needed resources to improve existing procedures.

Hereinafter, the last activity, communication, will be elaborated.

4.7 Communication

The aim of this activity is to communicate the problem, its solution, and the utility, novelty, and the effectiveness of the solution to researchers and other relevant audiences[166]. Due to the fact, that this work is an Action Research Methodology, the communication is done once within the PS-Organization and once for the world of science.

The main communication of the results of this work is mainly done with the PS-Organization. As already mentioned within the previous evaluation chapter, the process-audit procedure of the PS-Organization was firstly assessed and some improvements were introduced. Furthermore, supplementary suggestions were given to continually improve their process-audit procedure. So, through the last activity, the communication, it was possible to launch improvements within the PS-Organization. Concerning this fact, this last activity is an important last part of this work, which should not be underestimated. With the communication it was possible to clearly show and point out the weaknesses of their currently used process-audit procedure, what represented an important part of my engagement at the PS-Organization. Furthermore, this figurative representation through the maturity model helped to justify the need for further investments, like for example for the aspired digitalization. This fact should not be underestimated.

With regard towards the research aspect of this thesis, a globally applicable assessment model for the process-audit procedure was developed. It was taken care of a globally possible application of the assessment model. All of the developed dimensions and sub-dimensions, the same as the questionnaire are applicable for every organization which is performing process-audits within a production environment. Due to the fact, that this thesis will be published within the online library of the Vienna University of Technology, the communication with other researchers is as well partially ensured. A further communication with other organizations was not considered as necessary neither as appropriate.

This was the last activity of the Design Science Research Methodology[167] and concludes the development of the new maturity model. The following section of this work includes a closing discussion and outlook for future researches.

[166] Geerts, 2011
[167] Geerts, 2011

5 Discussion and Outlook

5.1 Discussion of the Results and Findings

In this master's thesis, a new maturity model was developed to assess the quality of the process-audit procedure. The new maturity model is a continuous representation, with as process areas the necessary steps to conduct conform and uniform process-audits. The used methodology of this work is the Predictive Validity Framework, through which it is possible to measure immeasurable values or parameters. In this case, the quality of the process-audit procedure is the immeasurable parameter. By using the Predictive Validity Framework, it is possible to measure the quality of the process-audit procedure with the newly developed maturity model. Additionally, to ensure a conform structure of this master's thesis, the development of the new maturity model follows the six activities of the Design Science Research Methodology.

At the beginning, one main research question with three sub-questions was stated:

> *Which steps do organizations need to follow, to be able to cover all phases/ aspects of process-audits?*
>
> 1. *How does an organization assess their current situation statement?*
> 2. *How does an organization ensure that process-audits are focusing on the right areas?*
> 3. *How does an organization ensure continuous improvement within the process-audit procedure?*

The answer to the main question lies in the different dimensions and sub-dimensions of the new process-audit procedure. While following these steps, and aiming to improve in a uniform way, an organization can ensure to perform conform and uniform process-audits. The supplementary integration of the PDCA-Cycle should help to guarantee continuous improvement. By combining the different steps which are necessary to perform process-audits with a maturity model, it is possible for an organization to assess their current situation by answering the attached questionnaire. By using the generic goals and generic practices of the CMMI as reference for the needed requirements of the different levels, a general validity is ensured. This establishes consistency and comparability with the international standard for process assessment. Consequently, the attached questionnaire fulfils the requirements of the first sub-question. It enables an organization with a tool to assess their current situation of their process-audit procedure.

One problem of the PS-Organization was that they were not sure if they were performing audits in every needed area and if the process-audits itself were focusing on the right subjects. To solve this problem and to avoid the occurrence of the same problem for other organization, one sub-dimension within the first dimension is about risk determination and the collection of information. This helps to determine which areas are relevant to check through process-audits and to collect enough relevant information to focus on the right subjects. To expand the idea of focusing on the right subjects during process-audits, the following two sub-dimensions are additionally of major importance: Standardized assistance form and Execution. To cover the important subjects of the audited processes during the execution of the audits, it is crucial to create the standardized assistance form in a way that it focuses on every field of the audited processes. This can be achieved thorough the six elements of a production process, which were mentioned in chapter 2.3. If the standardized assistance form focuses on these six elements, one can guarantee, that the audits are also covering every aspect of the processes. Summarizing, this means that a standardized assistance form can be constructed on these six elements.

The last sub-question was about implementing continuous improvement into the process-audit procedure. To fulfil this requirement, the different dimensions of the new maturity model are established on the PDCA-Cycle. This means that the process-audit procedure is not compromised out of individual and independent audits, but on coherent audits which are cumulated within the PDCA-Cycle. Including this into the new maturity model, one main focus lies on continuous improvement, and the goal is to improve the process from audit to audit, step by step. This refers again to the statement that it is not possible to create from the beginning on the perfect process-audit, but improved piece by piece.

All in all, this newly developed assessment model in form of a maturity model was able to fulfil all the stated research questions. Nevertheless, it needs to be mentioned once again, that the maturity model itself is only an assessment tool. While using this tool, it is possible to represent the current situation, the implementation of improvements is however not included within this model. The maturity model states what is necessary to improve the current process-audit procedure (definition of the levels), but how these improvements are realized is not included within this new maturity model.

The next sections explain the limits of this work and examine the results critically, before enumerating further research projects and giving one final conclusion. This is an important last part of this thesis in order to review the whole work from a critical point of view.

5.2 Limitation of the Approaches and Results

The structure of the individual components of the new assessment model are based on expert assessments and practical application of the case study organization the same as on scientific and practical literature. An empirical evaluation was not performed, but the so-called demonstration was only done by one case study within the PS-Organization. This restricts the visibility and verification of its applicability. Advantageous is of course the fact, that a specific problem statement is possible and precise adjustments to the needs of the PS-Organization are possible, but this creates an increasing subjective image. The use of a systematic literature review[168] should help to create a more general applicable model. On that account, we are convinced that this new maturity model can be applied in any industry organization which is producing any kind of products. Nevertheless, a wide and extensive application of this new assessment model can only be proved with an empirical evaluation within a greater amount of organizations and sectors. This would also enable to detect further weaknesses of the new model and help to continuously improve it. This would be important to ensure that the questionnaire is understood equally by different users.

Another point of criticism is the different process areas, here called dimensions and sub-dimensions, of the maturity model. The assessment itself with the corresponding questions is based on one globally accepted foundation, the CMMI[169]. However, the different sub-dimensions are based on different literature. Even if a systematic literature review was conducted to reduce this impact, it would still be favorable, if one already existing norm could have been used as foundation of the different dimensions and sub-dimensions. This would imply that the different steps which are necessary to conduct conform and uniform process-audits would be based on globally accepted standards. Nevertheless, the systematic literature review guarantees that all of the available information is considered. Accordingly, the selection and definition of the different dimensions and sub-dimensions are considered as adequate for this master's thesis.

Summarizing, the limits of this Action Research Methodology are mainly referring to scientific issues. Concerning the PS-Organization, this new maturity model was determined as adequate to assess their current process-audit procedure and to represent their weaknesses. With regard to the world of science, further researches are necessary to confirm this new maturity model. In the scope of this master's thesis, this was however not possible. Thus further research directions will be discussed in the following section.

[168] P. V. Torres-Carrion et al. , 2018
[169] Carnegie Mellon, 2006

5.3 Further Research Directions

Based on the experiences of this work, the following research points need to be clarified within following researches:

- The demonstration of the new maturity model needs to be done in other organizations to detect further weaknesses and confirm its applicability.
- Based on the supplementary demonstrations, the sub-dimensions and the questionnaire itself need to be adapted to create a more general assessment model.
- Verify if the model is applicable in other domains.
- Create a norm for conform and uniform process-audits → process areas of this maturity model

Regarding the applicability of this new model, it is of major importance to test the new assessment model within other organizations. This would allow conforming and improving the new maturity model. Furthermore, it would be interesting to see, if this new maturity model can also be used within other domains. The aim was to create a model which can assess the quality of production process-audits. However, processes do not only exist in the industry, but also in other domains like finance, health, banks and in the public sector. Accordingly, it would be interesting to verify its applicability in those domains. This would create a globally applicable tool, to assess the quality of processes in every domain. Additionally, it can be considered to reduce the number of sub-dimensions, to simplify the model and make it easy to use. The proposal is to combine A2 (Risk determination & Collection of information) with A3 (Standardized assistance form) and C1 (Monitoring & Reporting) with C2 (Analysis). Those sub-dimensions treat similar issues and could thus be combined.

Furthermore, to ensure conform and uniform process-audits on a globally accepted basis, it would be necessary to create some kind of process-audit procedure norm. Applying this norm towards this new assessment model would imply a standardized applicability for every organization within the production domain.

In addition to the world of science, further support from the PS-Organization is required as well. Firstly, they need to assess their process-audit procedures in every plant, which permit to compare the differences they have, depending on their location. Ideally, the results from the other plants would be similar, which would represent a consistent quality, independent from the location. If differences are detected, it should easily be possible to resolve those and adjust them. Secondly, the assessment needs to be done on a regular basis, to be able to determine improvements and in addition detect potential new deficiencies. The assessment does not need to be done on a weekly or monthly basis but could maybe be an interesting assistance tool for the annual balance.

5.4 Conclusion

Relating to the initially defined research question and sub-questions, it was possible to solve all the given problems within this thesis. Using a continuous representation, this new maturity model combines all of the given requirements and was demonstrated within the PS-Organization. The overall result can thus be stated as adequate.

Despite some deficiencies and certain restrictions, we are convinced that this new process-audit procedure maturity model can be a valuable tool to assess the currently used procedures and detect weaknesses. Furthermore, it can be an advantageous tool for organizations, which are planning on introducing process-audits. This new model allows them to introduce from the beginning on uniform process-audits and can help them to guide to more and more stable process-audits and therefore increase their quality, the same as their potential to detect failures before they get critical.

Nevertheless, the limitations and further research directions should be considered as well. Since this model was only applied within one organization, the significance and the applicability of this model is limited and requires further validations. This would be important to confirm its applicability within other organizations. Furthermore, a standardization of the different process-audit steps, the process-audit procedure, can be mentioned once again at this point.

A last important statement, worth to be mentioned at this point, is continuous improvement. It is nearly impossible to have from the beginning on the perfect tool or model, but it is possible to approach this state step by step. Therefore, continuous improvement is so important in today's world. In this case, while improving continually the process-audits it is possible to continually increase the quality of the production processes. Thus the importance to conduct process-audits in production organization, mainly in the automotive sector, should be emphasized here. They are an important and valuable tool to guarantee high quality products, and should not be neglected. Resources which are invested to improve the quality of an organization are always well invested.

Concluding, a quote from one of the pioneers from the quality management, William Edwards Deming, should help to understand this statement:

"*Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.* "[170]

[170] E. Deming, 1982

6 Appendix

6.1 Additional results from google research – Process-audit procedure

Hereinafter, the 7 additional results concerning the process-audit procedure from a google research are listed. They were mentioned in 3.3, in order to receive additional information. The first two results refer to books found with Google Books and the remaining 5 results are articles.

1. Ablauf eines Audits → **G. Schneider, I. K. Geiger, J. Scheuring**: "Prozess- und Qualitätsmanagement", p.120 , 2008

2. Auditablauf → **S. Pfaff, P. Dunkhorst**: "ISO 9001:2008 Basis für praxisgerechte Managementsysteme" , p. 227, 2009

3. *4 Phases of an audit* → https://asq.org/quality-resources/auditing ,(last accessed on the 27th February 2019)

4. Steps in the internal audit → https://advisera.com/9001academy/knowledgebase/five-main-steps-in-iso-9001-internal-audit/ ,(last accessed on the 27th February 2019)

5. Internal Audit Process Map → https://www.iso-9001-checklist.co.uk/download/ISO-9001-2015-internal-audit-process-map-sample.pdf ,(last accessed on the 27th February 2019)

6. Ablauf für das Leiten und Lenken eines Auditprogramms (nach ISO 19011) → http://www.paeger-consulting.de/html/iso_19011.html ,(last accessed on the 27th February 2019)

7. Definieren Sie konkrete Ziele in Ihrem Auditprogramm → https://www.qualitaetsmanagement-qm.de/qm-ausgaben-pro-sys/iso-9001-audit-plan-auditprogramm/ ,(last accessed on the 27th February 2019)

6.2 Questionnaire

Hereinafter, the improved questionnaire can be found. This questionnaire shows the results which are easily reachable. The needed adjustments and renewals can be found in 4.6 (Evaluation). All of the improvements are listed in orange.

Assessment of the Maturity level for every Process-Area

To determine the maturity level of every process area, according to the generic goals and practices of the CMMI, the following questionnaire was determined. (0: negative answer; 1: positive answer, Answers to questions with sub-questions will be calculated automatically e.g. 2.2)
Dimension:
Sub-dimension:
Identification Question:

Level 1: Acheive Specific Goals	
GP 1.1	***Achieve Specific Goals*** **(process needs to exist)**
Fulfillment (%):	
Reached Level 1?	
Level 2: Institutionalize a Managed Process	
GP 2.1	***Establish an Organizational Policy*** **(guideline to perform the process needs to exist)**
GP 2.2	***Plan the Process*** **(establish and maintain the actual plan to perform the process)**
GP 2.2.1	Define and document the plan for performing the process
GP 2.2.2	Define and document the process description
GP 2.2.3	Review the plan with relevant stakeholders and get their agreement
GP 2.2.4	Revise the plan as necessary
GP 2.3	***Provide Ressources*** **(adequate ressources need to be available to perform the process)**
GP 2.4	***Assign responsibility*** **(responsibilities need to be assigned to perform the process)**
GP 2.4.1	Assign overall responsibility and authority for performing the process
GP 2.4.2	Assign responsibility and authority for performing the specific task of the process
GP 2.4.3	Confirm that the people assigned to the responsibilities understand and accept them
GP 2.5	***Train people (*** **responsible people of the process need appropriated trainings)**
GP 2.6	***Manage Configurations*** **(designated components of the process need be placed under appropriate control)**
GP 2.7	***Identify and Involve Relevant Stakeholders*** **(necessary interactions of the process need to be regulated)**
GP 2.7.1	Identify stakeholders relevant to this process and their appropriate involvement
GP 2.7.2	Share these identifications with the process planners
GP 2.7.3	Involve relevant stakeholders as planned
GP 2.8	***Objectively Evaluate Adherence (supply credible assurance that the process is implemented as planned - by internal people which are however external to the process)***
GP 2.9	***Review Status with Higher Level Management*** **(the status of the process needs to be revised with a higher level management)**
Fulfillment (%):	
Reached Level 2?	

Level 3: Institutionalize a Defined Process	
GP 3.1	***Esatblish a Defined Process*** **(standard to perform the process needs to exist)**
GP 3.1.1	Establish an organizational standard
GP 3.1.2	Ensure that the organization's process objectives are appropriately addressed in the defined process
GP 3.1.3	Document the defined process and the records of the tailoring
GP 3.1.4	Revise the description of the defined process as necessary
GP 3.2	***Collect Improvement Information*** **(work products, measurements and improvement information of the process need to be collected)**
GP 3.2.1	Store process and product measures in the organization's measurement repository
GP 3.2.2	Submit documentation for inclusion in the organization's process asset library
GP 3.2.3	Document lessons learned from the process for inclusion in the organization's process asset library
GP 3.2.4	Propose improvements to the organizationa process assets
Fulfillment (%):	
Reached Level 3?	
Level 4: Institutionalize a Quantitatively Managed Process	
GP 4.1	***Establish Quantitative Objectives for the Process*** **(obtain agreement from relevant stakeholders about specific quantitative ojectives for the process)**
GP 4.1.1	Establish the quantitative objectives that pertain to the process
GP 4.1.2	Allocate the quantitative objectives to the process or its subprocesses
GP 4.2	***Stabilize Subprocess Performance*** **(stabilize the performance of one or more subprocesses to determine the ability of the process to achieve the established quantitative quality)**
GP 4.2.1	Manage KPIs of one or more subprocesses
GP 4.2.2	Predict the ability of the process to achieve its established quantitative objectives
GP 4.2.3	Incorporate selected process-performance measurements into the organization's process-performance baselines
Fulfillment (%):	
Reached Level 4?	
Level 5: Institutionalize an Optimizing Process	
GP 5.1	***Ensure Continuous Process Improvement*** **(select and systematically deploy process and technology improvements)**
GP 5.1.1	Establish and maintain quantitative process improvement objectives that support the organization's business objectives
GP 5.1.2	Identify process improvements that would result in measurable improvements to process performance
GP 5.1.3	Define strategies and manage deployement of selected process improvements
Fulfillment (%):	
Reached Level 5?	

Total Fulfillment (%)

Every 1 in orange represents an improvement through the new WI, Questions and Digitalisation

Plan			
Demonstrate ability of quality	**Risk determination & Collection of information**	**Standardized assistance form**	**Process-audit planning**
Does the commitment to conduct and improve process audits , fulfils the following requirements?	Does the process to gather production process relevant information, fulfils the following requirements?	Does the process to create standardized assistance forms, fulfils the following requirements?	Does the process to plan the execution of the process audits, fulfils the following requirements?

1	1	1	1
100%	**100%**	**100%**	**100%**
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
100%	**100%**	**100%**	**100%**
1	1	1	1

1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
100%	**100%**	**100%**	**100%**
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1
1	1	0.67	0.67
1	1	1	1
1	1	1	1
1	1	0	0
100%	**100%**	**83%**	**83%**
1	1	0	0
1	0.33	0.33	0.33
1	0	0	1
1	1	1	0
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Does the process to collect evidence, fulfils the following requirements?	Does the process to summarize and check the gathered information, fulfils the following requirements?	Does the process to analyze the information, fulfils the following requirements?	Does the process of following the process audits up, fulfills the following requirements?

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10 Glossary

This glossary is used to define the mode of expressions used within this thesis. The aim is to give a clear definition to important expressions used within this thesis.

Official Term	**Term used in this Thesis**	**Explication/ Definition**
Producer of sensors	PS-Organization	This master's thesis was established in cooperation with an organization, who is a producer of sensors. To not share any sensitive information or name the organization, a fictive name is used within this thesis.
Random Production Process Quality Audit Procedure	process-audit ("Quality Audit" Process)	By this term is meant, that the audits are focusing on different (random) production processes within the manufacturing area. Those audits verify if the production processes are running correctly and check if their quality corresponds to the given requirements. In this case it is NOT a matter of a system audit, but an audit of a random production process, for which a procedure should be defined. E.g.: printing process, soldering process, laminating process …
control	control	The English word control has two meanings in German. Control can mean: 1) "steuern", which means regulate or 2) "kontrollieren", which means check. If the word control is used in this thesis, it means to check something.
Level/ layer - Definition	Leve 1, 2, 3	Layered Process Audits (LPAs) require the involvement of multiple levels. Level 1 is the worker-level, here quality inspectors, level 2 is the engineer-level and level 3 is the management-level.
Capability Level	Maturity Level	In the title of this thesis, the same as in the Evaluation, the expression 'maturity levels' is always used. Strictly speaking, those are 'capability levels', since this new maturity model is a continuous representation. In order to not unnecessarily complicate the development of this new maturity model, the expression 'maturity levels' is used.

11 List of Abbreviations

AMM	Audit Maturity Model
BiC	Best-in-Class
BP	Best-Practice
CMM	Capability Maturity Model
CMMI	Capability Maturity Model Integration
DB	Data Base
DSRM	Design Science Research Methodology
EFQM	European Foundation for Quality Management
e.g.	For example
etc.	et cetera
GG	Generic Goal
GP	Generic Practice
h	hour
IATF	International Automotive Task Force
IPMM	Industrial Process Maturity Model
ISO	International Organization for Standardization
KPA	Key Process Area
LPA	Layered Process Audit
max.	maximum
MM	Maturity Model
PDCA	Plan Do Check Act
P-FMEA	Process – Failure Mode and Effects Analysis
PQA	Plant Quality Assurance
PVF	Predictive Validity Framework
SG	Specific Goal
SP	Specific Practice
SQA	Software Quality Assurance
TQM	Total Quality Management
VDA	Verband der Automobilindustrie
WC	World-Class
WCM	World-Class-Manufacturing