Fraunhofer IEM

HEINZ NIXDORF INSTITUT
UNIVERSITÄT PADERBORN

Master thesis

Industrial Engineering Mechanical Engineering

Methodology for planning maturity level-specific engineering training projects in industry

submitted by

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Paderborn, 25.04.2025

Master thesis no. MA0377

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on: 25.04.2025

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Declaration in lieu of an oath:

I hereby declare in lieu of an oath that I have prepared this thesis independently and without unauthorized outside help, have not used any sources or aids other than those specified and have marked the passages taken from the sources used verbatim or in terms of content as such.

Paderborn, 25.04.2025

Methodology for planning maturity level-specific engineering training projects in industry

Summary

In this thesis, a methodology for planning maturity-specific engineering training projects was developed. After analyzing the increasing complexity of technical systems and the associated challenges for companies, SE was identified as a suitable approach to meet these challenges. It became apparent that the successful introduction of SE depends heavily on the company-specific planning of the qualification measures.

Based on a comprehensive literature review, existing approaches to maturity measurement and qualification planning were examined. From this, requirements for a practice-oriented methodology were derived. The methodology developed takes into account the specific maturity level of a company, summarizes diverse role profiles in a standardized way using role clusters and evaluates the necessary competencies using a competence scale.

The application in a fictitious example company showed that the method can be used to implement tailored qualification planning. In particular, the consideration of the company's maturity level and competence profiles makes it possible to design individual learning paths for different target groups. This ensures that both basic training courses and specialized further training measures can be offered in line with demand.

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1 Introduction

This thesis deals with the development of a methodology for maturity level-specific qualification planning. This chapter begins by outlining the problem and explaining the aim of the work. This is followed by a brief description of the approach taken in the thesis.

1.1 Problem

The increasing complexity of technical systems presents companies with new challenges. The shift from mechanical and electrical systems to cyber-physical systems is leading to an increasing number of interfaces and a greater need for interdisciplinary collaboration [GO22, p. 4f., DAR+21, p. 21]. At the same time, development times are decreasing, while quality and flexibility requirements are increasing. This development requires efficient methods to make development processes manageable and to cope with increasing competitive pressure. [WSR+23, p. 4f.]

Systems engineering (SE) has established itself as a suitable approach for mastering the increasing complexity and coordinating interdisciplinary developments [GO22, 7f.]. However, the introduction of SE in companies is challenging. Different maturity levels of the organizations, diverse role profiles and heterogeneous competencies of the employees make it difficult to establish uniform SE approaches. Targeted training in particular represents a key challenge. [DAR+21, P. 118]

1.2 Objective

The aim of this thesis is to develop a methodology for planning engineering training projects that takes into account the specific maturity level of a company. The methodology developed is intended to support companies in designing qualification measures in line with their needs. Individual role profiles, company maturity levels and different competence levels are systematically taken into account. The modular structure of the methodology enables flexible variant management in order to map company-specific qualification paths.

1.3 Procedure

First, the existing challenges in the development of complex technical systems are analyzed and SE is classified as a solution approach. Building on this, existing approaches to maturity level measurement and qualification planning are examined, which serve as the basis for the development of the methodology of this work. Finally, the developed methodology is applied using a practical example and evaluated by experts in order to validate the benefits and feasibility.

2 Problem analysis including requirements for the methodology

2.1 Complex technical systems

Continuous technological progress poses new challenges for the development of products. The shift from mechanical and pneumatic/hydraulic systems to cyber-physical systems is accompanied by an ever-increasing number of interfaces and the growing need for interdisciplinarity. [GO22, p. 4f., DAR+21, p. 21] This leads to a continuously growing system complexity, which poses new challenges for product development. In order to develop a product that meets the requirements, it is necessary to have a common understanding and a common vision. Different development teams must work together to understand and develop systems. [WSR+23, p. 1] A methodology that brings stakeholder needs, expectations and constraints to a solution is essential. Development times are also becoming ever shorter and time-to-market is decreasing, while the complexity of development continues to increase. This increases competitive pressure and the need for more efficient development approaches is growing. [WSR+23, p. 4f.]

In addition to the increasing complexity of new systems, life cycle complexity is also increasing. Due to the desire for circularity across several life phases, all life phases of a system must be considered with foresight, as shown in Figure 2-1. To this end, it must be ensured that materials and information flow back into the individual life cycle phases and are taken into account in the development of new products. Aspects such as use, maintenance, servicing and recyclability must be planned as early as the development stage. [GO22, 5f., Wei14, p. 13]

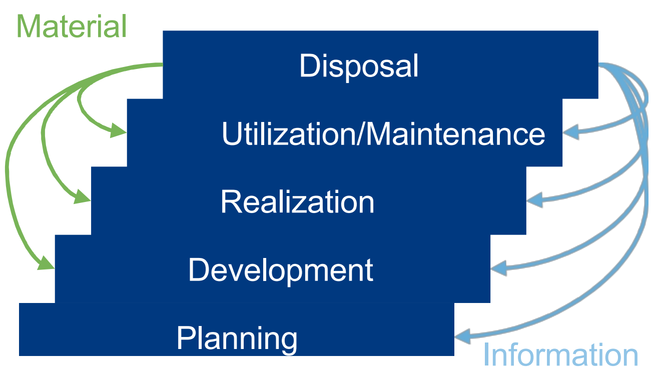


Figure 2-1 Life cycle phases and repercussions in the development according to [GP21, p. 14]

2.2 Systems Engineering

Conventional, discipline-specific development processes are no longer sufficient to meet the requirements of complex system development. With SE, an approach has been developed to master complexity and achieve an interdisciplinary optimum. All disciplines involved are integrated and all phases of life are taken into account. Holistic thinking is also promoted. [GO22, p. 7f., Wei14, p. 11f., DAR+21, p. 21]

2.2.1 Definition of systems engineering

There are a number of industry-specific works with different definitions for SE, such as INCOSE, EISNER and NASA. [INC19-ol, Eis08, p. 5, NAS16, p. 3] This paper refers to the GfSE definition, which translates the INCOSE definition into German:

> *"Systems engineering is a transdisciplinary and integrative approach that enables the successful realization, use and decommissioning of technical systems using system principles and concepts as well as scientific, technological and management methods."* [GfS24-ol]

INCOSE also defines six key areas for SE: [WSR+23, p. 2]

- Firstly, the criteria and objectives of the stakeholders should be taken into account. To this end, stakeholder requirements are determined in the early development phases and the concepts and functions of the system to be developed are defined.
- A suitable life cycle model must also be developed in order to take into account the complexity and uncertainties in the development and to counteract changes.
- Several alternative solution concepts and architecture alternatives must be created.
- Requirements must be created and the solution architecture modeled for each phase of development.
- During design synthesis, a physical architecture is created that fulfills the previously defined functions [IBM24-ol]. Constant verification and validation are necessary here.
- During the entire development process, relevant systems and services should be taken into account and the behavior of individual system elements in relation to the overall system should be examined. A satisfactory solution should then be found by considering the problems and possible solutions.

Modern systems are developed under a variety of disciplines. None of these disciplines can meet all requirements alone. This is why an interdisciplinary approach such as SE is necessary. Interaction with stakeholders during development must also be encouraged. [DAR+21, p. 28] SE helps to manage the disciplines involved in development. In this way, an orderly development process can be created that supports the product life cycle and the requirements of customers and other stakeholders can be satisfied. Risks, such as delayed delivery or failure to meet requirements as well as excessive costs, are minimized by SE. [WSR+23, P. 2]

Systems are an important component of SE and are defined by INCOSE as follows:

> *"A system is an arrangement of parts or elements that together exhibit behavior or meaning that the individual constituents do not"* [ISO/IEC/IEEE 15288:2023, p. 11]

A system therefore has more functions together than each of its individual elements and can be physical, conceptual or a mixture of both. A complete system includes all the components required for operation. [WSR+23, p. 1f., INC19- ol]

A system can be viewed from the inside and from the outside. The system boundary separates the system under consideration, also known as the system of interest (SoI), from its environment. The internal view describes the elements of the system that lie within the system boundary. The external view also describes elements that are not part of the system but interact with it. Environmental elements are also referred to as the system environment or system context. The system environment also includes other systems with which the system interacts. [SEB23-ol, p. 96ff.] The demarcation of a system from its environment is shown in Figure 2-2.

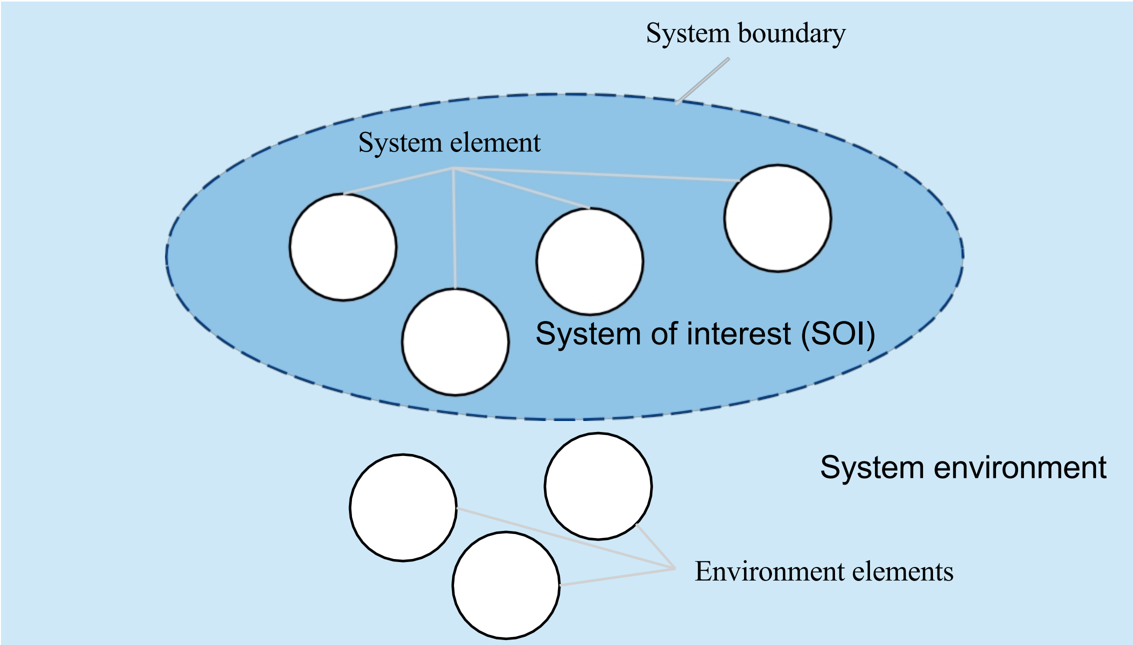


Figure 2-2 Delimitation of system and system environment with system boundaries according to [SEB23-ol, p. 98]

2.2.2 Benefits of systems Engineering

The use of SE begins in the early phases of product development in order to master complexity and manage changes. When developing new systems, only a small proportion of the total costs are incurred in the early phases of product development. However, a large proportion of the costs have already been determined at this stage. For example, only 20% of the costs are incurred in the concept phase, whereas 80% of the costs have already been determined at this stage. Similarly, the costs for error correction increase the later errors are discovered during development. [WSR+23, p. 7] The "rule of 10" states that the cost of eliminating a bug increases 10-fold with each subsequent development phase. Sufficient time should therefore be invested in the early phases of development in order to avoid late error detection and save costs. [DAR+21, p. 64, Ver24-ol] SE supports this approach, which is also referred to as frontloading [GO22, p. 115]. The distribution and increase in costs over the product life cycle are shown in Figure 2-3.

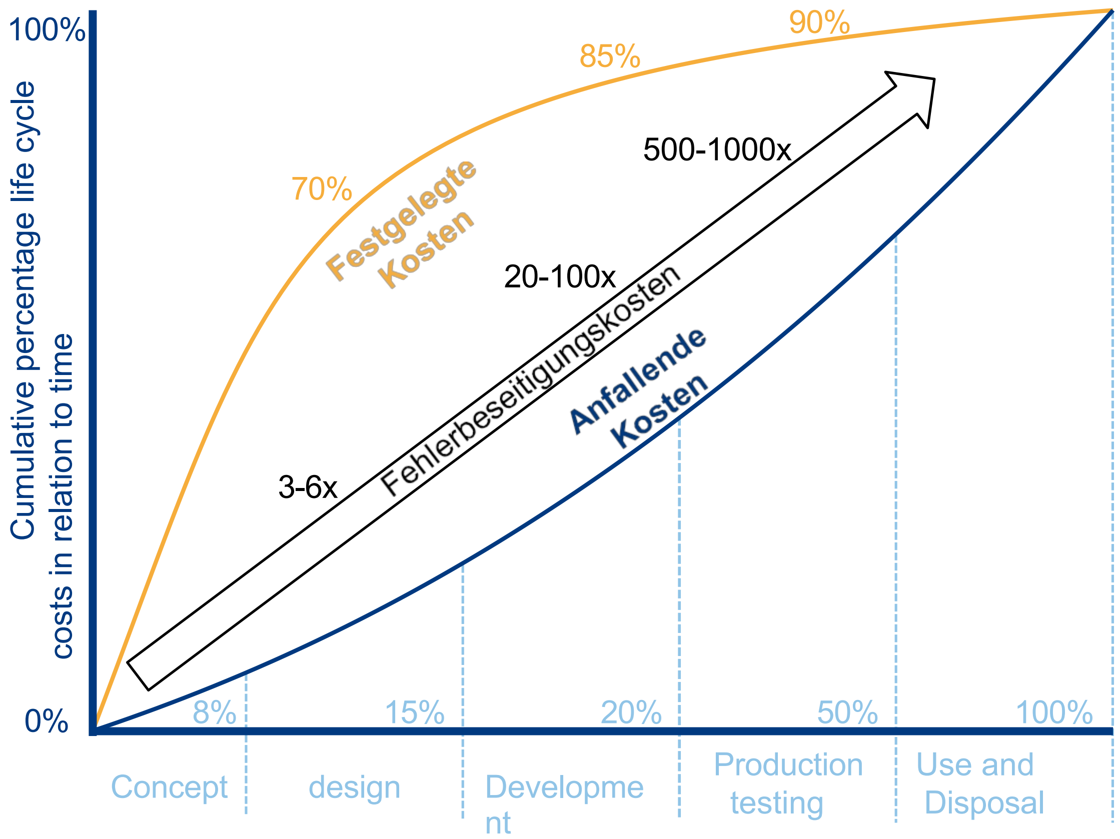


Figure 2-3 Cost distribution in a product life cycle according to [WSR+23, p. 7].

SE is already used in a large number of companies in mechanical and plant engineering, as well as in the automotive industry. It is already standard in the aerospace and defense industries in order to reduce risks in development. [GO22, p. 13] A study by ELM AND GOLDENSON examined the effectiveness of SE. 148 development projects with different SE competencies were examined for compliance with the objectives of quality, costs and time. A clear correlation between project success and increasing SE competence was found, which is shown in Figure 2-4. The majority of projects in which SE competence was low were only able to demonstrate a low level of project success, while the proportion of successful projects increased with increasing SE competence. [EG12, P. 28]

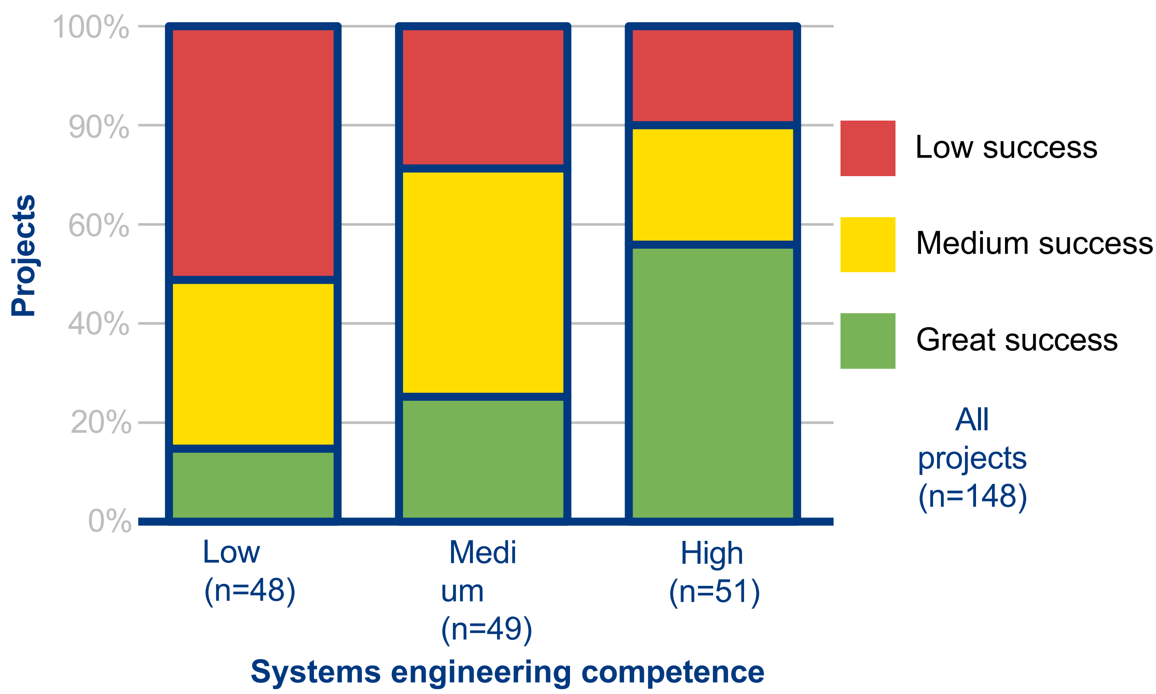
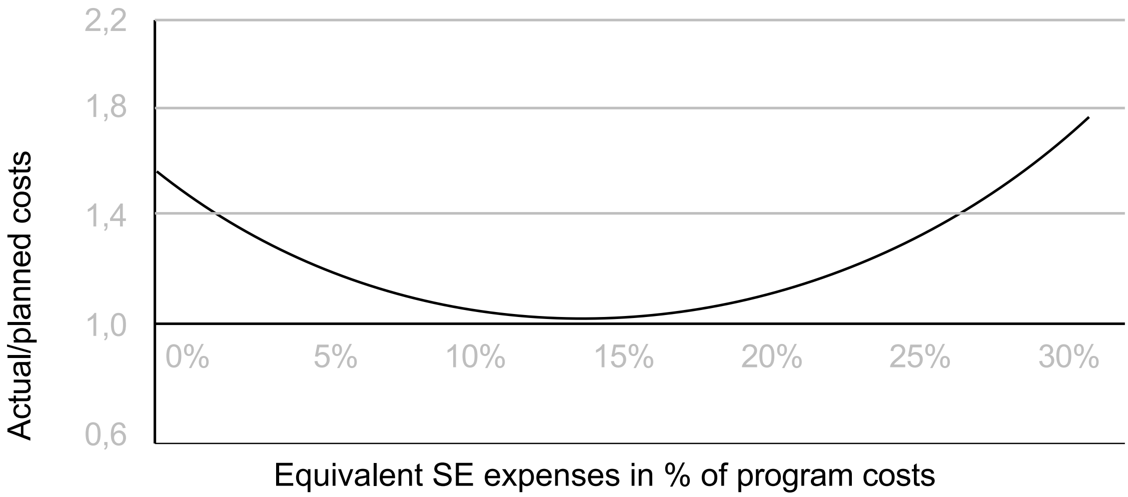


Figure 2-4 Project success dependent on systems engineering competence according to [EG12, p. 28]

Another study by HONOUR examined the relationship between SE and project success by investigating the effects of the intensity of SE use on the cost and time planning of development projects. In the study shown in Fig. 2-5, it was found that projects deviate from the planned costs (section a) and deadlines (section b) if both too little and too much SE is used. HONOUR thus found that the use of SE has a positive effect on project success up to a certain level. However, too much use has a negative effect on deadlines and costs. An optimum level of SE effort must therefore be found. In the study, this was around 14% of the program costs. [Hon10, p. 1430] a)



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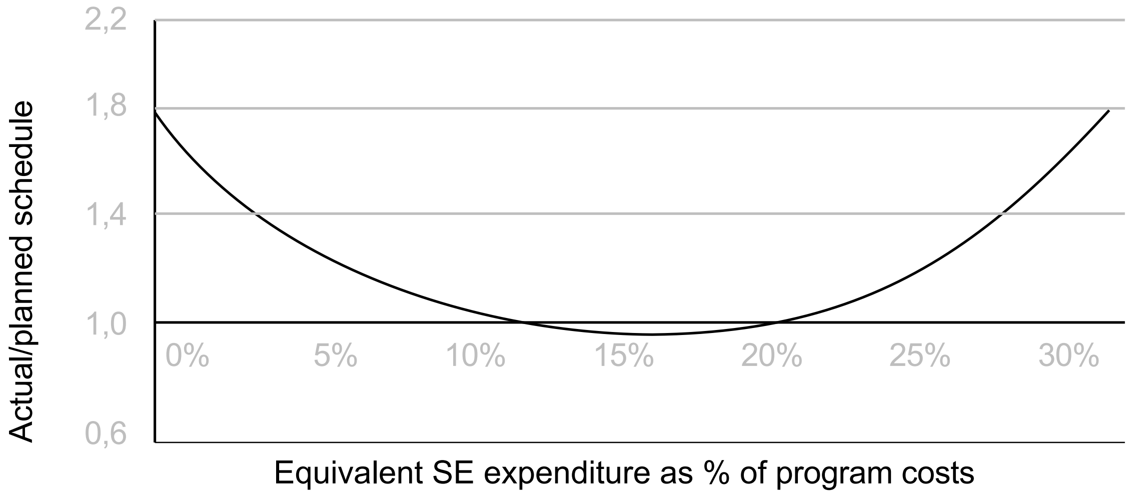

Figure 2-5 Time and cost plan deviation depending on the systems engineering effort according to [Hon10, p. 1430].

2.2.3 Characteristics of systems engineering

In order to successfully implement SE in companies, a holistic approach is necessary that also considers people and the organization. [MUNDT ET AL. identify 12 SE principles that are necessary to successfully implement SE:

- **Interdisciplinarity** means that different perspectives must be considered and different disciplines must work together. [MWA+23, P. 1309]

- **Holistic** describes that the system as a whole must be considered throughout the entire development process. The effects of different disciplines must be considered. [MWA+23, P. 1309]
- **Stakeholder centricity** means that all stakeholder needs must be understood and taken into account. [MWA+23, P. 1309]
- **Reuse and standardization** result from the reuse of knowledge through uniform processes, tools and interfaces. [MWA+23, P. 1309]
- **Risk-driven and evidence-based decision-making** describes finding decisions by analyzing alternatives. Decisions should be reviewed by experts, finding a balance between cost, schedule and performance. [MWA+23, P. 1309]
- **Early verification and validation** means defining test criteria at an early stage and continuously checking whether these are achieved. Models can provide support here. [MWA+23, P. 1309]
- **Interface management** describes the ability to keep interfaces simple and ensure a uniform understanding of interactions. [MWA+23, P. 1309]
- **Documentation** is a central part of SE. It must be consistent, complete, transparent and traceable. [MWA+23, P. 1309]
- **Effectiveness over efficiency** aims to achieve the greatest possible value while utilizing the available resources. The main goal should not be to minimize costs. [MWA+23, P. 1309]
- **Iterations and adaptability** are necessary because systems are developed iteratively in SE. [MWA+23, P. 1310]
- **Complexity in order to manage complexity** describes the need for complex models and organizations in order to be able to develop complex systems. [MWA+23, P. 1310]
- **Top-down and up-front development** is development from the top down with self-contained development phases. Frontloading plays a decisive role in SE in order to be able to recognize problems at an early stage (see chapter 2.2.2). [MWA+23, P. 1310]

2.2.4 SE processes

SE comprises 30 processes that contain proven procedures for solving development tasks. The 30 processes can be divided into **technical processes**, **technical management processes**, **agreement processes** and **organizational project support processes**.

The **technical** processes represent the main processes of the SE. Processes that serve the direct creation of value are summarized here. The entire life cycle of a system is represented by the individual processes. [GO22, p. 116f.] The technical processes are shown in Figure 2-6.

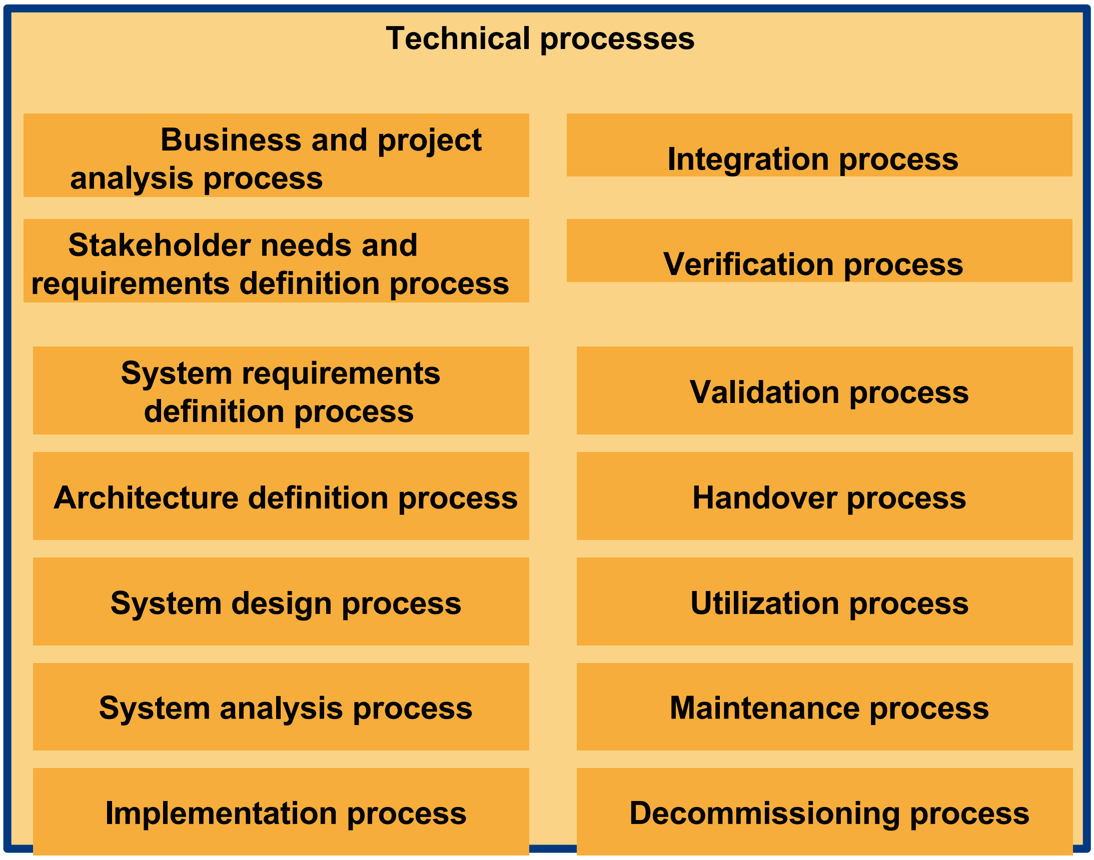

Figure 2-6 Technical processes of the SE [WSR+23, p. 101ff.].

Technical management processes are used to coordinate the development process. They serve as an interface between the technical development steps and project management. The technical management processes also facilitate collaboration between the system engineer and the project manager. [GO22, p. 70ff.] Figure 2-8 summarizes the processes.

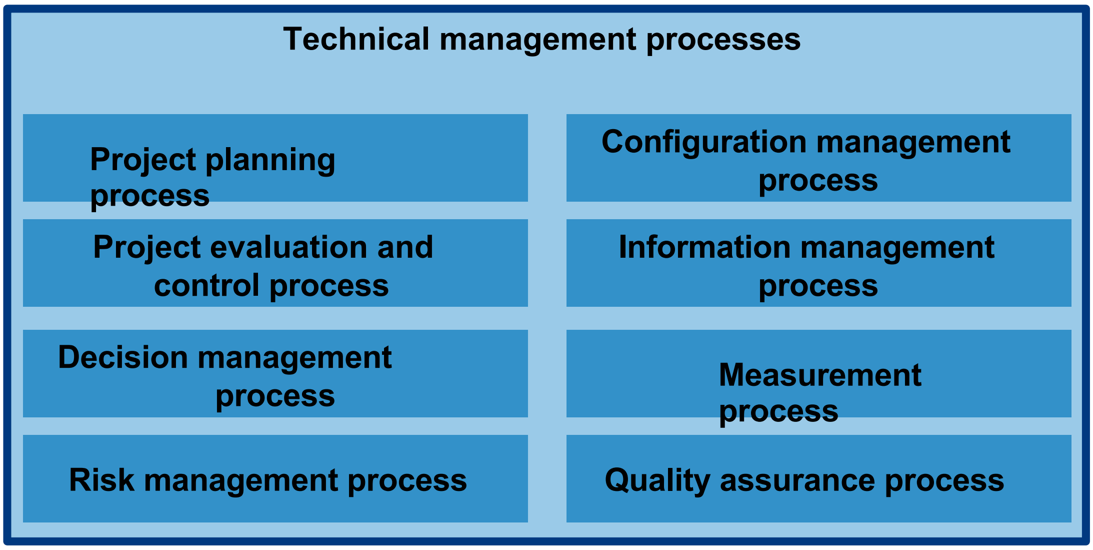

Figure 2-8 Technical management processes of the SE [WSR+23, p. 101ff.].

Organizational project support processes have been defined to meet the organizational requirements of a project. These processes create the prerequisites for successfully carrying out the development project. These include, for example, setting up a suitable infrastructure and recruiting personnel. [GO22, p. 118] Figure 2-7 shows the associated processes.

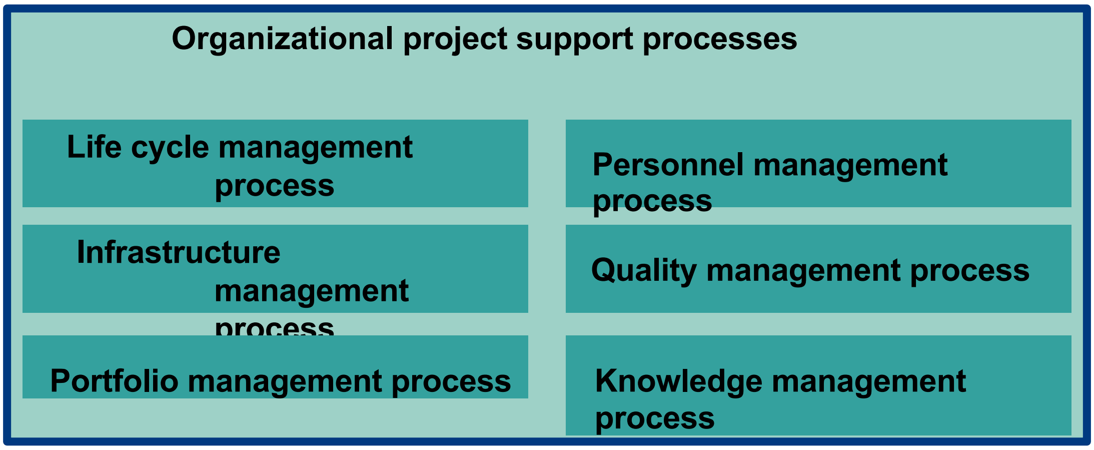

Figure 2-7 Organizational project support processes of the SE [WSR+23, p. 50ff.].

Finally, the **agreement processes** are used to reach agreements between different parties. In this way, suitable suppliers or other partners can be identified and recruited. Figure 2-9 shows the agreement processes.

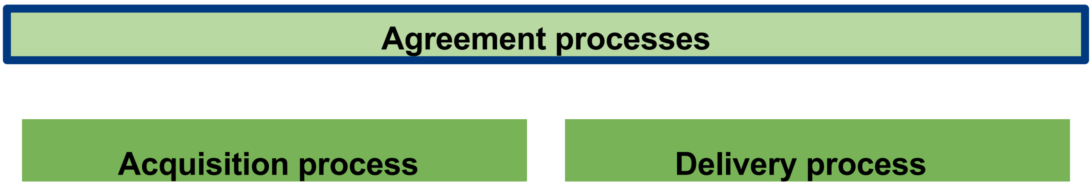

Figure 2-9 Agreement processes of the SE [WSR+23, p. 44ff.].

The extent to which the respective processes are required depends on the use case. The adaptation of the development processes and adaptation of the SE deployment to the use case is also called tailoring. [ISO/IEC/IEEE 15288:2023, p. 20f., GO22, p. 109]

2.2.5 SE methods and tools

Methods are used to support the activities of a company. The systems engineer is responsible for selecting the appropriate methods. There is a wide range of methods, from information procurement to information processing and decision-making. The application varies depending on the application context. Methods used in SE have not been developed specifically for SE and relate to areas such as quality management. For example, interviews or the scenario technique can be used to obtain information. Methods such as the 635 method and the morphological box are used to process information. In order to make decisions on the basis of information, a cost-benefit analysis or utility analysis can be carried out. The use of methods must be checked regularly during application. Tailoring (see chapter 2.2.6) can be used to determine a selection of suitable methods. The task, the environment and the stakeholders must be taken into account. [GO22, p. 47] When applying and selecting methods, care must be taken to ensure that they are not used "for the sake of the method". The criterion for the use of special methods must always be the progress of the project. It is important to note that using too many methods can be detrimental to the progress of the project. [GO22, p. 48f.] GRÄßLER AND OLEFF define the three questions "What", "How" and "With what" for the selection of methods. First, the "What" should clarify which task is to be completed. "How" deals with the question of which working method to choose. Only after the previous questions have been clarified does the third step
"With what" refers to the selection of suitable methods. [GO22, P. 49]

To support the tasks of the SE, there are a number of *tools* in addition to the methods. INCOSE provides a detailed overview of various tools for different application purposes. The tools presented are assigned to the processes of the SE Handbook (see chapter 2.2.4), among others. The detailed list of all SE tools is presented in [Int25-ol].

2.2.6 Tailoring

The methods and standards of the SE can often not be applied to all organizations or projects without further ado. Adaptations are necessary to tailor the SE to the company. This is to ensure that it meets the requirements of the projects in which it is used. Tailoring adapts the processes in such a way that the benefits of these processes outweigh the risks. Without suitable tailoring, the costs can exceed the benefits (see section 2.2.2). [WSR+23, p. 215] The effort should only be so high that all desired functions of a system can be realized without exceeding time or costs. Figure 2-10 shows that both an excessive limitation of SE processes and the use of too many SE processes can lead to risks. Tailoring is carried out at company level, divisional level and project level, whereby the most suitable SE practices are selected, supplemented and concretized. [GO22, P. 35]

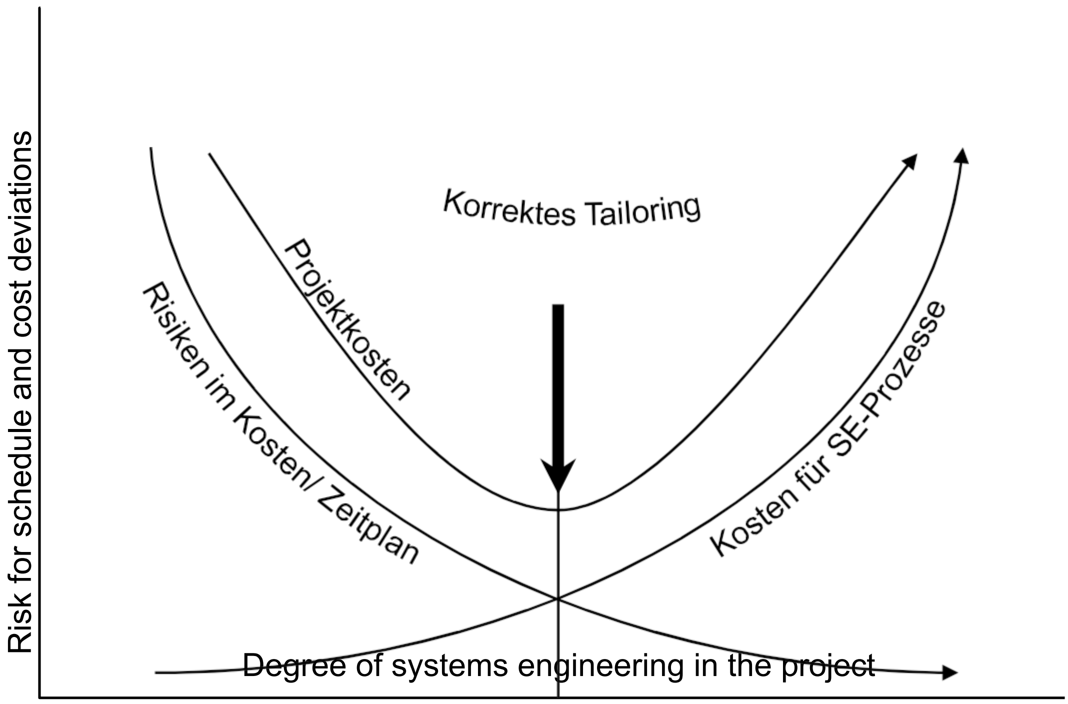

Figure 2-10 Balance between costs and risks in tailoring according to [WSR+23, p. 216].

2.2.7 Development methodologies

Development processes in SE begin with the recording of stakeholder needs, which are then translated into system requirements. These are broken down into smaller and smaller segments until the lowest level of detail is reached. Elements are then integrated until a functioning, validated system has been developed.

has been developed. Life cycle models of product development, such as ROYCE's waterfall model or BOEHM's spiral model, represent the life cycle phases graphically. However, graphical representations tend to depict the development phases as linear. However, this does not adequately depict the incremental, iterative and recursive procedures that are common in SE. [FM91, p. 2ff., WRF+15, p. 33f.]

The V-model is a sequential graphical representation of the life cycle phases in development, which takes up these problems and represents the development phases as they are common in SE. The V-model was first developed by BOEHM in 1979 for software development and taken up by BRÖHL UND DRÖSCHEL in 1995. It describes holistic, methodical support to support interdisciplinary collaboration. At the center of the model is a "V", which breaks down the system into individual elements and subsystems in the left leg and reassembles them in the right leg. The properties of the elements are repeatedly verified and validated, as shown in Fig. 2-11. Verification describes the process of checking whether a system fulfills the defined specifications, i.e. whether a system has been developed correctly. Validation checks whether a system fulfills the requirements for the defined benefit, i.e. whether the right system has been developed and the customer's needs are met. Verification and validation are also referred to together as property assurance. [VDI/VDE 2206:2021, p. 17ff.]

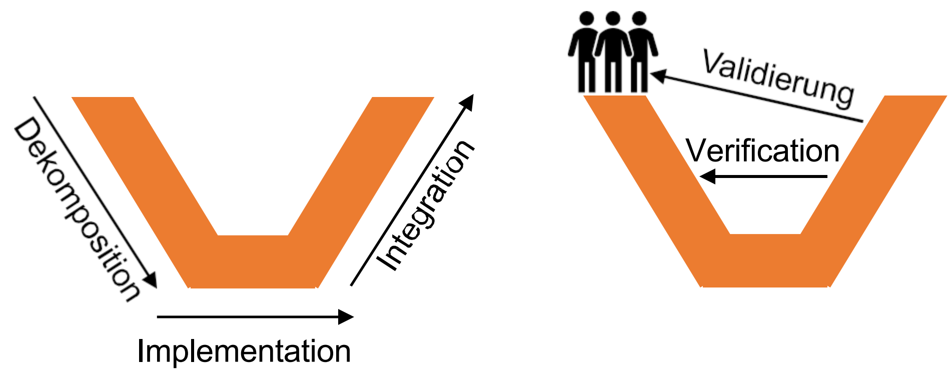

Figure 2-11 Basic idea of the V-model according to [Grä18, p. 12]

In VDI/VDE 2206 from 2004, the idea of the V-model was transferred from software development to the development of mechatronic systems. Due to the ever-increasing complexity and networking of systems, as well as digitalization and connection to the Internet of Things and Services, the 2021 guideline was revised in VDI/VDE 2206:2021 and adapted to the development of cyber-physical systems. The guideline is intended to help obtain an interdisciplinary, holistic view of the system to be developed, as required in the SE. [Boe79, p. 3f., VDI/VDE 2206:2021, p. 2ff.]

The V-model does not describe a chronological sequence, but merely depicts logical relationships. Development tasks should run in parallel and can be iterated through at each point of the V-model. Critical subsystems can be worked on until they are ready for series production until the higher-level system is developed. [VDI/VDE 2206:2021, p. 2f.] The V-model is independent of the project organization and can be used in agile development projects as well as in classic projects [VDI/VDE 2206:2021, p. 18ff.].

The V-model of VDI/VDE 2206:2021, shown in Figure 2-12, is made up of three different strands that are run through in parallel. The middle strand represents the core tasks of system development, while the outer strand represents the parallel modeling and analysis of the system. The inner strand refers to the development of requirements and includes the continuous examination of the requirements. Interdisciplinary cooperation is emphasized in the V-model by the representation of different disciplines with dotted, dashed and solid lines. [VDI/VDE 2206:2021, P. 21]

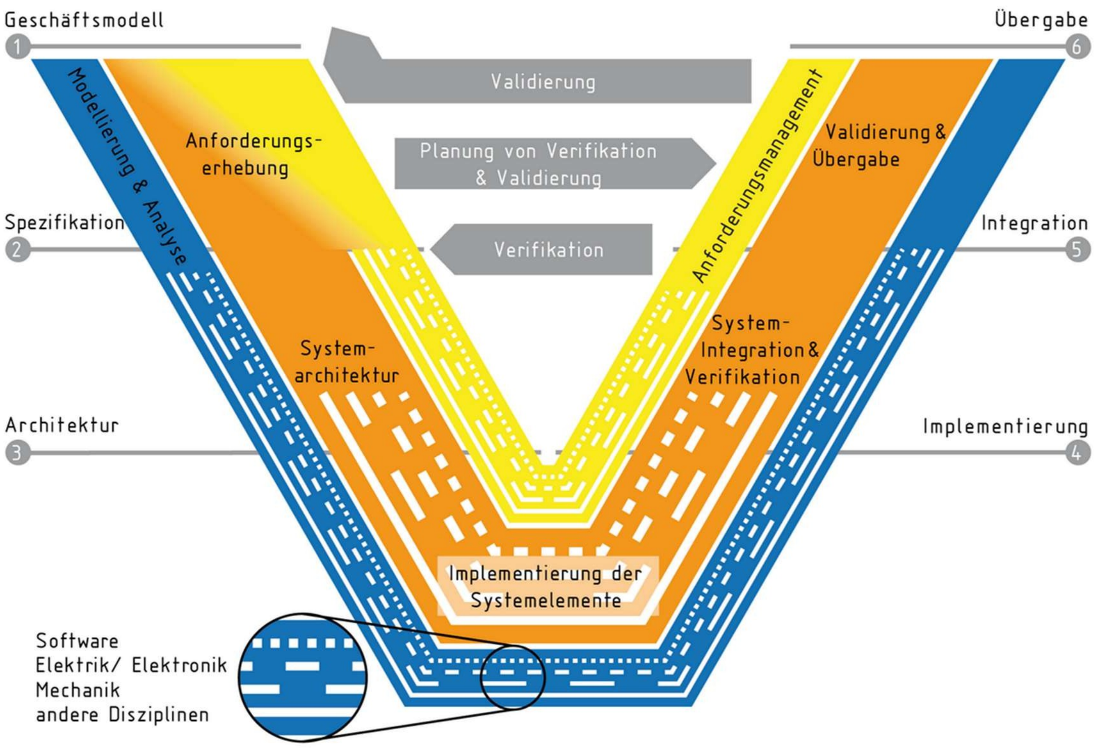

Figure 2-12 V-model from [VDI/VDE 2206:2021, p. 22]

Parallel to the development tasks, property validation should always be planned and carried out. This is represented in the V-model by arrows between the legs of the model. The planning of property validation should already take place in the left leg. In addition to the development tasks, criteria for verification and validation are identified and it is determined how these are to be checked. [VDI/VDE 2206:2021, p. 24ff.]

2.2.8 Roles in systems engineering

Roles represent a specific function within a process and must not be confused with job descriptions. [BGH+18, p. 13f.] A number of role profiles are proposed in the literature for SE. [DAR+21, p. 72f.]

One approach to defining roles comes from KÖNEMANN ET AL. In the SE4OWL research project, they found that role descriptions can vary between companies. This makes it difficult to introduce SE in line with competencies, which is why 14 clusters were defined in which all roles that are relevant for the introduction of SE can be categorized. Each of these roles requires a different understanding of SE and its processes. By dividing them into role clusters, the qualification can be specifically tailored to the competencies of the individual roles. [KPM+23, p. 27] The individual role clusters are explained in more detail below.

Customer representative

Customer representatives are the interface between the customer and the company. The roles in this cluster therefore serve as a source for all customer-relevant information. [Wec23-ol]

Project manager

The second role cluster is responsible for planning and coordinating the project. The roles in this cluster assume responsibility for achieving the project objectives and serve to monitor resources. [Wec23-ol]

System developer

Roles within this cluster are responsible for maintaining an overview of all requirements and dividing the system into individual system elements and interfaces. System developers take care of the integration of the system and liaise with the relevant technical experts. [Wec23-ol]

Specialist developers

In this role cluster, new technologies are developed based on the specifications of the system developers and systems are realized based on the system developer cluster. [Wec23-ol]

Production planner

Production planners prepare the realization and handover of a product. [Wec23- ol]

Production employees

The roles in this cluster are concerned with the processes required to realize a product. This includes, for example, assembly and production, but also goods issue and dispatch. [Wec23-ol]

Quality manager

The seventh cluster ensures that all quality standards are met within the company. To this end, there is close cooperation with V&V. [Wec23-ol]

Internal support

Internal support includes the support side during development. This includes IT support, qualification support and SE support. [Wec23-ol]

Process and guideline manager

This role cluster is used to develop internal guidelines for the creation of process flows. At the operational level, process and guideline managers monitor compliance with all specifications. [Wec23-ol]

Service technician

The roles in this cluster are responsible for all service-related tasks such as installation, commissioning and user training. Maintenance and repair are also part of the tasks. [Wec23-ol]

Innovation and strategy manager

The cluster is responsible for the commercial implementation of products or services. New business models and processes are also designed here. [Wec23-ol]

Management

Roles in this cluster always have the vision and goals of the company in mind and are crucial for the progress of the project. [Wec23-ol]

V&V

The cluster is responsible for the verification and validation of the system. The role cluster should be involved at an early stage of development. This ensures that the system can be verified and validated later on. [Wec23-ol]

Customer

The customer is the client for the development and therefore has an impact on the design of the system. [Wec23-ol]

Based on the defined competencies of the Extended INCOSE Competency Framework, which is presented in chapter 2.3.1, the necessary degrees of fulfillment of individual role clusters were identified. To this end, three matrices were drawn up together with industry partners to examine the relationships between *processes and roles*, *competencies and processes*, and *competencies and roles*. [KWA+22, p. 6, KPM+23, p. 28] The *role-competence* matrix is shown in Figure 2-13.

	N= not relevant K = know V= understand A= apply B = master	Customer representative	Customer representative	Project manager	Internal supervisor	Process and guideline manager	System engineer	Developer	Production coordinator/planner	V&V employee	Production employee	service technician	Quality manager	Innovation and strategy management	management
Core competencies	Systemic thinking	V	A	A	A	B	A	V	V	A	V	V	V	A	V
	System modeling and analysis	V	A	A	A	B	A	A	V	A	V	V	V	A	V
	Consideration of system life cycle phases	V	A	A	A	B	A	A	V	A	V	V	V	A	V
	Agile thinking/ customer benefit orientation	V	A	A	A	A	A	A	V	A	V	V	K	A	V
Professional competencies	Requirements management	V	A	V	A	B	A	V	V	A	N	V	A	A	V
	System architecture design	N	V	V	A	B	A	A	V	V	V	N	A	N	K
	Integration, verification & validation	V	V	V	A	B	V	V	V	A	A	N	V	V	K
	Operation, service and maintenance	A	K	V	A	B	V	K	K	V	V	A	K	N	K
	Agile methodological competence	V	A	A	A	B	A	A	V	A	V	V	V	A	V
Social and personal skills	Self-organization	V	A	A	A	A	A	A	V	A	A	V	V	A	V
	Communication & Cooperation	A	A	A	A	V	A	V	A	V	A	A	V	A	V
	Lead	K	V	A	A	K	A	V	V	V	V	N	V	V	V
Management skills	Project management	N	V	A	A	B	V	V	K	A	N	N	A	V	V
	Decision management	K	A	A	A	B	A	V	V	V	V	N	V	A	A
	Information management	V	V	A	A	B	A	V	V	V	V	V	V	V	K
	Configuration management	V	V	A	A	B	A	V	V	V	A	V	K	V	K

Figure 2-13 Role-competence matrix according to [KPM+23, p. 28]

2.2.9 Model-Based Systems Engineering (MBSE)

Information about a system is often stored in individual documents and is difficult to synchronize. This makes it difficult to manage and ensure the quality of the information and to check it for accuracy, completeness and consistency. The ever-increasing complexity makes it more difficult to keep all the necessary information and data about different documents up to date and manage them. As a result, the relevance of model-based approaches continues to increase and traditional, document-based approaches are being replaced. By using MBSE, information that was previously recorded in individual diagrams, texts and tables can be better recorded, analyzed, shared and managed. [WSR+23, p. 219f., Fri09, p. 16]

MBSE is defined by INCOSE as follows:

> *"Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."* [INC07, P. 15]

In MBSE, a system model is developed which, according to WEILKIENS, ideally represents an image of a real system or a system to be developed. The system is abstracted to such an extent that only the attributes that are relevant for a previously defined purpose are taken into account. System models form the core of MBSE and contain all information from requirements and functions through to the property assurance of all disciplines in a single system model. Elements can thus always be kept up to date, even if they are contained in different models. WEIL- KIENS also refers to such an ideal system model as a "single source of truth". [Wei14, p. 22] Figure 2-14 shows a simplified example of the relationship between various elements across different models. Interactions between the different models can also be immediately understood. If, for example, the requirements change, the structure or behavior must also be adapted. In contrast to the document-centered SE approach, the use of MBSE can improve decision-making and the system understanding of all persons involved. Information about all models can always be kept up to date, as the communication and system understanding of all those involved is improved. Errors in development are reduced and quality is increased through improved traceability. Information can be reused across models, which increases the efficiency and effectiveness of development. As with the document-based SE approach, MBSE requires tailoring, i.e. adapting the effort to the needs of the project. [GO22, p. 53ff., Fri09, p. 15ff.]

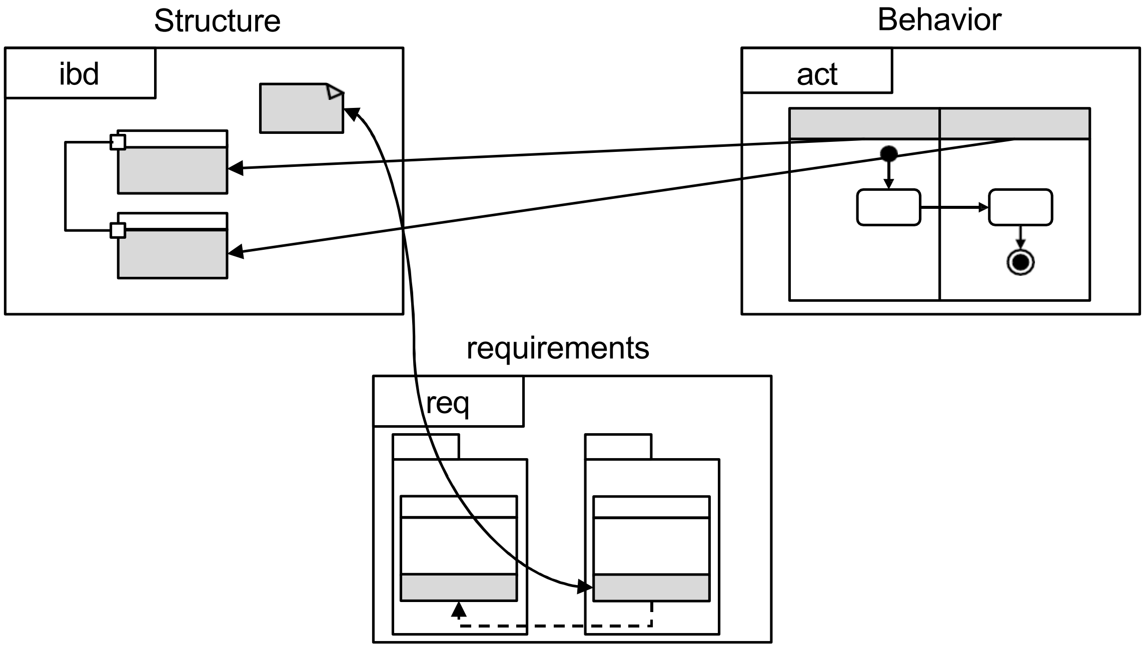

Figure 2-14 Simplified representation of element linking via various models in MBSE according to [Fri09, p. 18].

2.3 Qualification

Qualification is understood to mean the acquisition or improvement of a person's professional skills. A suitable qualification thus increases the possibilities of being able to perform certain tasks better. [Lie24-ol]

The introduction of SE in companies is a challenging process, as SE is a very complex and all-encompassing subject area. [DAR+21, p. 68] The introduction of SE affects the work of a large number of people or organizations. A comprehensive understanding of SE and its processes is necessary in order to successfully introduce SE. Existing processes must be structured and the use of SE must be adapted to the existing company processes. In addition to adapting company processes, employees must also be motivated and qualified in order to ensure a successful SE introduction. All stakeholders within development, right up to management, must understand why SE offers added value. Without this motivation and acceptance of SE processes, SE cannot be successfully integrated into the company. There is often a lack of acceptance for the restructuring of processes, particularly at middle management level. This is often due to the lack of quantifiability of the added value of SE. The success of SE only becomes clear in the medium to long term. The employees' lack of experience with SE also poses major challenges for the introduction. [DAR+21, p. 69f.] Another problem with the introduction of SE is the need to adapt SE methods and processes to the needs of the company.

company, as these cannot be adopted without further ado. Suitable modules must be selected and combined individually for each company. [DAR+21, P. 70]

The successful implementation of SE requires the selection of suitable training and further education measures. An understanding of interdisciplinary cooperation should already be created during studies. However, there is often a lack of practical orientation here. The promotion of students' social skills is also currently inadequate. [DAR+21, P. 115]

In addition to studies, further training measures are necessary within companies. Digitalization enables a new design of qualification formats, which is made clear by an increase in digital offerings. Further training offers are becoming increasingly individualized and can often be provided on-demand. [DAR+21, P. 117]

2.3.1 Competencies

Competencies are described as the willingness and ability of an individual to behave in a thoughtful and individual way in their professional, social or private life. [CJ22, p. 2] Competencies can be divided into three categories: professional, methodological and social competencies. [WJ02, p. 2] For a better understanding, competencies must be distinguished from learning objectives. LEISEN defines competencies as follows:

> *"Competencies are available skills and abilities to solve certain problems and to be able and willing to use the problem solutions successfully in variable situations."* [Lei15, p. 2]

The definition makes it clear that, in addition to the ability to do something, competencies also always include execution. Competencies can only become visible through execution. This requires motivation and the will to do something. Competencies are therefore observable [LD18, p. 2]. While competencies are acquired by learners, learning objectives are set by teachers. These define specific goals that are to be achieved within one or more learning units. [Lei15, p. 2] Learning objectives must be formulated in a verifiable manner. [CJ22, P. 3]

Depending on the role, different competence levels are required in certain competence fields. [BGH+18, p. 13f.] In order to identify suitable formats for further training, the competence level in the company must first be identified. Competence levels help to determine the current level of knowledge in an area and to build suitable formats on this. In this way, the training formats can be adapted to the existing skills and requirements. [BGH+18, p. 11] Competence levels help to identify and structure the learning objectives for further training. INCOSE defines competencies as personal attributes or inputs of a person.

person. These can describe technical skills or behavior that are necessary to carry out certain activities in the company. Competencies can be used to record a person's knowledge and skills. Competencies support the execution of processes. However, competence goes beyond execution and also includes an understanding of the context of the processes. It also includes an understanding of one's own role in an organization and one's own behaviour. Competency models define the necessary competencies in each case. [BGH+18, p. 7f.]

KÖNEMANN ET AL. propose a competency framework that serves to define suitable SE competencies and supplement the INCOSE Competency Framework [BGH+18] with agile development methodologies. They also summarize some competencies in order to increase the understanding of the competencies. The groups of competencies have also been adapted. The *"Core Competencies"* comprise all competencies that include engineering and SE. *"Social/ Personal Competencies"* include the competencies that deal with the behavior of the individual person. "*Management Competencies"* accompany and manage the SE processes. The *"Technical Competencies"* comprise the mindset, methodological knowledge and skills required to carry out technical SE processes. Figure 2-15 shows the adapted framework.

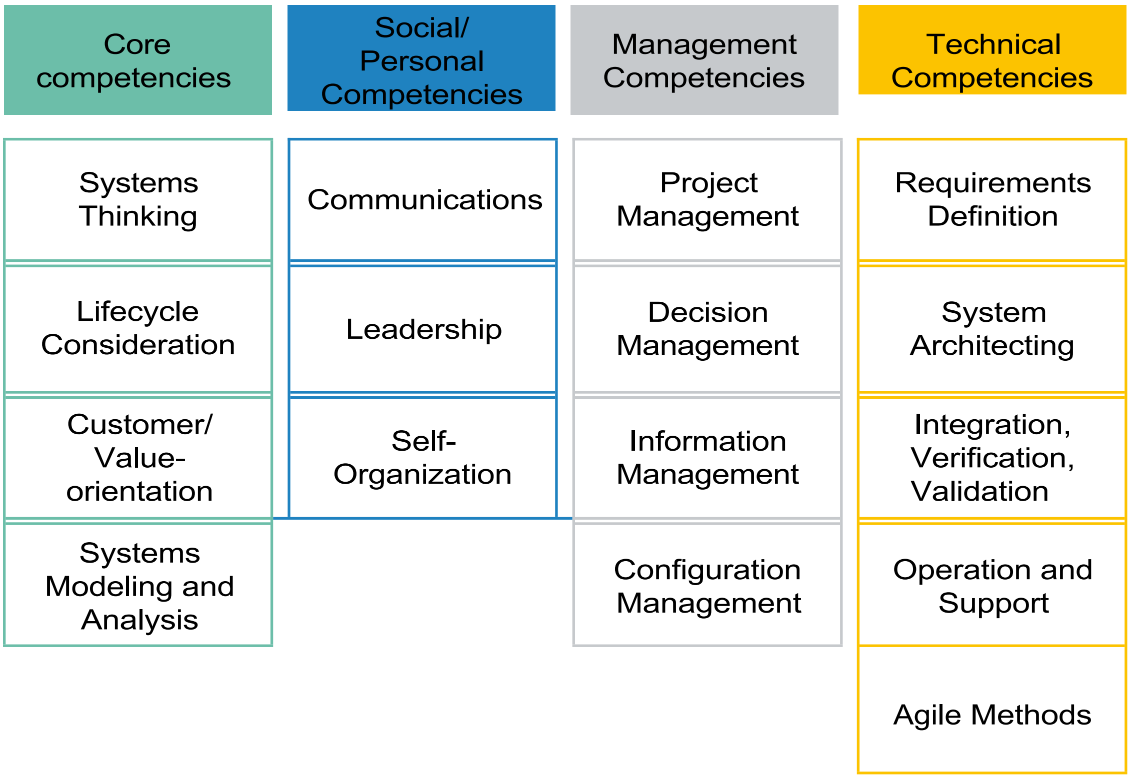

Figure 2-15 Adapted competence framework according to [KWA+22, p. 5f.].

For the ISO 15288 processes, KÖNEMANN ET AL. identify roles that carry them out. The roles and processes are linked together in a process-role matrix. The degree to which a process is carried out is graded from "None" to "Supporting" to "Responsible".

"Supporting" to "Responsible". The identified competencies are then linked to the ISO 15288 processes in a matrix. A role-competence matrix is derived by multiplying the process-role and competence-process matrices. This reflects the required competencies per role and evaluates the necessary degree of competence fulfillment. [KWA+22, p. 5f.]

BLOOM presents a pyramid-shaped competence model for the definition of competence levels. The pyramid shape of the model indicates that the lower levels form the basis for the competence levels above. The width of the levels indicates that significantly more people need to reach the lower competence levels than the upper levels. The majority of employees should therefore have the "Recognize" competence level, while only certain employees need to reach the "Master" level. [BEF+56, p. 18] BLOOM's taxonomy was adapted by KÖNEMANN for the SE qualification and reduced to the four levels "Recognize", "Understand", "Apply" and "Master".
"mastery". [KWA+22, p. 6] The adapted competence model is shown in Figure 2-16.

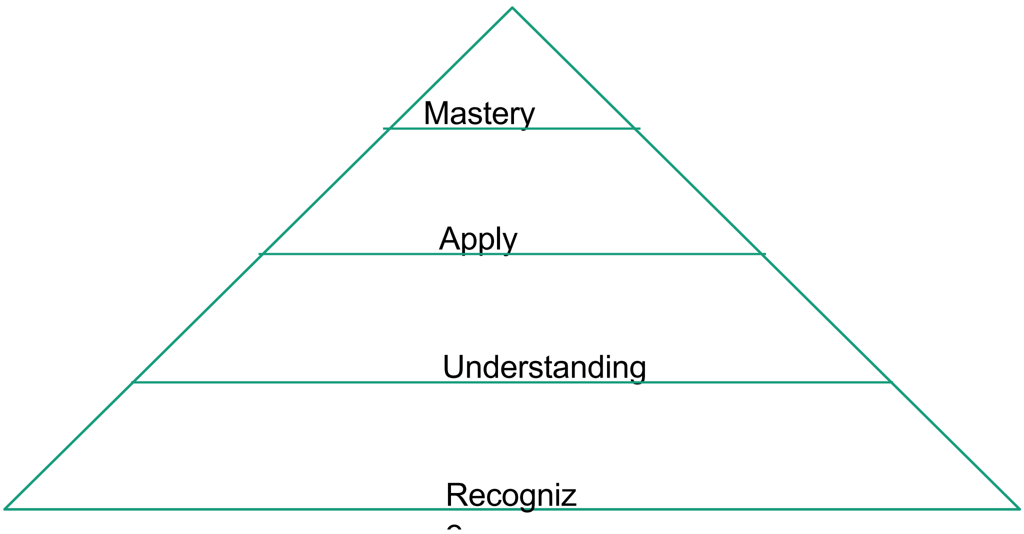

Figure 2-16 Adapted competence pyramid according to [KWA+22, p. 6].

The *"Recognize"* competence level includes the ability to reproduce content verbatim or in a meaningful way. The *"Understand"* level builds on the competencies and supplements them by being able to understand and interpret the content. The *"Apply"* competence level describes the ability to apply learned content to one's own problems and situations. The highest level, *"Master",* also describes the ability to analyze, evaluate and synthesize content.

and synthesize content. The four competence levels make it possible to determine which skills are required for different stakeholders and roles. [KAD22, P. 2]

2.3.2 Learning strategies and formats

Six archetypes for qualification were identified in the SE4OWL research project in order to impart the necessary skills to the roles. Archetypes differ in their focus during the introduction of SE. A distinction is made between the desired competence level and the current introduction phase of SE in the company. The archetypes are shown in Figure 2-17. The introduction phases of the SE are shown on the X-axis in the diagram and the desired qualification level on the Y-axis. [KPM+23, P. 29]

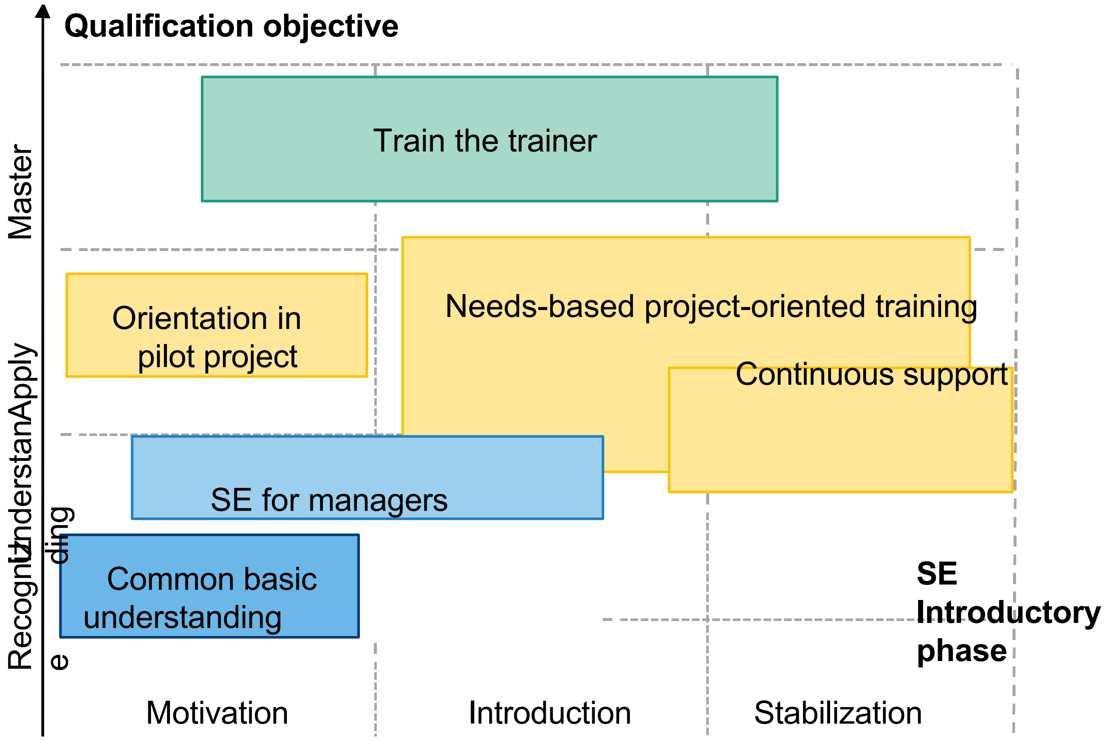

Figure 2-17 SE qualification archetypes according to [KPM+23, p. 29].

The six different archetypes are aimed at different groups and implementation strategies. "Common basic understanding", for example, can mean creating awareness for the topic and is aimed at everyone involved in a project. Depending on the archetype, different learning formats make sense. [KPM+23, P. 29]

Another aspect that must be taken into account when selecting qualification formats is the different learning formats. [DAR+21, p. 72] There are several learning formats for the qualification of individual roles within an organization. New media should also be used in these learning formats to support learning.

[DAR+21, p. 17, Pro21, p. 12] Digital training courses increase the availability and individuality of courses. However, the required skills are also increasing due to the advancing digitization, which is why training offers must be continuously adapted. [DAR+21, P. 117]

PROHASKA emphasizes that digitalization is bringing the aspect of lifelong learning more to the fore. The half-life of knowledge is falling dramatically, which is why skills should be learned instead of facts. However, digitalization also increases the possibility of individualizing learning. E-learning offers the possibility of freely organizing learning phases and content. [Pro21, p. 14] PROHASKA defines a range of possible learning formats and divides these into face-to-face and online formats. [Pro21, p. 28]

KÖNEMANN ET AL. identify possible formats for the different qualification levels. Seminars or serious gaming approaches are often sufficient to achieve low qualification levels such as "recognizing". Other methods, such as mentoring, are required to reach higher levels such as "mastering". [KAD22, p. 1] A number of possible learning formats for qualification are described in the literature. These include the literature by PROHASKA, KÖNEMANN ET AL. and WAGEN- KNECHT, although these do not consider SE qualification in particular. KÖ- NEMANN ET AL. assign learning formats to the competence levels in SE. These essential learning formats for SE are explained in detail in [Pro21, KAD22, WJ02].

The individual qualification formats are suitable to different degrees for achieving different competence levels. The breakdown of the qualification formats for individual competence levels is shown in Figure 2-18.

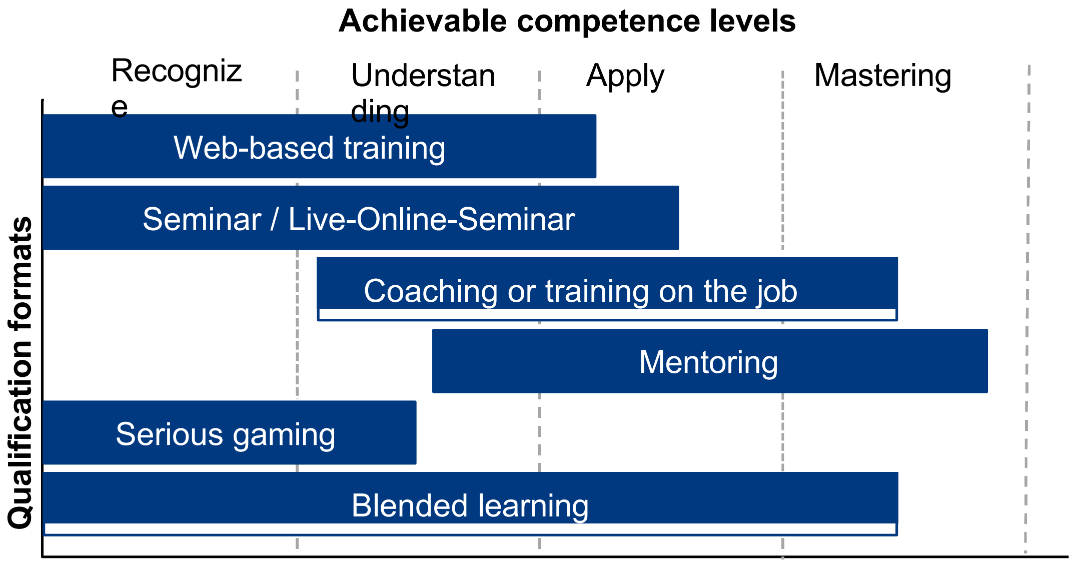

Figure 2-18 Assignment of the qualification formats to the competence levels according to [KAD, p. 1]

2.3.3 Change management

Change management (CM) is an approach for successfully implementing changes in a company. [Dop14, p. 89] Change here means the transformation of a stable state into a new stable state. [Pes10, p. 33] Changes in a company often pose major challenges, such as employee resistance to new methods and procedures. People prefer stability, fundamentally question changes and react defensively. These defensive reactions occur with both positive and negative changes. [Con92, p. 2] CONNER describes eight phases of change before a stable state emerges.

Initially, the change starts with a stable state, the **status quo.** The first reaction to change is a state of shock. In this phase of **immobilization**, a person cannot react to a new situation. In the **denial** phase, it is assumed that the change is misinformation. In this phase, the affected person does not initially deal with the change any further. In the following phase of **aggression**, affected persons react negatively and irrationally to the change. Only in the fifth phase of **negotiation** do people begin to accept a change and try to minimize the negative effects for themselves. In the **resignation** phase, those affected realize that their own actions have no influence on the change, which has a negative effect on motivation. In the **testing phase**, the new limits are accepted, but possibilities within them are tested. The last phase describes **acceptance**. Here the change is finally accepted and a new stable state is achieved. [Con92, p. 7]

2.4 Problem definition

The problem analysis makes it clear that the use of SE is essential for many companies. This is due to the ever-increasing complexity of development and growing competitive pressure. The need for interdisciplinary cooperation between different disciplines will continue to increase in the future. Traditional, discipline-oriented development approaches are therefore less and less suitable for the development of complex technical systems. [DAR+21, P. 115]

However, the introduction of SE is proving difficult. The necessary qualification measures vary greatly depending on the role, as different specialist areas have different requirements for the SE solutions. The roles often lack the intrinsic motivation to change existing work processes and adopt new approaches such as SE. [WJ02, p. 558] Managers in particular must be motivated in order to inspire them to use SE. Acceptance problems also arise due to the difficulty of quantifying the benefits of SE. [GCW+13, p. 31f.

fundamental willingness to change on the part of all stakeholders involved is necessary in order to successfully establish SE in the company. [DAR+21, P. 69]

In addition to the various roles, the necessary qualification planning also depends on the maturity level of the company. As shown in chapter 2.2.6, an individual decision on the required methods, processes and tools is necessary for each company. GAUSEMEIER ET AL. state that there are also differences in SE application between individual sectors. [GCW+13, p. 48ff.]

In addition to in-depth knowledge in a specialist area, all those involved should have a strong basic knowledge of the overall system. Both GAUSEMEIER ET AL. and DUMITRESCU ET AL. came to the conclusion in their studies that experts require basic knowledge in all disciplines as well as expert knowledge in one specialist discipline. [GCW+13, p. 51, DAR+21, p. 112f.] This competence profile of generalists and specialists is described by DUMITRESCU ET AL. as T-shaped, as shown in Figure 2-19.

DUMITRESCU ET AL. found that current training formats often do not bring the desired success. Among other things, this is due to the lack of adaptation of the training content to the company. Individual learning paths are therefore necessary. [DAR+21, p. 118] There is a lack of qualification offers in the literature that take into account the different roles and maturity levels in companies.

This results in a need for suitable training formats that are specifically tailored to the needs of companies. The different roles and maturity levels in the companies should be taken into account. Training formats must be adaptable in order to specifically address the individual needs of the participants.

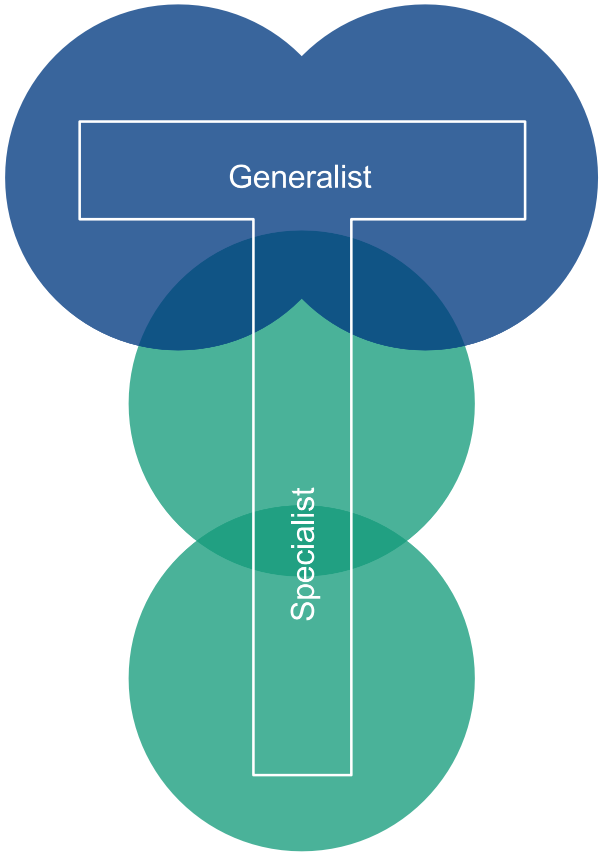

Figure 2-19 T-shaped competence profile according to [DAR+21, p. 113].

2.5 Requirements for the methodology

The problem analysis results in a series of requirements that need to be taken into account when developing a *methodology for maturity level-specific planning of SE training projects*.

A1) Analysis and consideration of company maturity: In order to adapt the qualification specifically to the needs of a company, the maturity of the company must be taken into account. Depending on the level of knowledge and current use of SE, different implementation practices make sense. A company with a high level of maturity requires specialized, role-specific training, while generic basics make more sense in the early phases of implementation. Company maturity is decisive for the selection of suitable methods, processes and tools, as SE approaches must be individually tailored to the company.

A2) Iterative adaptation to company needs: Qualification planning should not be static, but should be able to adapt iteratively to the changing needs of a company. This is particularly important as SE implementation processes take place over longer periods of time and need to be continuously adapted. As shown in the problem analysis, companies need individual learning paths and ongoing adjustments to the content in order for qualifications to be successful in the long term.

A3) Consider change management approaches: Qualification measures should be closely linked to change management approaches in order to successfully accompany the introduction of SE. This includes sensitizing employees and managers to the advantages of SE and recognizing and overcoming resistance at an early stage. A lack of acceptance and motivation can be key obstacles. Training courses that integrate change management methods can help to promote the necessary acceptance and willingness to change.

A4) Support in the formulation of learning objectives: Clear and verifiable learning objectives are essential in order to evaluate the success of qualification measures and to build skills in a targeted manner. The problem analysis emphasizes that learning objectives must be individually tailored to the needs of the participants. This requires the use of competence models that take different competence levels into account. Such learning objectives help companies to measure the benefits of training and to adapt training formats in a targeted manner.

A5) Support in the selection of qualification strategies: The methodology of this work is intended to support companies in differentiating between various strategies in qualification planning and weighing them up against each other. To this end, a decision support system is to be developed that enables the well-founded selection of alternative strategies.

3 State of the art technology

This chapter explains the approaches relevant to this work. First, Chapter 3.1 presents various approaches to maturity measurement from the literature. Chapter 3.2 explains existing approaches to qualification planning and Chapter 3.3 explains approaches that support decision-making between different alternatives.

3.1 Approaches to maturity level measurement

Maturity models are used to objectively assess the current performance of a company and to improve this performance. Maturity models can therefore be suitable for fulfilling task 1 "Analysis and consideration of company maturity" and task 5 "Support in the formulation of learning objectives" of this thesis. In the following, a number of different maturity models from the literature are presented and examined for their suitability in this thesis.

3.1.1 Maturity model for the introduction of systems engineering according to WILKE ET AL .

WILKE ET AL. develop a model for measuring maturity levels in the company. They place particular emphasis on the aspects of SE. The maturity model developed consists of 19 fields of action, which are evaluated and shown in Figure 3-1. The assessment takes place in the five levels *"Not consciously present", "Individual/Ad Hoc", "Fragmented", "Established", "Systematic promotion"*. The individual levels are described for each field of action in order to ensure a clear assessment. To ensure a better understanding of the fields of action, each field of action was provided with a brief description. Two references to other fields of action are also provided for each field of action in order to link them. [WHT+23, p. 3] Info boxes and questions for each field of action serve as a support and orientation basis for the evaluation. The model serves as a basis for recording the current situation in a company. Further measures can be introduced on the basis of the evaluation of the individual aspects. Based on the corporate objectives, target scenarios are created and critical areas for action are identified. WILKE ET AL. recommend carrying out the ACTUAL analysis with external help, for example with moderated maturity assessments. [WHT+23, P. 4]

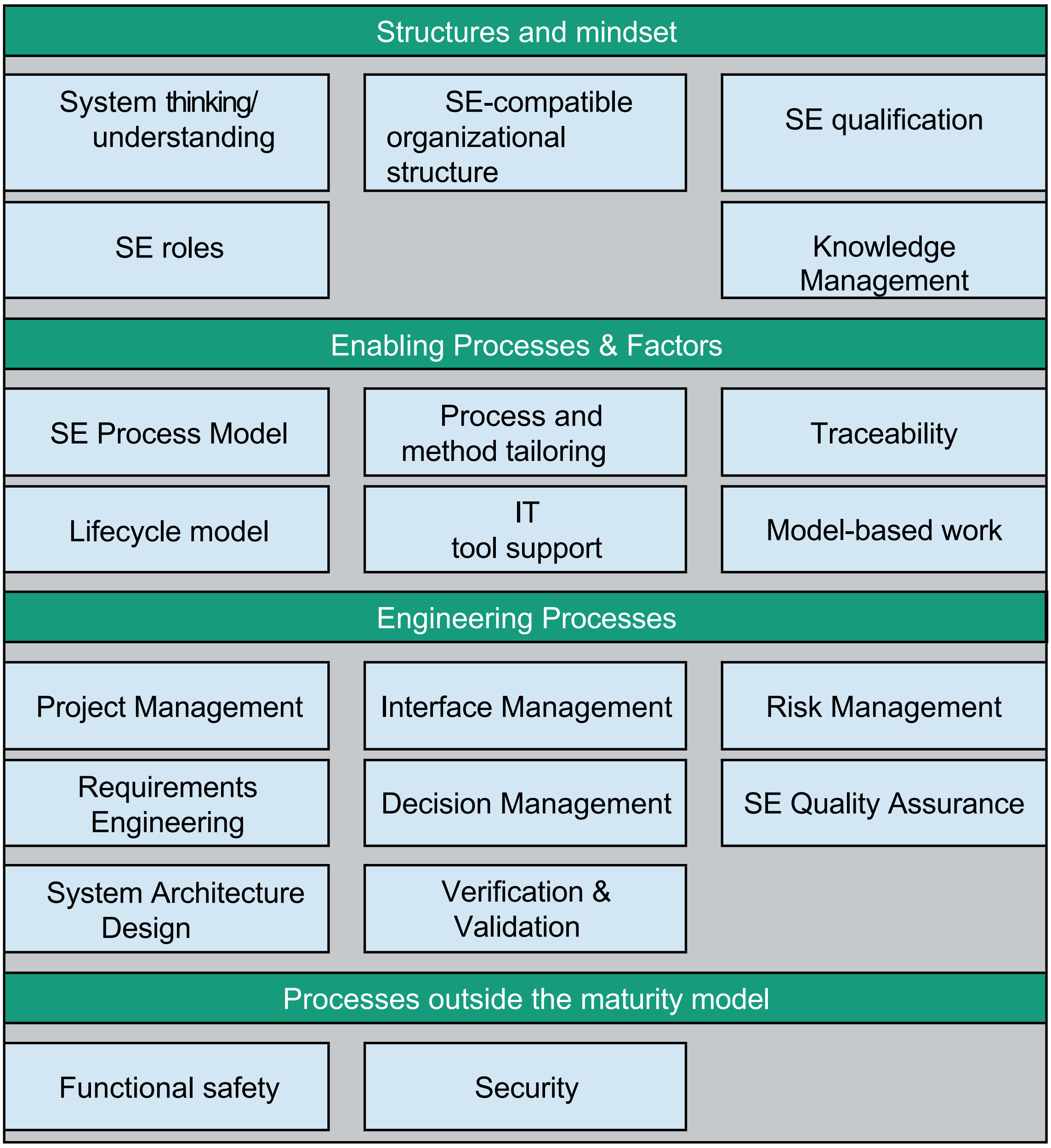

Figure 3-1 Fields of action of the maturity model according to [WHT+23, p. 3]

Assessment: The maturity model provides a sound basis for assessing the current situation in a company. The reference to the SE and its processes is given. The model's fields of action are clearly described and can be evaluated in a standardized manner. Additional information on the individual levels supports the assessment. However, no recommendations for action are given for the planning of specific measures based on the ACTUAL analysis.

3.1.2 Maturity model for MBSE according to VOGELSANG ET AL

VOGELSANG ET AL. present a maturity model for the introduction of MBSE in companies. Assistance is provided for the selection of suitable subject areas.

offered. The aim of the model is to define goals for the introduction and to measure current skills. By comparing the desired and existing skills, steps for the introduction can be derived from the model. The model focuses on an incremental introduction and improvement of individual focal points. [JVB17, p. 1f.]

Skills that can be achieved form the core of the maturity model. Individual capabilities can build on one another. *Focus areas* describe activities or fields and combine several skills. Individual skills within a focus area are arranged in ascending order of maturity. In turn, focus areas are summarized in *engineering functions*. These describe the possible views of a system. The MBSE Maturity Matrix can be formed from the capabilities, focus areas and engineering functions. The engineering functions and focus areas form the rows and the maturity levels form the columns of the matrix. The skills can be found in the cells of the matrix. Figure 3-2 shows a section of an MBSE Maturity Matrix. The gaps in the matrix result from dependencies between individual skills. [JVB17, P. 3]

		Maturity level											
Engineering Functions	**Focus areas**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Context analysis	Operational Context				A	B	C	D	E		F	G	
	Knowledge Context			A	B	C		D					
Requirements	Scoping		A	B	C	D	E						
	Goal Modeling		A				B	C	D	E	F		
	Scenario Modeling			A	B	C	D	E	F		G		

Figure 3-2 Section of an MBSE Maturity Matrix according to [JVB17, p. 3].

Strategies for introduction can be derived from the maturity matrix. To this end, initial workshops are first held with the help of key stakeholders. In these workshops, a questionnaire is used to assess the individual capabilities and check whether they are already being implemented. This allows the current status to be determined. The results of the workshop are then transferred to the maturity matrix. In this step, the matrix depicts the current status and the goals. Based on the results, the differences between the current status and the goals are examined. In a further workshop, the matrix and suggestions for improvement are validated and discussed. A roadmap can then be drawn up on this basis. This describes which skills need to be learned in order to achieve the goals. [JVB17, p. 3ff.]

Assessment: The MBSE Maturity Model provides a comprehensive framework for assessing and planning competencies in companies. The standardization of terms is essential for the assessment of the current state of a company. However, many of the terms used here are not standardized in the industry. Another

Another problem is the evaluation of the ACTUAL state on the basis of interviews. Answers in interviews are often subjective and frequently do not correspond to the actual situation. [JVB17, P. 5]

3.1.3 Automotive SPICE Maturity model

Automotive SPICE (ASPICE) is a process model for development in the automotive industry. ASPICE defines best practices and enables development teams to organize projects. The processes are based on the V-model. [Tal24-ol]

A maturity model was developed for the ASPICE processes in [VDA23] in order to evaluate the processes of an organization. This can be extended as required to include other processes outside of ASPICE. [VDA23, p. 8] The model for measuring maturity is based on a 2-dimensional framework. The first dimension describes the processes that are defined in a process reference model. These are mapped on the X-axis of the framework. The second dimension describes capability levels (CL) and their attributes (PA). The attributes describe measurable properties of a capability. The second dimension is mapped on the Y-axis of the framework. [VDA23, p. 14] The ASPICE processes can reach five levels, which are explained in Table 3-1. In order to assign the levels, a total of 9 process attributes are assigned to them. The process attributes are evaluated in four levels: *not achieved (N), partially achieved (P), largely achieved (L)* and *fully achieved (F)*. To achieve a level in the assessment, all attributes of a level must be at least largely achieved and the attributes of the lower levels must be fully achieved. [VDA23, p. 18ff.] The attributes are evaluated on the basis of indicators. Base practices (BP) evaluate whether processes are successful. They therefore reach level 1 of the framework. Generic practices (GP), on the other hand, refer to the individual levels and assess the extent to which the individual attributes of the levels are achieved. [VDA23, p. 24] The process model with the relationships between evaluation indicators and process capabilities is shown in Figure 3-3. A detailed description of the processes and indicators of ASPICE can be found in [VDA23, p. 28ff. The individual capability levels and attributes are described in [VDA23, p. 100ff].

Table 3-1 Process capability level translated from [VDA23, p. 18f.].

Level 0: Incomplete process	The process is not implemented or misses its purpose.
Level 1: Executed process	The implemented process achieves its process purpose
Level 2: Managed process	The process described above is now implemented in a controlled manner (planned, monitored and adjusted), and the work products are appropriately created, controlled and maintained.

	are created, controlled and maintained in an appropriate manner.
Level 3: Established process	The previously described managed process is now implemented through a defined process that is capable of achieving its process outcomes.
Level 4: Predictable process	The previously described established process now works predictively within defined limits to achieve its process results. Quantitative management requirements are identified, measurement data is collected and analyzed to identify assignable causes for deviations. Corrective actions are taken to eliminate assignable causes for deviations.
Level 5: Innovative process	The predictable process described above is now continuously improved in order to respond to organizational change.

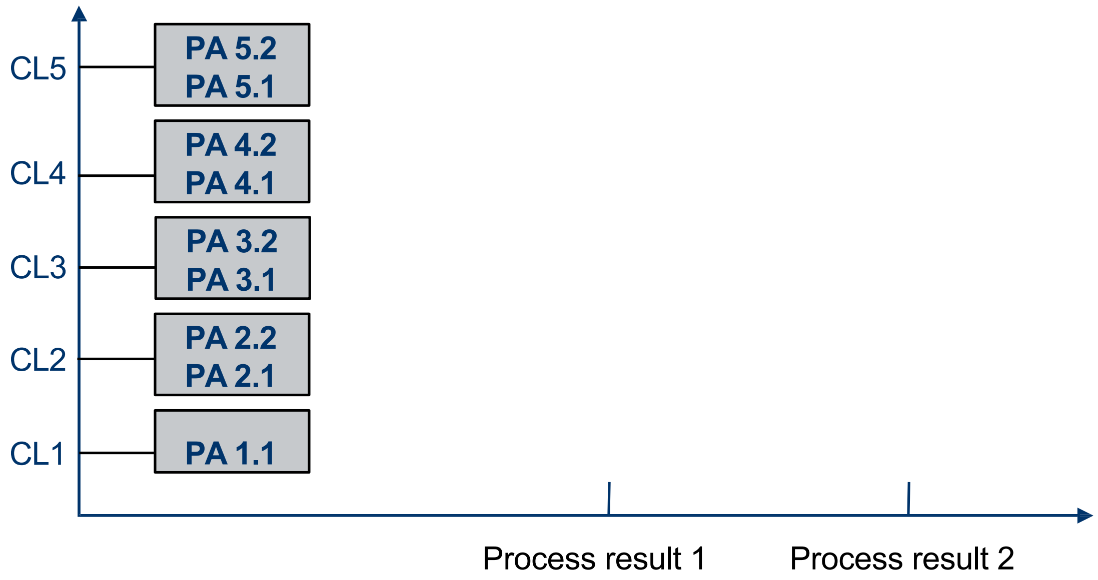

Figure 3-3 ASPICE evaluation framework according to [VDA23, p. 25].

Assessment: ASPICE offers a detailed framework for assessing maturity levels in companies. The extensive explanations of the processes and indicators as well as the individual capability levels enable a clear assessment. However, ASPICE is very generic and heavyweight, which is why it can only be used to a limited extent for the introduction of SE and MBSE [JVB17, p. 1]. For processes outside of ASPICE the framework can be adapted, but further effort is required for planning.

3.1.4 Maturity model for the introduction of SE and MBSE according to BRETZ

BRETZ examined existing maturity models and developed a maturity model for the introduction of SE and MBSE in companies. On the one hand, the model serves to record the current status of SE and MBSE, and on the other hand, it supports companies in defining needs-based targets for the introduction. [Bre21, p. 97f.] BRETZ identifies 16 action elements for the introduction and summarizes these in the four categories of *foundations, organization, processes* and *infrastructure*. [Bre21, p. 98f.]

To check the relevant processes, Bretz compares the SE/MBSE targets with the processes in a target contribution matrix. This makes it possible to check the extent to which a particular action element contributes to improving the defined objectives. The evaluation is carried out in four levels from 0 (no contribution) to 3 (very strong contribution). The broad impact of the matrix indicates the proportion of the objectives influenced by an action element. The depth effect corresponds to the average effect of an action element on the influenced goals. The target contribution index is calculated from the depth and breadth effect and indicates how large the contribution of an action element is to the targets. The target contribution index can be used to find relevant action elements. [Bre21, p. 100f.]

Once the objectives have been identified, the current situation in the company is reviewed. For this purpose, performance levels are defined for all action elements. The levels of the individual fields of action have already been defined in the model. Figure 3-4 shows a section of the action element evaluation. The remaining action elements can be found in [Bre21, p. 102ff]. The current status is compared with the maturity level descriptions for the evaluation and documented in a table. [Bre21, p. 107]

The planned maturity levels can be defined using the target contribution matrix. The first step is to check which maturity levels offer high added value at low cost. For this purpose, the previously calculated weighted effects of the action elements are calculated in comparison to the previous performance level and the rank is derived from this. The performance level with the highest progress represents the target maturity level of an action element. [Bre21, p. 107ff.]

Finally, a plausibility check is carried out to determine whether the target maturity level is higher than the ACTUAL maturity level. Otherwise, it must be checked whether the ACTUAL maturity level is already sufficient and does not need to be pursued further. [Bre21, p. 109]

Field of action	Maturity level				
Mindset	**Not available**	**Individual/ Ad Hoc**	**Fragmented**	**Established**	**Optimized**
Dissemination and use of SE-typical ways of thinking in the organization	No systemic and cross-disciplinary thinking present.	Systemic and cross-disciplinary thinking only in Individuals present.	Individual areas and/or disciplines have internalized the internalized the desired mindset.	The basic SE mindsets are internalized throughout the company.	The desired ways of thinking are continuously promoted and optimized within the company.
Knowledge base	**Not available**	**Individual/ Ad Hoc**	**Fragmented**	**Established**	**Optimized**
Knowledge base for SE-specific expertise incl. accessibility	No knowledge base for SE-specific expertise available.	Knowledge is available individually and may be Documented.	Specific content is documented and available within a few areas.	A (company-internal) public knowledge base is established, the quality of the content is fundamentally assured.	The knowledge base is established and continuously optimized.

Figure 3-4 Assessment levels of the fields of action (extract) according to [Bre21, p. 102]

Evaluation: The model allows the current status to be evaluated and helps to identify relevant processes and goals. The target contribution matrix can be used to check which maturity levels are appropriate for certain fields of action. The fields of action and levels are clearly described and thus enable a precise assessment. The model is tailored to the introduction of MBSE and SE and thus enables simple application to the processes of ISO 15288. Processes outside of SE can also be examined, but further effort is required here. The initial analysis of the actual state requires additional planning due to the necessary calculations.

3.2 Approaches to qualification (planning)

Comprehensive planning is necessary for the implementation of qualification measures. The literature presents approaches that support planning. The various approaches have an initial analysis of the current situation in common and then differ in their structure as they progress. Some important approaches from the literature are presented below.

3.2.1 Qualification planning cycle according to KLING ET AL .

KLING ET AL. investigate how further training projects can be designed so that learning content is integrated into everyday working life. To this end, they developed a model based on Deming's PDCA cycle [Sch24-ol]. The model aims to create needs-based qualifications. This requires planning that identifies what is to be changed by the qualification. Metrics are also required to measure the success of the qualification measures. [KKS16, p. 7] The model is divided into six stages and describes a possible qualification planning process. Individual phases can overlap and cannot be strictly separated from one another. The time for individual phases is also not fixed and can vary. [KKS16, p. 8] Figure 3-5 shows the six stages of the model.

The first stage of the model is *target definition*. By formulating a uniform goal, measures can be better coordinated. Efficiency can also be increased by formulating objectives. The SWOT analysis [Gab24-ol] is suggested as a possible method for defining needs and objectives. The objectives to be defined should always be formulated SMART (specific, measurable, accepted, realistic, time-bound). [KKS16, p. 9ff.]

The second step is a *needs analysis*. Here, requirements for the content of the training courses must be identified. To this end, the necessary and missing skills that are required to achieve the objectives are examined. [KKS16, p. 12ff.]

The analysis of needs is followed by the *planning of* suitable measures. Qualifications should be based as far as possible on the current status of the participants. Preliminary discussions can help to ascertain the level of knowledge.

When *carrying out* the qualification, it is important to ensure that the premises are suitable for the measures and that a positive atmosphere prevails. [KKS16,
S. 16]

Figure 3-5 Cycle of qualification planning according to [KKS16, p. 8].

After the qualification, what has been learned should be integrated into everyday working life. It can be useful to repeat the content in order to anchor it. Follow-up events are considered to be particularly useful in order to deepen what has been learned. [KKS16]

The final step of the model is the *evaluation* of the measures implemented. This involves assessing the achievement of the previously defined objectives. In the case of long-term qualification projects, it is suggested that an interim balance sheet be drawn up.

Assessment: The qualification planning cycle offers a structured approach to qualification planning. The model is tailored to teachers, but can easily be adapted to other areas. The model takes account of needs-based qualification. According to the principle of the PDCA cycle, the measures introduced are checked and adapted if necessary. As the model specializes in the qualification of teachers, it must be examined whether the approach is suitable for complex projects such as SE. The use of tools has also not yet been considered. Change management approaches are indispensable for qualification in SE. These have not yet been taken into account.

3.2.2 Process model for the development of vocational training according to KUGELMEIER ET AL .

KUGELMEIER ET AL. developed a process model for vocational qualification together with various Fraunhofer Institutes. [KP21, p. 4] The model is divided into eight phases, which are subdivided into the development and planning of the measures. The model is presented in an "8-form", as Figure 3-6 shows.

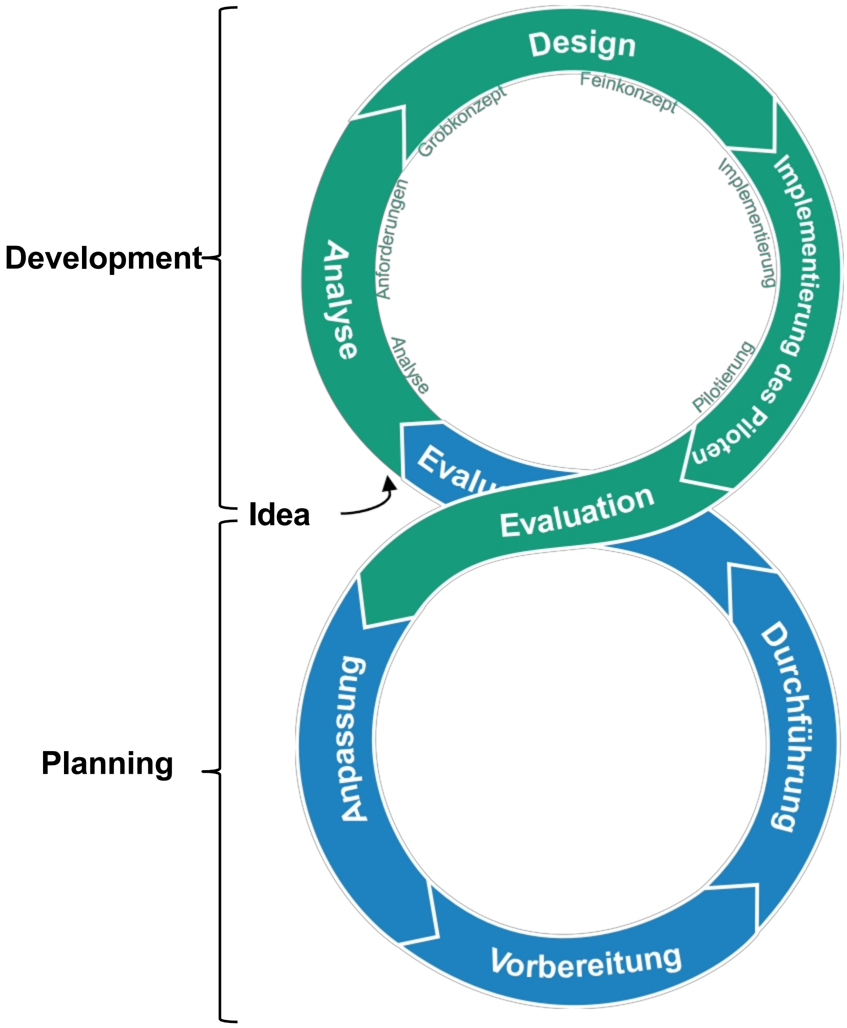

Figure 3-6 8-phase process model for further training according to [KP21, p. 10].

The process model begins in *phase 0*, where the *idea* for a training measure is first generated. Before the actual development, it is first checked whether a training measure is sensible and feasible. Initial content is already roughly defined here and possible target groups and their needs are identified. [KP21, S. 10]

Phase 1 deals with the analysis. This is divided into two sections: *"Analysis of the context of continuing education"* and *"Derivation of requirements"*. First, all information relevant to the development is collected. This includes an analysis of the target groups and the content of the training. Also framework conditions for the organization and premises are also defined here. Objectives for the training can then be derived from the analysis. These should be formulated SMART so that they can be better understood. Learning objectives for further training are also recorded here. [KP21, P. 11]

Phase 2 of the model deals with the design of the measures. First, the *rough concept* is defined, whereby the formats, methodology and timing are determined. The *detailed concept* builds on this basis. This is where the individual learning units are formulated in detail and coordinated with each other. A comparison with the learning objectives also takes place in this step. The goal of this phase is a script that describes the course of events and the content of the training. [KP21, P. 11]

Phase 3 involves the *implementation* of the training plan. First, the previously developed detailed concept is implemented and suitable learning content is created. At the end *of* this *pilot implementation*, the training measure must be sufficiently advanced that it can take place at any time. The subsequent pilot training must be designed in such a way that it is as realistic as possible. Participants should come from the target group of the training. [KP21, P. 11]

Phase 4 serves to *evaluate the training* and to compare the current status with the target status of the training. Here it is checked whether the planned training content meets the derived requirements and whether the pilot training was successful. The results are used to derive the need for optimization and to decide whether the training can take place as planned or whether a further run through of the previous phases is necessary. [KP21, P. 11]

Phase 5 follows after the transition from planning to operation of the training measure. Based on the evaluation, the training measures are *adjusted* and optimizations are carried out. These must be clearly documented for all those responsible. [KP21, P. 11]

In *phase 6*, all necessary *preparations are made* that are required for a successful measure. This includes preparing the learning materials and the premises. [KP21, P. 11]

Phase 7 describes the planned *implementation* of the training measures. [KP21, S. 12]

In the final *phase 8*, the implemented measure is *evaluated*. If there are deviations between the target and actual status of the training, the previous phases are run through again and adjustments are made. [KP21, P. 12] [KP21]

Evaluation: KUGELMEIER ET AL. offer a structured approach to qualification planning. By analyzing the target group at the beginning of planning, different roles and maturity levels are included. The adaptability of the measures during and after planning makes it possible to tailor them specifically to a use case.

The iterative structure of the approach enables constant adaptation of the planning. Individual requirements are determined and taken into account in the planning. The model supports the definition of learning objectives based on the required skills and refers to the BLOOM taxonomy.

3.2.3 Development of learning content according to the ADDIE- model

A very well-known model for planning qualifications is the ADDIE model. The name of the model stands for the five individual phases of the model: Analyze, Design, Develop, Implement and Evaluate. [KG24, P. 1]

The model begins with *the analysis* of training needs. Here it is checked whether a need exists and how it can be measured. If a need is identified, the target group for the training is analyzed. First, the current level of knowledge of the learners is recorded. As much information as possible about the participants should be found here in order to tailor the training measures to them as well as possible. Finally, the results of the analysis should be recorded in a project plan. [KG24, P. 1]

A concept is created when *designing* a training course. [KG24, p. 1f.] The aim of the design phase is to identify objectives and suitable methods for these. The de- sign phase creates a basis for addressing missing skills. [Bra09,
S. 60]

In the *development phase*, the content of a course is developed. During content creation, the content is implemented and elements are designed. This is followed by tests to check the accuracy of the content. [KG24, P. 2]

Implementing describes the sharing of content with learners. Teachers and learners are prepared for the course in this phase so that it can then take place. [KG24, p. 2f., Bra09, p. 133f.]

Following the implementation and during the creation of the course, the content *is evaluated.* The quality of the training is assessed here. [Bra09, p. 152] The results from the analysis are compared with the results of the training. It is checked whether the objectives have been achieved and is intended to ensure that all phases of the design have been designed appropriately. [KG24, p. 3] Figure 3-7 illustrates the process of the ADDIE model.

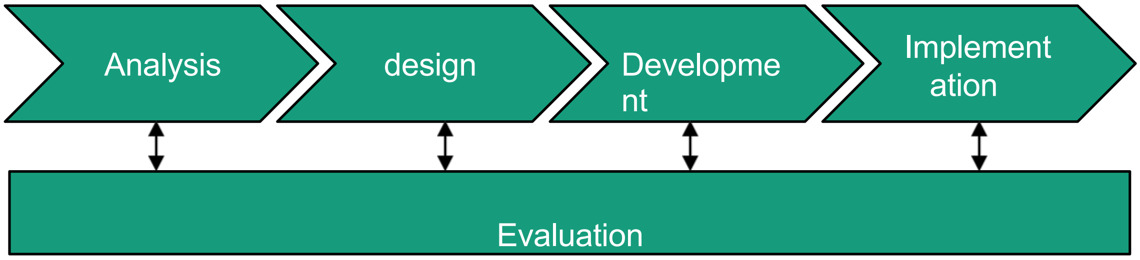

Figure 3-7 Sequence of the ADDIE model according to [Aka25-ol]

Evaluation: The ADDIE model offers a structured and easy-to-understand approach to qualification planning. The constant evaluation offers the opportunity to check content and adapt it quickly if necessary. The model emphasizes the analysis of needs and adapts content accordingly. The analysis of the target group at the beginning of the planning process enables different roles and maturity levels to be taken into account. However, aspects of long-term learning and change management approaches are not taken into account.

3.2.4 Reference model for further training according to DIN PAS 1032

DIN PAS 1032:2004 defines a reference model for qualification planning and takes particular account of e-learning. The reference model is divided into three parts.

The *process model* describes the individual categories and their processes, but does not specify the order of the individual categories and processes. It is noted that these must be adapted to the context of the application and that individual processes can be skipped if they are not required. [DIN PAS 1032- 1:2004, p. 8] Figure 3-8 shows the categories and processes in abbreviated form. A detailed list and description of all processes can be found in [DIN PAS 1032-1:2004, p. 9].

The *description model* defines how individual processes are to be described. For this purpose, the elements that must be specified individually for each process are described. If an element cannot be described, this must be justified. [DIN PAS 1032-1:2004, P. 13]

The *integration of process model and description model* explains in detail how the individual processes of the process model must be described. [DIN PAS 1032-1:2004, P. 15]

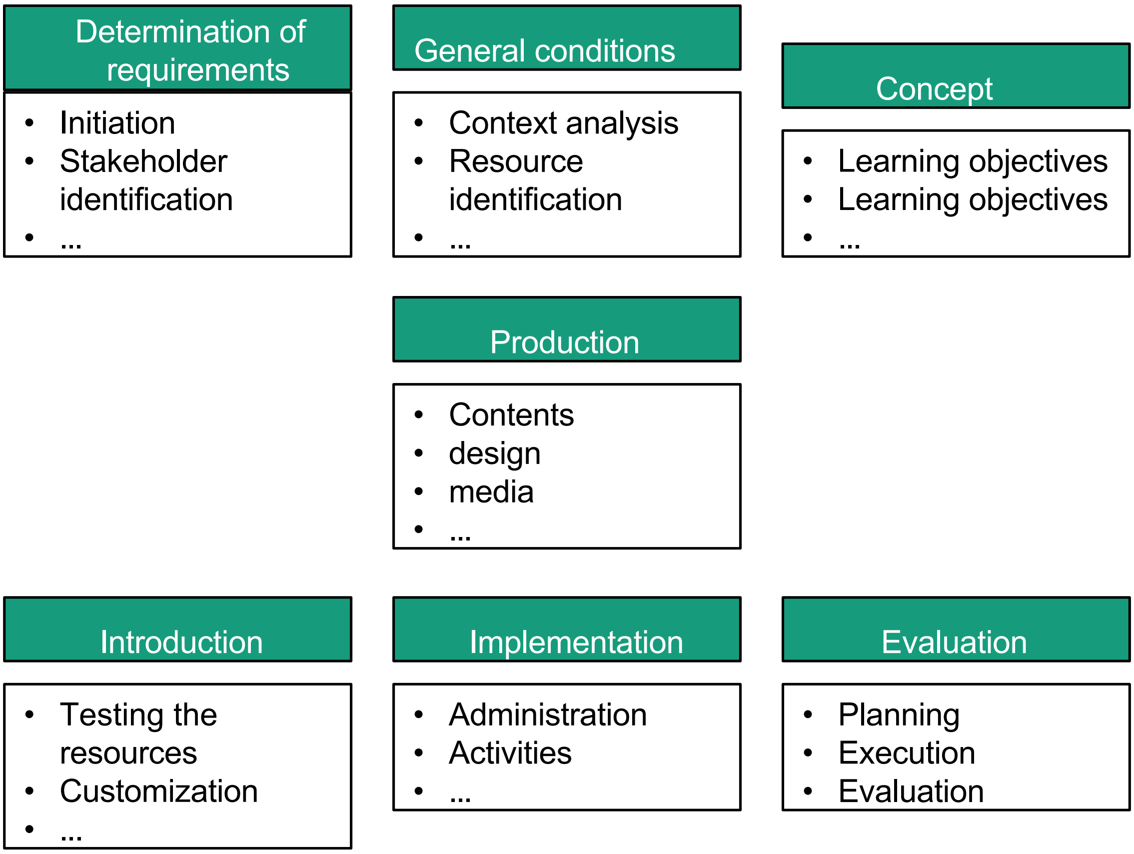

Figure 3-8 Process model of DIN PAS 1032:2004 (abridged) [DIN PAS 1032-1:2004, p. 9].

Assessment: DIN PAS 1032-1 offers a comprehensive collection of processes for the planning and implementation of training. The model remains flexible and does not prescribe any fixed processes, which makes individual planning possible. However, the standard does not provide any support in the selection or prioritization of suitable processes. This can make the planning process more difficult and time-consuming. Although the description model enables detailed documentation of all necessary steps, it significantly increases the effort involved in creating qualification measures. This could pose a particular challenge for companies with limited resources. The definition of learning objectives is supported by the model, but there are no concrete guidelines for formulating the learning objectives.

3.3 Approaches to the selection of alternatives

The large number of possible qualification strategies requires support in the decision-making process. However, there are no methods available in the literature for the planning of qualification measures. This chapter therefore draws on methods from other areas, which are explained in the following chapters.

3.3.1 Pros and cons lists

Pros and cons lists offer help in structuring the advantages and disadvantages of decisions. The characteristics of the alternatives are examined and evaluated. The advantages and disadvantages can also be evaluated on the basis of weightings. For this purpose, the importance of the aspects considered is taken into account for each alternative. The best alternative can then be found based on the sum of the weightings. Another evaluation option is the veto method. Here, only the negative aspects of the alternatives are considered and the alternative that addresses the fewest negative aspects is implemented. [Fla21, p. 83ff.]

Evaluation: Lists of pros and cons make it possible to weigh up alternatives when making decisions. The qualitative comparison of the advantages and disadvantages ensures a comprehensive evaluation and consideration of the alternatives. The methodology is therefore well suited to comparing different alternative strategies in the context of this work.

3.3.2 Benefit analysis

Benefit analyses (NWA) are suitable for supporting decisions on various alternatives. In an NWA, all aspects of a decision are evaluated and included in the decision-making process on the basis of weightings. The alternatives are evaluated with regard to the fulfillment of the objectives and a score is calculated. This score indicates the extent to which an alternative is suitable for fulfilling the objectives. [Küh21, p. 5f.]

Evaluation: The utility analysis is well suited to making decisions about different alternatives. However, a weighting of the alternatives is assumed here and a numerical evaluation of the goal fulfillment is necessary. Therefore, the NWA method is not suitable for the procedure in this work.

3.3.3 Morphological box

A morphological box offers the possibility of breaking down a problem into smaller segments and finding alternative solutions for sub-problems. In this way, several alternative solutions can be found for complex problems, which are made up of various partial decisions about the alternatives. [Kau21, p. 163f.]

Evaluation: Morphological boxes are well suited to breaking down complex problems and comparing different approaches to solving individual problems. However, the method is not suitable for this work, as the alternative strategies to be examined do not involve different problems.

3.3.4 Decision trees

Decision trees can be used to support complex decision-making situations. They represent a multi-stage decision-making process across several alternatives and can be clearly visualized. Decisions can be related to each other in terms of time or logic. The number of alternatives must not be too high in order to facilitate decision-making. [SB18, p. 121ff.]

Evaluation: Decision trees are well suited to depicting individual decisions in a comprehensible way and thus to illustrate the decision-making process. A decision tree can be used to illustrate possible questions within qualification planning. This method is therefore suitable for illustrating the framework for decision-making within this work.

3.4 Need for action

In the following, the approaches presented in the state of the art are compared with the requirements set out in Chapter
2.5 are compared below. Figure 3-9 summarizes the result.

○ Not fulfilled ◐ Partial fulfilled ● Fully Fulfilled Fulfilled

	Requirements				
	A1	A2	A3	A4	A5
Maturity level models					
Maturity model for the introduction of systems engineering according to Wilke et al.	●	◐	◐	○	○
Maturity model for MBSE according to Vogelsang et al.	●	◐	◐	●	○
Automotive SPICE maturity model	●	◐	●	○	○
Maturity model for the introduction of SE and MBSE according to Bretz	●	◐	●	●	○
Approaches to qualification planning					
Qualification planning cycle according to Kling et al.	◐	○	○	●	○
Process model for the development of professional development according to Kugelmeier et al.	◐	●	◐	●	○
Development of learning content according to the ADDIE model	◐	●	○	●	○
Reference model for further training according to DIN PAS 1032	◐	◐	○	●	○
Approaches for selecting alternatives					
Lists of pros and cons	○	○	○	○	◐
Benefit analysis	○	○	○	○	○
Morphological box	○	○	○	○	○
Decision trees	○	○	○	○	●

Figure 3-9 Evaluation of the investigated state of the art based on the derived requirements

A1) Analysis and consideration of company maturity: All of the maturity models presented offer a good basis for assessing company maturity. The reference to the SE is given in all four approaches. Specific training measures can be planned on the basis of the maturity levels determined. The presented approaches to qualification planning support the consideration of a company's maturity and offer the possibility of being merged with the maturity level models.

A2) Iterative adaptation to company needs: The maturity models are based on predefined SE processes. However, all of the models presented make it possible to adapt them to company-specific processes. However, additional effort is required here. Some of the approaches to qualification planning offer the possibility of being iteratively adapted to the specific needs of the SE. The qualification planning cycle according to KLING ET AL. mainly relates to teacher training in schools. This approach is therefore not suitable for use in the complex processes of SE. The approach of KUGELMEIER ET AL. and the ADDIE model enable an iterative approach to planning and are therefore suitable for the planning of SE training measures. Although the DIN PAS 1032 reference model offers a broad selection of processes, the structure of qualification planning is not predefined. Additional effort is required to plan an iterative approach that can be adapted to the company's needs.

A3) Consider change management approaches: The maturity model according to WILKE ET AL. is only used to assess the initial situation. However, further planning steps are necessary in order to implement change management approaches. Planning further steps on the basis of the maturity level assessment is possible in principle and recommended by the authors, but no procedures are presented here. The remaining maturity models take change management approaches into account in part by deriving incremental steps for implementation.

A4) Support in the formulation of learning objectives: The maturity model according to VOGELSANG ET AL. offers support in formulating suitable learning objectives. A roadmap is drawn up on the basis of the maturity level assessments in order to plan objectives. BRETZ's target contribution matrix makes it possible to determine suitable targets for qualification. Both approaches enable the identification of discrepancies and the derivation of targets. However, no suitable guidelines are given for formulating these objectives. All approaches to qualification planning begin with an analysis of the current situation and therefore basically enable the definition of learning objectives. However, none of the approaches offer templates for defining these and reference is made to frameworks such as Bloom's Taxonomy.

A5) Support in the selection of qualification strategies: A decision tree is suitable for enabling well-founded decision-making within this work, whereby decisions can be understood. This should provide the framework for the selection of alternative strategies. In addition, pro and con lists should support the selection process by comparing possible approaches.

4 Development of the methodology

The following chapter explains the solution approach for a methodology for planning maturity-specific further education projects in SE. The methodology aims to fulfill the requirements derived in chapter 2.5 and to meet the need for action from chapter 3.4. Chapter 4.1 first provides an overview of the methodology. The following chapters explain the individual steps of the methodology.

4.1 Overview of the methodology

The methodology of this work is divided into four planning phases, as shown in Figure 4-1. The structure is based on the analysis and planning phase of the 8-phase process model for continuing education by KUGELMEIER ET AL. which was presented in Chapter 3.2.2. The diagram illustrates the iterative nature of the methodology.

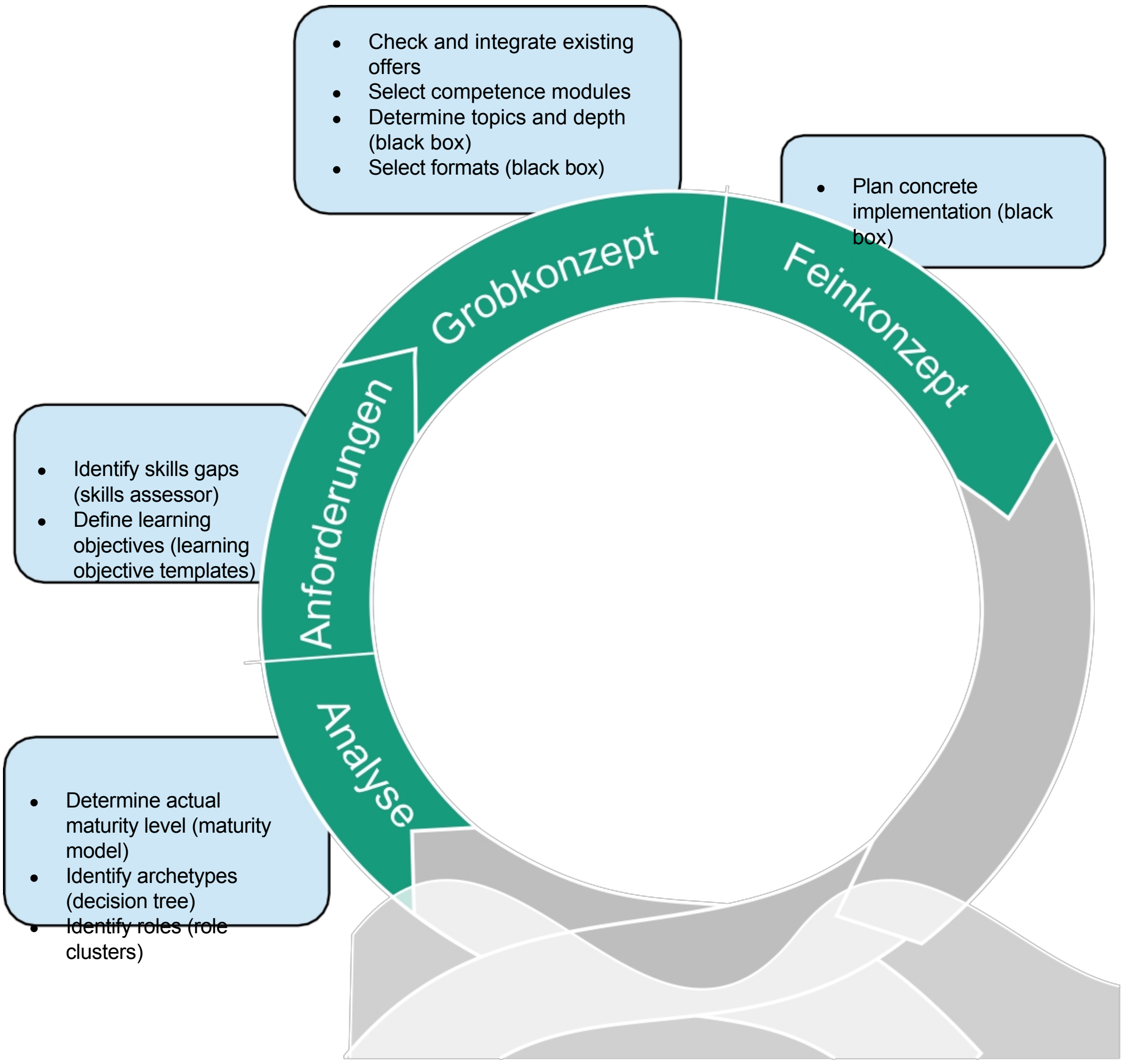

Figure 4-1 Process model for maturity level-specific qualification planning

The first section comprises the **analysis** of the current situation for the SE training measures. The first step is to clarify the framework conditions for the measures. This includes measuring the maturity level of the company with regard to SE. The maturity model according to BRETZ [Bre21] is used for this purpose. Then, with the help of a decision tree, suitable archetypes are identified on the basis of the maturity levels for further training and the competencies of the employees are measured. At the end of the analysis phase, a check is made as to who should be trained. To do this, the roles in the company are divided into role clusters and the number of people to be trained is checked. The decision on the archetypes should be considered iterative, as alternative archetypes may have to be selected based on the boundary conditions.

In the second section, the **requirements** are determined. To this end, the competence gaps for the individual roles are identified with the help of the JAVAID [JM23] competence determiner. The competency assessor determines the current competencies and compares them with the ideal competencies of a role. Specific learning objectives are also defined here for competencies that are to be acquired as part of the qualification.

Once the skills gaps have been identified, the next step is the **rough design** of the training concept. In this step, suitable modules are selected for training, if necessary. Existing training courses should be reviewed here and integrated into the planning. The topics and the depth of the topics for each module are then determined based on the selected competence modules. This is also the basis for selecting suitable formats for the training.

The final step is the **detailed design**. This is where the actual implementation of the qualification is planned. In this paper, however, the implementation planning is only considered as a black box.

4.2 Examination of the learning modules

In order to be able to manage the large amount of content, a procedure is necessary that enables the selection of relevant content. Suitable modules can be selected during qualification planning on the basis of predetermined criteria, allowing planning to be tailored to requirements.

NIEMEYER specifies various criteria that modules must fulfill. Individual modules must be closed in terms of content for subdivision and form an independent unit. It must be possible to test the knowledge acquired within a module and a time frame must be defined for each module. Modules can range from individual seminars lasting a few hours to complex courses lasting several hundred hours. For more complex projects, however, it is advisable to to divide modules into sub-modules. [Ver13, p. 10] As a rule of thumb, a module should not deviate greatly from a time frame of 40 hours. Modules should always be seen as part of the whole, whereby several modules may often be necessary to learn certain skills. Finally, it must be possible for the learning content to be recognized and tested by third parties. Modules can be further subdivided into individual learning contents [Nie05, p. 62]. These are also referred to as building blocks, whereby a module is made up of several building blocks. [Ver13, p. 11]

In order to be able to select suitable learning modules, the content must be clearly defined. The adapted INCOSE framework according to KÖNEMANN ET AL [KWA+22, p. 5f.] provides a good basis for suitable competencies that can serve as modules. In the following chapters, the individual competencies are first examined in more detail in order to derive suitable learning objectives for them later in the thesis. INCOSE maps the standard in the field of SE and therefore provides a good basis for the competencies required in SE qualification projects. The adapted framework according to KÖNEMANN ET AL. expands this basis to include agile aspects, which are playing an increasingly important role in today's development. KÖNEMANN ET AL. also summarize the INCOSE competencies. In this way, they reduce the number of competencies, which facilitates clustering. Individual competencies therefore represent several competencies of the INCOSE Competency Framework.

4.2.1 Core competencies

The core competencies form the basis for engineering and SE processes. They serve as the basis for further processes. The core competencies include **systems thinking**, **life cycle considerations**, **customer benefit orientation** and **system modeling and analysis**.

Systems Thinking

Systems thinking comprises the competence to apply fundamental concepts of systems thinking in SE and to understand the role of one's own system in the overall context. This competence combines the INCOSE competences *of systems thinking* and *capability engineering*.

According to INCOSE, systemic thinking is the understanding of systems and their links with the environment. This includes system boundaries and interfaces. Systems thinking is relevant in order to be able to master the ever-increasing complexity of systems. Only with systems thinking can the effects of one's own system on other systems be understood.

Capability engineering describes the focus on achieving a desired effect instead of reaching a certain performance level. This involves developing systems that can be flexibly adapted to dynamic conditions. Static systems with a fixed baseline can thus be avoided. To do this, a distinction must be made in development

It must be possible to differentiate between a product and a capability during development and the effect of a system must be considered independently of the expected mechanisms.

Life cycle approach

The **life cycle approach** describes the competence to consider all life cycle phases of a system and not just the operating phase during development. This includes requirements definition, architecture design and the development phase. The life cycle approach refers to the *Life Cycles* and *Business and Enterprise Integration* competencies of the INCOSE framework.

The transitions between the *life cycle phases* must be considered. Different elements of a system can have different life cycles, which should be taken into account in the planning. These can depend on the scope of a project, characteristics of the system or customer requirements. The consideration of lifecycles forms the basis for project planning, which is why the choice of lifecycles can strongly influence the success of the project.

The competence of the life cycle approach also includes the *business and business integration* of INCOSE. It describes that the business or company itself should be viewed as a system. SE must be understood as part of the whole and only represents part of the activities that are necessary for a successful company.

Customer benefit orientation

Customer value orientation was added to the Extended INCOSE Competency Framework. It encompasses the competence to place the benefit for the customer at the center of development and to ensure a high level of customer satisfaction. This adds an agile approach to the INCOS framework.

System modeling and analysis

System modeling and analysis is the ability to provide data and information in cross-domain models. With the help of modeling, the understanding of a system can be improved and decision-making can be supported.

4.2.2 Social and Personal competencies

The social and personal competencies consider the behavior of actors. They are subdivided into the competencies of *communication*, *leadership* and *self-organization*.

Communication

Communication describes the ability to communicate constructively, efficiently and consciously. Communication also takes place across domains. The feelings of other people must be recognized and taken into account. This competency combines the competencies of *communication*, *ethics and professionalism* as well as *emotional intelligence* from the INCOSE framework.

Communication involves the exchange of information via verbal principles as well as body language and behavior. *Communication* plays a decisive role both inside and outside an organization. *Communication* is necessary in order to exchange information between individuals and groups and thus enable a common understanding.

Ethics and professionalism describes the competence to act in a way that is expected of systems engineers. This also includes using knowledge and skills in a targeted manner. To this end, the skills expected of a systems engineer must be consolidated and applied in a targeted manner.

Emotional intelligence is the ability to recognize the feelings of others and respond to them appropriately.

Leadership

Leadership is the ability to select suitable goals for a system and achieve them in teamwork. Team members should be guided in achieving these goals. The competence comprises the INCOSE competencies of *technical leadership*, *team dynamics*, *negotiation*, *coaching and mentoring*.

Technical leadership is the application of technical knowledge and experience in SE with appropriate competencies. This includes understanding customer requirements, problem solving, creativity and innovation skills as well as team-building skills and communication. In addition to the fundamental core elements of SE, management also needs the ability to oversee all processes in the company.

Team dynamics influence the behavior and performance of a team. *Team dynamics* can have a positive or negative influence on a project.

Negotiation skills describe the ability to find the best possible result between two parties. To do this, contradictions must be uncovered and eliminated. System engineers must be able to satisfy various stakeholders and achieve the best possible goal. Negotiation skills are therefore essential.

Coaching and mentoring is the ability to support individuals in a targeted manner and thus develop their knowledge and performance. In this way, knowledge and skills can be passed on across generations.

Self-organization

Self-organization describes the ability to organize oneself. It comprises the INCOSE competencies of *planning*, *decision management* and *simultaneous development*.

Planning is the ability to draw up and coordinate plans across several disciplines. This includes plans on how to develop a system, tailoring to project-specific requirements and planning the necessary effort and resources.

Concurrent development focuses on aspects of parallelization by integrating processes and thus reducing time-to-market.

4.2.3 Management skills

Management competencies include all the skills required to monitor and manage SE activities in a system environment. The management competencies include the competencies of **project management**, **decision management**, **information management** and **configuration management**.

Project management

Project management describes the ability to identify, plan, coordinate and adapt activities. The aim of **project management** is to develop a satisfactory system that meets quality, cost and time requirements. It combines the INCOSE competencies of *project management*, *finance*, *quality*, *planning*, *monitoring and control* and *concurrent development.*

The *Project Management* competency is the ability to plan activities and meet time and cost constraints while developing a satisfactory system.

Finance describes the ability to estimate and track the costs of a project. This requires an understanding of the prevailing financial processes.

Quality focuses on satisfying the customer by optimizing the processes involved in production.

Monitoring and control is the competence to check whether current plans can be adhered to. To this end, the current status is determined and corrective measures are initiated in the event of deviations.

Planning and *simultaneous development* have already been explained under the competence of self-organization.

Decision management

Decision management is the competence to identify, characterize and select alternatives in a structured and analytical manner. Both opportunities and risks must be taken into account. Decision management includes the INCOSE competency *of risk and opportunity management*. Risks can have both negative and positive effects on a project.

In *risk and opportunity management*, negative risks must be minimized and opportunities maximized. Management takes place during the entire development period.

Information management

Information management is the ability to distribute the right information to specific stakeholders at the right time. Information management thus encompasses the INCOSE competencies *of procurement and supply* and *design* for....

Procurement aims to ensure that a product with the desired requirements is procured, while *supply* ensures that the customer receives a product that meets the requirements. The needs and required characteristics of a supplier must be examined and defined in detail. This is the only way to make a suitable selection.

Design for... ensures that the requirements of all life cycle stages are taken into account in the system design. If the life cycle stages are not taken into account during development, they can no longer be achieved later on, or only at increased cost.

Configuration management

Configuration management is the ability to harmonize system functions, performance and properties of a system and to ensure their consistency.

4.2.4 Technical competencies

The cluster of technical competencies includes the necessary mindsets, methodological knowledge and skills to carry out technical SE processes. This includes the competencies of **requirements definition**, **system architecture design**, **integration, verification and validation**, **operation, service and maintenance** and **agile methods**.

Requirements definition

The competence of **requirements definition** means identifying and analyzing the needs and expectations of stakeholders and deriving requirements for the system to be developed. This competence comprises the INCOSE competences of *requirements definition* and *business and company integration*.

The *definition of requirements* is the analysis of the needs and expectations of the stakeholders in order to derive requirements for a system. These describe the problem that needs to be solved during development.

Business and company integration describes the ability to integrate the processes of the SE into the other processes of a company. SE represents only a part of all processes of a company. The competence therefore takes into account all internal stakeholders such as infrastructure, portfolio management, human resources, quality management, production, sales and others.

System architecture design

The design of the system architecture describes the ability to identify the elements of a system and assign them hierarchically. It must also be possible to define the interfaces, the behavior and the resulting requirements for a solution. This summarizes the *System Architecture* and *Interfaces* competencies of the INCOSE competencies.

System architecture defines the structure of a system as well as interfaces and the derivation of requirements. A solution that delivers an optimal result for all stakeholders can be derived from the system architecture. The system architecture includes the creation of concepts that satisfy a number of needs. Individual elements must then be put together to form an overall system. On the other hand, it must be possible to demonstrate different solution variants.

Interfaces are always necessary when elements interact with each other. For this reason, interactions inside and outside the system must be identified in interface management.

Integration, verification and validation

Integration is the ability to combine a set of system elements into a unit that can be verified or validated. **Verification** describes the process of checking whether a system fulfills the defined specifications, i.e. whether a system has been developed correctly. **Validation** checks whether a system fulfills the requirements for the defined benefit, i.e. whether the right system has been developed and the customer's needs are met. The competence corresponds to the INCOSE competence of *integration, verification and validation*.

Operation, service and maintenance

This describes the expertise required to put a system into operation and maintain its functionality over its service life. The competence summarizes *the transfer, operation and support competences* of INCOSE.

The *transition competence* describes the integration of a verified system into the planned environment. Stakeholder requirements are taken into account for this purpose.

The *operational and support competencies* support the system during its lifetime. This includes maintaining and repairing the system in the event of failures or errors, as well as updating it to meet new requirements and technologies.

Agile methods

This competence describes the ability to use agile methods that support parallel work. The agile methods competence was added to the Extended INCOSE Competency Framework and refers to the values of concurrent working, which has already been explained in the context of the competencies **of self-development** and **project management.**

4.3 Analysis phase

The first phase of the process model for maturity level-specific qualification planning initially comprises the maturity level measurement, which is explained in chapter 4.3.1. Suitable archetypes for qualification are then selected on the basis of the company's maturity using a decision tree. The decision tree is derived in chapter 4.3.2.2. As a final step in the analysis, the roles in the company are grouped into clusters in order to create a common basis for companies for subsequent steps and to be able to assign employees to specific training courses.

4.3.1 Maturity level measurement

At the beginning of the development of qualifications in a company, it must be checked how mature it is in the area of SE. In his dissertation, BRETZ presents a maturity model that can be used to determine the SE maturity of a company. Based on maturity levels, several fields of action are examined that are relevant for the implementation of SE in the company. Low maturity levels indicate a lack of or immature implementation, while high maturity levels indicate detailed implementation. [Bre21, p. 101] The model is part of a framework that can be used to introduce SE and MBSE. In this work, the maturity model can be used to create an interface between the introduction and qualification of SE.

As part of an expert workshop with experts from Fraunhofer IEM, the aspects of the maturity model relevant to qualification planning were identified. In order to

To identify the maturity of a company's SE competencies, it is first necessary to examine the extent to which the SE roles and processes are already established in the company.

The BRETZ maturity model offers the opportunity to first identify relevant SE processes for the company based on the company's objectives. To this end, corporate goals are first defined, for example in workshops with relevant stakeholders. The extent to which each process contributes to the corporate objectives is then examined. The assessment is carried out in four stages from "no contribution" to "strong contribution". The weighted target contribution index is calculated from the broad impact and deep impact of the process. This index can be used to select the relevant processes. The calculation of the indices is explained in more detail in [Bre21, p. 99ff. If all SE processes are to be examined, this step can be skipped and the subsequent maturity assessment can be carried out for all processes. The SE roles and processes are assessed in each of the six levels
"Non-existent", "Ad Hoc / undefined", "Individually controlled", "Defined and established", "Quantitatively predictable" and "Optimized".

Another important field of action for measuring maturity in qualification planning is the "scope rollout" field of action. This describes the current scope of the SE solutions, measured in terms of the (sub)organizations affected [Bre21,
S. 103]. The field of action can thus be used to measure the extent to which SE is already being used in the company. The assessment is carried out in five stages: "not available

Field of action	Maturity level					
Reach Rollout	**Not available**	**Individual area**	**Development area**	**Enterprise -wide**	**Value chain**	
Scope of the SE solution measured by the (sub)organizations affected	SE is not used in the company.	Individual areas of the company use SE approaches, but not universally.	SE is used throughout Engineering, but not throughout the entire company.	SE is rolled out and used throughout the entire company.	SE activities extend beyond the boundaries of the company, e.g. also to suppliers and partners.	
SE roles and processes	**Not available**	**Ad hoc / undefined**	**Individually controlled**	**Defined and established**	**Quantitatively predictable**	**Optimized**
SE-relevant process incl. associated roles	The process is not executed.	Necessary tasks are carried out "somehow". ("Base Practices")	Concrete goals for artifacts (word products) and performance are specified, but the overarching process is missing.	The SE processes are defined and established company-wide.	The process is analyzed and controlled using quantitative parameters.	The process is continuously optimized on the basis of quantitative parameters.

4-2 Description of the fields of action of the maturity model according to [Bre21, p. 103ff].

The process is continuously optimized on the basis of quantitative key figures. A detailed description of the relevant maturity levels is shown in Figure 4-2.

The current status of a company with regard to SE maturity can be identified on the basis of the fields of action shown and the description of the maturity levels. The assessment of the maturity levels is crucial for the selection of suitable archetypes for qualification. This is explained in chapter 4.3.2.2 using a decision tree. The identified maturity levels are recorded in a table for later decision support, which is shown as an example in Figure 4-3.

Field of action	Maturity level					
Range Rollout	Not available	Individual area	Development area	Enterprise -wide	Value chain	
SE Roles and processes	Not available	Ad hoc / undefined	Individually controlled	Defined and established	Quantitatively predictable	Optimized

Figure 4-3 Exemplary assessment of the maturity levels of relevant fields of action according to [Bre21, p. 153]

4.3.2 Selection of suitable archetypes for qualification

Archetypes of qualification should be selected on the basis of the maturity level measurement in order to design a procedure for further training. KÖNEMANN presents archetypes on the basis of which qualification projects can be further planned. [KPM+23, p. 29] The archetypes also support the selection of qualification formats. To this end, KUMAR [Kum23] examined them and derived suitable profiles for learning formats that support them.

Based on the maturity levels identified in chapter 4.3.1, a decision tree will be used below as a decision-making aid to select suitable archetypes for qualification in a company. However, company preferences or participant numbers may require a selection of archetypes that deviate from the decision tree. The fact sheets on the learning formats [Kum23, A-5ff.] provide information on the time required and suitable group sizes. The process of archetype selection should therefore be regarded as iterative and only serves as a recommendation for the selection of qualification strategies.

4.3.2.1 Examination of the archetypes

In order to create a suitable decision-making aid for archetype selection, the archetypes must first be examined more closely for their characteristics. These were developed by a panel of experts as part of the SE4OWL research project. The archetypes and their characteristics are presented in more detail below.

Common basic understanding

The archetype is an approach that focuses on interdisciplinary exchange and thus creates awareness for the topic of SE. The focus here is on understanding the fundamental interrelationships of SE as part of basic training and reflecting on them in the group. This allows all stakeholders to come together regardless of their level of expertise. The archetype is suitable for the motivation phase of the SE introduction and serves to achieve the qualification goal of "recognition". [KSD25, P. 5]

SE for managers

This archetype focuses in particular on managers. They play a major role in the introduction of SE, particularly with regard to change management. They are enablers of change in a company and therefore need an understanding of what it means to introduce and use SE. SE for managers can communicate the benefits of SE in an understandable way. The archetype is suitable for the introductory phase and creates the qualification level "Understanding". [KSD25, p. 5f.]

Orientation in pilot project

The archetype follows an application-oriented approach to qualification. On the one hand, participants should gain an orientation in SE, on the other hand, the application of SE should be qualified in a pilot project. Here, a team of developers is trained and thus independently recognizes the added value of SE through its application. At the beginning there is an initial introduction, followed by continuous coaching. With an orientation in the pilot project, the qualification goal of "application" can be achieved. [KSD25, P. 6]

Needs-based project-oriented training

This archetype is aimed at targeted further training for specific roles within the company. Projects are accompanied over a longer period of time and basic and expert knowledge is imparted as part of training courses. At the beginning, all participants take part in basic training. The knowledge is then deepened for specific roles. New in-depth training courses on individual topics can be used repeatedly throughout a project. In this way, the SE methods can be applied. Processes, methods and tools must already have been defined and roles and tasks specified. Needs-based, project-oriented training courses are suitable for understanding and for the qualification goal of "application". [KSD25, S. 6]

Continuous support

This qualification strategy focuses on the aspect of continuous learning in an organization. Based on self-directed, proactive learning, employee queries are questions from employees are collected, documented and answered. Continuous support requires a trained organization where processes, methods and tools are already defined. This archetype is therefore suitable for the continuation phase of the SE introduction. The aim of this archetype is application. [KSD25, P. 6]

Train the trainer

This archetype focuses on the training of coaches and trainers with the task of bringing SE into the company. Three areas must be taken into account. Firstly, the challenges and working methods of the company must be communicated to the trainers. Secondly, the necessary SE skills must be identified. Thirdly, the necessary didactic and moderation skills must be imparted. Either internal trainers can be trained or external service providers can be recruited to learn the company-specific conditions. For this archetype, the qualification objective "mastery" must be achieved. Since the training of trainers is relevant for all archetypes, the decision on this archetype is made in addition to the selection of the remaining archetypes. [KSD25, P. 6]

Certification

The certification archetype was not addressed in the SE4OWL research project. However, certifications are part of the "orientation in the pilot project" archetype. In this work, certification is defined as a separate archetype due to its typical characteristics, such as fixed and standardized training content and the issuing of certification certificates. Typical certifications for the SE are SE- Zert and CSEP. Certifications are suitable for the qualification objective "Apply" and can be used in the motivation phase of the introduction. [KSD25, P. 6]

4.3.2.2 Decision tree for archetype selection

The archetypes can be differentiated on the basis of the current SE introduction phase on the one hand and the desired qualification objective on the other. In an expert workshop with Fraunhofer IEM employees, a decision tree was derived based on the properties of the archetypes, which is presented in the form of a Business Process Model and Notation (BPMN) diagram.

The **Train the Trainer** archetype is always chosen first. A decision must be made here as to whether a trainer should be trained internally as an expert or whether external trainers should be purchased. Both decisions offer several advantages. Internal trainers can carry out repeated training sessions without incurring additional costs for the training. However, internal trainers require extensive training beforehand in which they are trained as experts on the topic. This can be particularly useful for long-term qualification plans in a company. External trainers can be purchased and already offer the necessary SE knowledge. However, this must be adapted to the company. External trainers are particularly suitable for short-term qualification measures.

In the next step of the decision tree for decision support, the archetypes are divided based on the SE introduction phase. As the qualification in this work is to be planned on a maturity level-specific basis, the question of *where the company currently stands in the SE implementation* is decisive here. The evaluation of the SE processes and roles from the maturity level assessment in chapter 4.3.1 is used for this purpose.

If the maturity level is "not available" or "ad hoc / undefined", it can be deduced that processes and roles are not sufficiently in place. The implementation phase is then in the motivation phase. First, the **SE** archetype is selected **for managers**. The introduction of SE managers is relevant for the further procedure, as they are seen as enablers for implementation projects. Only when the management of a company is convinced of SE can a holistic introduction be guaranteed. Once the managers have been introduced to the topic, the company must ask itself which further procedure it prefers. If SE is to be applied in the company and tested in a real project, the **orientation** archetype **is** chosen **in the pilot project.** If the basic understanding of SE is to be ensured first, the **Common Basic Understanding** archetype can be selected. If some experts are to be trained and certified,

Table 4-1 Pro and contra list for the archetypes

Common basic understanding	
Pros	**Cons**
Standardized vocabulary	No project reference
Low barrier to entry	Little depth of content
Breaking down silo thinking	Less acceptance
Broad participation possible	

Orientation in the pilot project	
Pros	**Cons**
High acceptance	Effectiveness depends on project
Measurable benefit	Not useful for all roles
Direct testing of the content	Time pressure on the project makes it difficult Learning
Motivation through visible success success	Suitable project necessary

Certification	
Pros	**Cons**
High standard	No broad impact in the UN
International recognition	No project reference
Technical depth	Low transferability without company-wide introduction
Ideal for specialists	Cost-intensive

the **certification** archetype is recommended. To support the decision, the three archetypes are compared in a pros and cons list in Table 4-1.

If the SE maturity in the company is "Individually controlled", "Defined and established", "Quantitatively Predictable" or "Optimized", roles and processes in the company are already sufficiently defined. The next step is to decide whether *SE* is *already being broadly applied in the company*. The assessment of this question is based on the scope rollout field of action. If the maturity level here is "not available" or "single area", it can be concluded that SE is not widely used. **Needs-based project-oriented training** is then recommended based on the decision tree. This allows the majority of employees in a project to apply and experience SE. If the maturity level is "development area", "company-wide" or "value chain", SE is already being used in at least some areas of the company. **Continuous support** is then suitable in order to pick up the remaining employees and as repetition for experienced employees.

The decisions in the decision tree, shown in Fig. 4-4, are to be understood as recommendations for action and should be examined individually by each company. The decision-making process is iterative and continues until suitable archetypes have been selected. Combinations of different archetypes can also be used.

After an initial selection of archetypes has taken place, it is necessary to check "Who" should be trained as part of the qualification. The number of employees plays a major role here, as some archetypes are only suitable for certain group sizes. Therefore, the process of archetype selection is iterative and certain decisions may need to be reconsidered.

Once archetypes have been selected, suitable formats that support the archetypes must be chosen. The selection of formats depends heavily on the size of the company and the number of participants, as well as the goal of the qualification. The KUMAR learning format profiles [Kum23] can be used as a decision-making aid here. The selection of formats is beyond the scope of this paper and is considered here as a black box.

4.3.3 Selection of relevant roles for qualification

Once the archetypes have been selected, the next step is the analysis phase. There are no uniform designations for certain roles between different companies. Role descriptions also vary and can change over time. Standardized role descriptions such as the roles according to INCOSE [She96, p. 479ff.] do exist, but often cannot be clearly assigned. [KWA+22, p. 3] The role clusters according to KÖNEMANN ET AL. can be used here to group roles in the company into clusters. Based on the role descriptions employees in companies can thus be clearly assigned to one or more role clusters. The role clusters are explained in detail in [KWA+22]. Based on the clear role clusters, the necessary skills can be analyzed clearly in the following steps of this work.

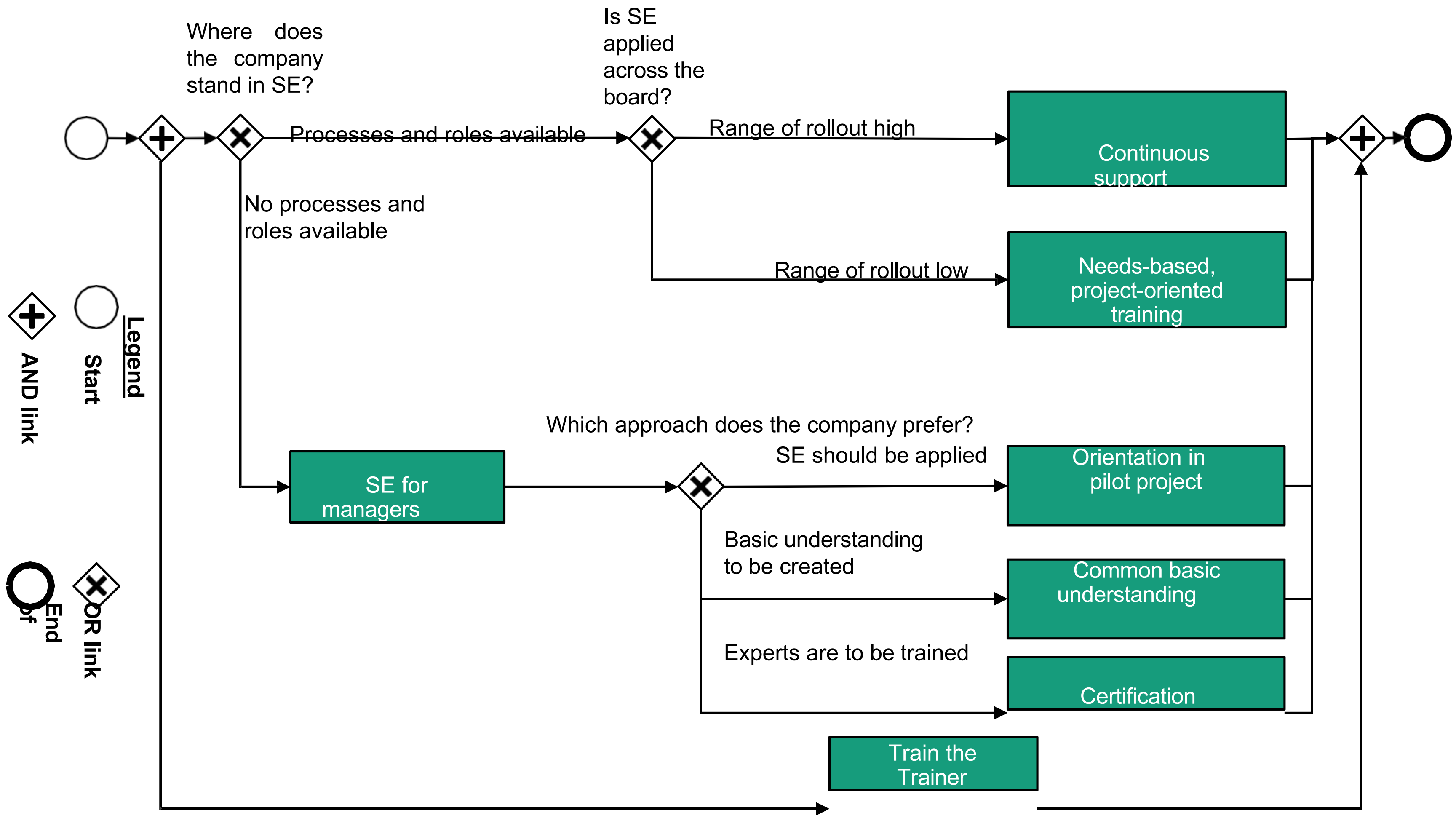

Figure 4-4 Decision tree for selecting suitable archetypes

4.4 Requirement definition

The second phase of the methodology describes the definition of requirements for qualification measures. First, learning objectives for the competences and competence levels are defined in chapter 4.4.1. The learning objectives serve as an overview of the competencies to be learned and to check learning progress. The learning objectives of the competencies differ according to the selected archetypes. Chapter 4.4.2 explains how the competencies of the roles are determined and specifies which competence levels are achieved in the archetypes. Finally, it is necessary to compare the current competencies with the desired competencies. JAVAID's competency determiner is used for this purpose [JM23].

4.4.1 Definition of learning objectives for the qualification

Once the archetypes and roles have been defined, the next step is to develop learning objectives for the individual competencies. To do this, it is necessary to determine which competence level the individual competences can achieve in the respective archetypes. The competences to be considered from chapter 4.2 were examined by experts as part of this work and the respective competence levels to be achieved were determined based on the archetypes. The competence levels to be achieved are not identical for all competences of an archetype, as these set different priorities for qualification. The table of target competence levels for the archetypes is shown in Table 3-1.

Learning objectives for each competence can now be derived specifically from the identified qualification levels. In the SE4OWL research project and in the expert workshop for this work, corresponding learning objectives were defined for each level of the individual competencies. With a few exceptions, these can be divided into the categories of process skills, methodological skills and tool skills. The learning objectives formulated in the workshops are deliberately kept general so that they can be applied in different companies. One example of this is the learning objective of tool competence in requirements management at the "Apply" level: "Participants can define, link and analyze requirements in a requirements tool." These learning objectives must be further specified for company-specific qualification, as general specifications are not sufficient to develop tailor-made training measures. For the tool competencies in requirements management, it is necessary to name specific tools in the learning objectives that are used in the respective company. For example, the IBM DOORS tool can be defined as a requirements tool. A corresponding learning objective would then read:
"Participants will be able to define, link and analyze requirements in the IBM DOORS tool." Specific content must also be defined for the process and methodological skills and adapted to the respective company requirements.

Table 4-2 Levels of competence to be achieved in the various archetypes

Competence	SE qualification archetypes					
	Common basic understanding	SE for managers	Orientation in pilot project	Needs-based project-oriented training	Continuous support	Train the trainer
Systemic thinking	2	4	4	4	2	6
System modeling and analysis	2	1	4	4	4	6
Consideration of system life cycle phases	2	1	4	4	4	6
Customer benefit orientation	2	2	4	4	2	6
Requirements management	2	1	4	4	4	6
System architecture design	2	1	4	4	4	6
Integration, verification & validation	2	1	4	4	4	6
Operation, service and maintenance	1	1	4	4	4	6
Agile methodological competence	2	1	4	4	4	6
Self-organization	2	1	4	4	4	6
Communication & collaboration	1	4	4	4	4	6
Lead	1	4	4	4	4	6
Project management	2	2	4	4	4	6
Decision management	1	4	4	4	4	6
Information management	1	2	4	4	4	6
Configuration management	1	1	4	4	4	6

Legend

1	Know
2	Understand
4	Apply
6	Mastery

The expert workshop agreed that training should be divided into process and method training as well as tool training. According to the experts, training within a company only makes sense up to the fourth level, "Apply". The "mastery" level is only relevant for the "train the trainer" archetype, whereby the qualification for this takes place externally. For this reason, the learning objectives in this paper are only defined for the competence levels "Know", "Understand" and "Apply". The subdivision of the competencies into methods & processes and tools and the differentiation according to competence levels results in a total of 48 different learning modules. It was also found that the core competencies described in section 4.2.1 cannot be specifically trained. These competencies are achieved by qualifying the remaining competencies. The subdivision of the competences into the competence level-specific modules is shown as an example in Table 4-3. The entirety of the identified modules can be found in the appendix in Table A- 1, Table A- 2, Table A- 3, Table A- 4 and Table A- 5.

Table 4-3 Section of the breakdown of the qualification modules

Competence	Definition	1 Knowledge	2 Understanding	4 Apply
Requirements management (process, method)	The ability to analyze the needs and expectations of stakeholders and use these to define requirements for a system.	**Process**: The participants can needs, Stakeholder requirement, system requirements, and system element requirements differentiate between requirements documents. Know them the importance of traceability and understand why tools are necessary for this, **Method**: The participants know the basic process of requirements management . This includes identifying, formulating, deriving and analyzing of requirements	**Process**: The participants can understand how requirements sources identified, requirements derived and written become. You know the Different types and levels of requirements **Method**: Participants can read requirements documents or models (links etc.). They can read and understand context descriptions and interface specifications	**Process**: The participant can independently sources of requirements identify requirements, requirements derive, write, convert into requirements documents or models document, link, derive analyze. **Method**: Participants can independently document, link and analyze requirements documents or -document, link and analyze requirements documents or models. They can create and analyze context descriptions and interface specifications. create and analyze
requirements management (tool)		**Tool:** The participants know that there is a tool for the Requirements management gives.	**Tool:** The participants can in the requirements tool reading and requirements view and comment/review.	**Tool:** The participants can in a requirements tool Define requirements, link and analyze.
System architecture design (process, method)	The competence to a system associated elements, their hierarchy, and their interfaces or their behavior and the therefore related derived requirements for the development of a implementable Define the solution.	**Process**: The participants know the purpose of architecture models. They can roughly categorize them in the development process. **Method**: The participants know that there i s a dedicated methodology and modeling language for architecture modeling.	**Process**: The participants can understand, why architecture models as a inputs and outputs of the development process are relevant. **Method**: The participants can create architectural models behavior and the relevant information extract.	**Process**: The participants know the relevant process steps for architecture models and know where in the development process their inputs and which outputs they produce within them. **Method**: The participants can create architecture models of average complexity. They are in the position for them relevant Reproducible information and in accordance with the method and modeling language modeling language.
System architecture design **(tool)**		**tool:** The participants know that there is a dedicated tool for the viewing and, if necessary, the editing of architecture models.	**tool:** The participants can architecture models in a View tool and comment/review.	**Tool:** The participants can Architecture models in a Create tool and analyze.

4.4.2 Determining the competencies of the roles

Once the objectives of the qualification have been determined and learning objectives have been specifically defined, the employees' current competencies are measured. The competency assessor, which is presented by JAVAID in [JM23], is suitable for the assessment of competencies. It is based on the competencies of KÖNEMANN ET AL [KWA+22, p. 5f.], which are examined in the context of this work. The role evaluation is based on the role clusters assigned to the employees in chapter 4.3.3. It should be noted that the competency assessor uses the roles to represent the final target competencies, which are not directly targeted in every archetype. Often, basic knowledge should first be created in intermediate steps. The competency assessor must therefore be expanded so that the target competencies of the archetypes are taken into account in the assessment. A training requirement in a competence can be derived if the current competence of a role is below the target competence of the archetype. If the current level is at or above the target competence of the archetype, qualification within the selected archetype is no longer necessary. It should then be checked whether the role should be further qualified within another archetype. If the target level of an archetype is above the maximum value required for a role, it should also be checked whether qualification within this archetype makes sense. Selecting an archetype that has a lower qualification target may make sense here. The breakdown of the target competence levels between roles, archetypes and competencies is shown in Fig. 4-5.

The figure shows that the current maturity in the competencies "Operation, Service and Maintenance" and "Integration, Verification & Validation" is below the target level to be achieved with the archetype "Common Basic Understanding". A qualification requirement can be derived from this.

The target level of the role has already been reached for the "System architecture design" competence, and the "Agile methodological competence" competence even exceeds this. Here, it should be checked individually whether there is still a need for further qualification or whether the existing qualification is already sufficient.

In the competence "Requirements management", the competence level intended for the current archetype has already been achieved. However, the final target competence is still higher. Here it should be checked whether it makes more sense to continue the qualification on the basis of another archetype.

As there is no selection of individual modules for the "Common basic understanding" archetype, an individual decision must be made as to whether the selected archetype makes sense. The competencies "Operation, service and maintenance" and "Integration, verification & validation" require further qualification, which is why basic training may be useful. For the remaining competencies, the maturity for the archetype has already been reached.

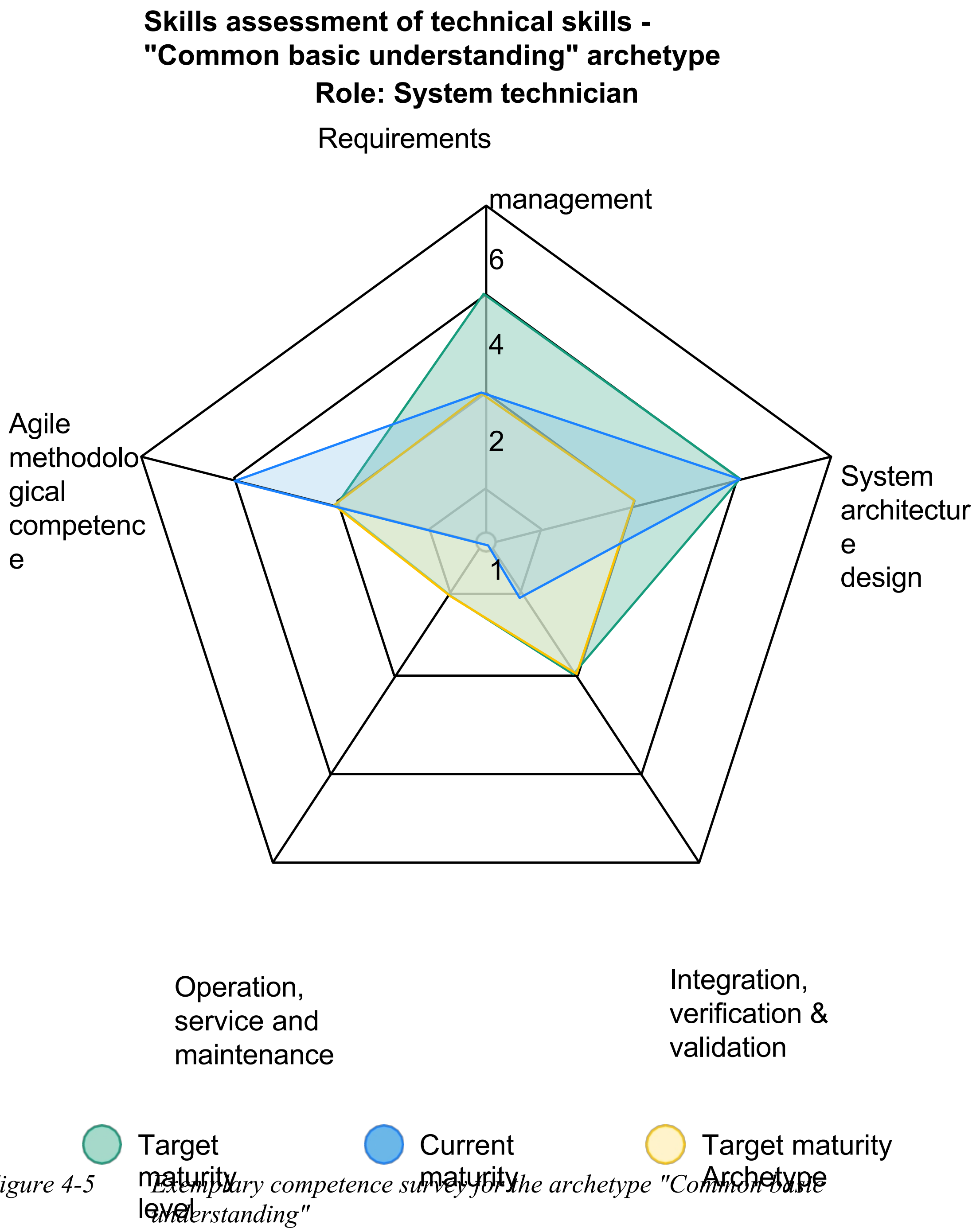

Figure 4-5 Exemplary competence survey for the archetype "Common basic understanding"

4.5 Setting up the rough concept

Once it has been determined which archetypes are to be used for the qualification and learning objectives have been defined for the specific company, the rough concept of the qualification follows. In addition to the scheduling of the measures, the content and implementation are defined here. No company-specific methods are considered for the majority of archetypes, especially those with a lower level of maturity. Standard training courses with minor adaptations make sense here. The rough conception of these archetypes is explained in more detail in chapter 4.5.1. The archetypes **needs-based project-oriented training** and **continuous support**, on the other hand, require the selection of special modules in order to achieve the learning objectives. The planning of this type of work is discussed in more detail in chapter 4.5.2.

4.5.1 Rough conception of archetypes without module selection

The **common basic understanding** archetype comprises simple basic training courses for SE. Depending on the given format, these training courses, which can be internal or external, usually take place in two to three-day sections in which an overview of the SE topic area is provided. This type of training is often carried out by external companies and therefore only includes a small amount of company-specific content. [Fra25-ol, Gla25-ol]

The **SE** archetype **for managers** requires more individualized content as a **common basic understanding in** order to convince managers of the topic. Here, managers learn the basics of SE and what it means for the company to apply it. The archetype can therefore also be understood as basic training specific to managers. This archetype can take two days, for example, and can take place internally or externally. [VDI25-ol]

Certifications also do not require any further content planning, as the content is specified by the curriculum. However, scheduling is necessary. Certifications take place externally with certification providers and offer their own modules for qualification. [SEZ22-ol] The duration of a certification training course varies depending on the type of certification. SE-Zert training courses have a duration of 12 days, for ASEP three days are scheduled. [Rüc25a-ol, Rüc25b-ol]

The **orientation** archetype **in the pilot project** functions as a hands-on approach. Qualification takes place here through the application of SE in a real project in the company. The qualification then generally corresponds to the duration of the project. Content is specified by the project itself and is not selected.

4.5.2 Rough conception of archetypes with module selection

In these archetypes, a specific selection of skills was made, which are further developed as learning modules in line with requirements. The core competencies of KÖNEMANN ET AL [KWA+22, p. 5f.] describe competencies that cannot be specifically qualified. They arise through the learning and application of the remaining competencies. When selecting and designing modules, it is important to check whether there are redundancies in the content of individual modules due to previous training courses.

In the case of **continuous support**, specific content is provided, for example in a learning management system, so that it can always be accessed. Learning paths can be defined for the qualification that are tailored to the employees and needs of the company. Continuous support is made available to employees at all times and supports continuous learning. The archetype is therefore not time-limited. [SAP25-ol]

In the **needs-based, project-oriented training** archetype, training is tailored to the needs and requirements of the company. Based on the skills and learning objectives identified in chapter 4.4, modules must be selected that are tailored to the desired learning objectives. Existing training courses in the company must also be taken into account. If, for example, training courses on project management already exist for the desired level, no new qualification measures need to be developed for this module. These existing modules can then be used if they fulfill the learning objectives. The archetype also makes it possible to select or exclude certain skills for qualification if they are not required. Modularization into individual skills allows companies to only train skills that are necessary. The duration of the training depends on the number and desired depth of the individual modules. Concrete topics and content must be defined based on the identified competencies. The learning objectives can support this.

If, for example, the learning objectives Understanding requirements management, Applying architecture design and Recognizing operation, service, maintenance have been identified for the developer role cluster, it must first be checked whether the desired competencies can already be covered by existing training courses. For example, if there is already a training course for operation, service and maintenance that reaches the "Recognize" competence level, it is not necessary to set up a new training course for this. If basic training is already offered for architecture design, but only reaches the "Understand" level, this can be used as an introduction to the topic. Further measures, such as workshops in company-specific application examples or coaching in the working environment, can be used to supplement the introduction in order to reach the "Apply" level. If requirements management has not yet been dealt with in the company, new content must be developed here.

be built up here. After basic training on the topic by external experts, the knowledge can be further deepened using company examples. The specific content and necessary tools can be assigned to the competence pyramid as shown in Fig. 4-6

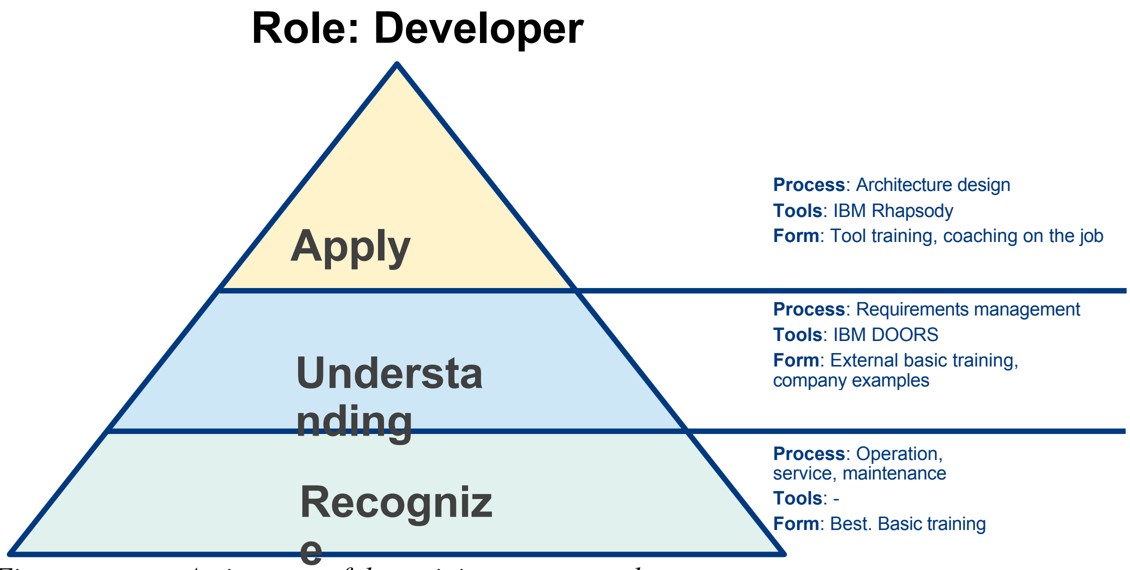

Figure 4-6 Assignment of the training content to the competence pyramid

4.5.3 Selection of learning formats

Once the content of the training courses has been defined, specific formats must be selected and planned. The KUMAR learning forum profiles can be used to support the selection of formats. [Kum23, A-5ff.] These provide a detailed description of the various formats. KUMAR assigns suitable learning formats to the different archetypes in a matrix and evaluates the suitability for different archetypes. [Kum23, p. 85] The identified learning profiles, shown as an example in Figure 4-7, provide further information on the individual learning formats.

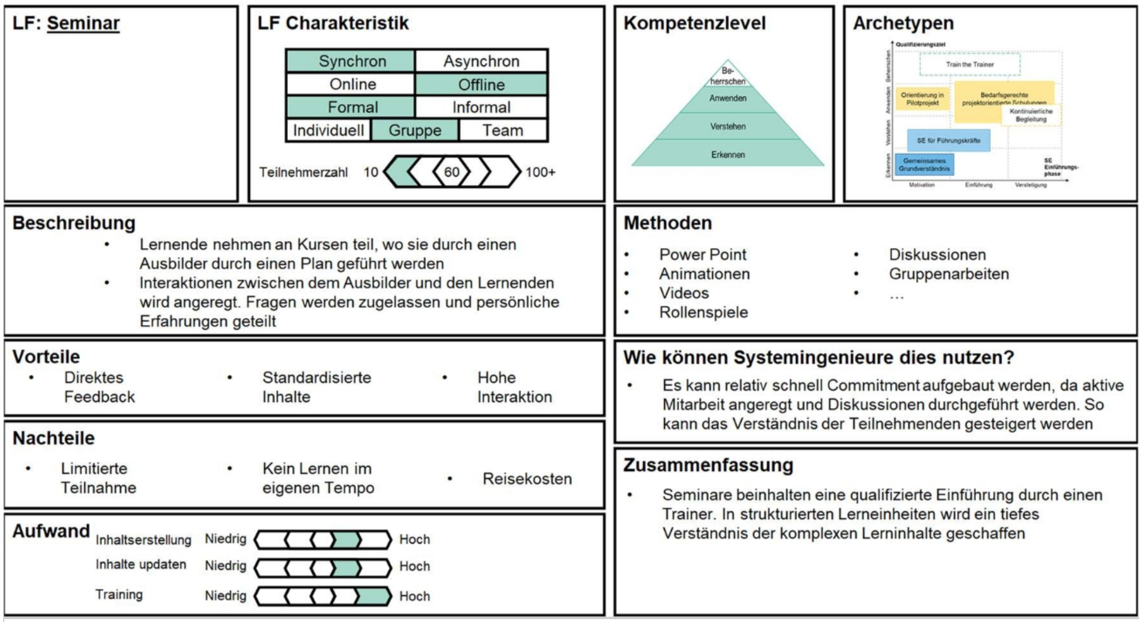

Figure 4-7 Learning profile translated according to [Kum23]

4.6 Detailed design

Once the rough concept has been drawn up, the detailed design of the qualification measures follows. Here, the individual learning units are worked out in detail and designed in such a way that the previously defined learning objectives can be achieved. The learning units are compared with the learning objectives and care is taken to ensure that the learning units are coordinated with each other. [KP21, p. 11] The didactics must also be worked out. The AVIVA model, for example, can be used for this purpose. The detailed concept must be designed in such a way that piloting can take place in the next step on the basis of the concept. Learning materials must be created and the learning content must be designed in such a way that the measures can be implemented at any time. The detailed design is outside the scope of this work and is considered a black box from here on.

5 Application and validation of the methodology

In this chapter, the methodology for maturity level-specific qualification planning is applied using an example. It was not possible to apply it in a real company as part of this work due to the time required to plan and implement such a project. It is therefore based on a fictitious example. For this purpose, ChatGPT is intended to support the creation of a fictitious company that uses the method. The Pro version of ChatGPT 4o was used as the model here. Chapter 5.1 first explains how ChatGPT was trained to apply the model. The following chapters explain the fictitious application in the four phases of the model.

5.1 Training the methodology

The application is to be carried out using fictitious examples. To do this, it is first necessary for the artificial intelligence (AI) to have a thorough understanding of the methodology developed. In order to train the AI, the methodology was first explained step by step and possible questions that companies can ask themselves in qualification planning were specified. The AI was instructed to ask questions in the event of discrepancies.

The analysis phase was explained using the decision tree for archetype selection. An image of the decision tree from section 4.3.2.2 was provided for this purpose and the process was explained in detail. This forms the main component of the analysis phase and already takes the maturity model into account. The role clusters were then explained in detail. Once the analysis phase had been described in detail, ChatGPT was asked to explain it in detail. This served to check whether the AI had understood the process. After the first explanation run, there were some inconsistencies in the decision tree process. The AI did not initially understand that the decision had to be continued after the selection of the **SE** archetype **for managers**. The **Train the Trainer** archetype was also not fully understood and was not initially taken into account by the AI in the decision-making process. In further iterations, the errors in understanding were corrected and it was checked again whether the AI understood the process. In this way, the understanding of the analysis phase was gradually built up until the phase was fully understood.

For the request phase, ChatGPT was asked to analyze the relevant tables for the competency assessor and understand the context of the content. Initially, the AI was unable to identify any connection between the competence level tables of the archetypes and the learning objectives, so that a more detailed explanation of the rows and columns of both tables was necessary. After a few more detailed explanations of the correlations and tables, the AI was able to independently identify generic learning objectives for the selected archetypes from the tables and adapt them to the specific company.

For the rough design, ChatGPT was already able to select competencies as modules based on the original descriptions of the methodology. This was done by comparing the existing competencies with the desired competencies. If existing competencies are below the desired competencies, the corresponding competencies are selected as modules. To do this, the AI compares the determined fictitious competencies of the role clusters and compares them with the desired competencies of the roles. If the current level of competence is below the target value, the AI derives a need for action in this competence. Existing offers of qualification measures in the fictitious companies were also taken into account by the AI during the selection process. If the fictitious company already has training courses in a relevant area, these are integrated into the qualification planning. The selection of formats was considered a black box in the context of this work, but ChatGPT offers the option of making suggestions for formats.

The detailed design is also outside the scope of this work and was therefore not considered further by the AI.

5.2 Application of the methodology

In the following, the methodology will be applied to two fictitious example companies. Section 5.2.1 presents the application at the company Thesis Masters GmbH, section 5.2.2 explains the implementation at NovaTech GmbH.

5.2.1 Application at Thesis Masters

In the following, the fictitious company Thesis Masters GmbH is first presented in more detail and then the implementation of the methodology is described.

5.2.1.1 Company description of Thesis Masters

Thesis Masters GmbH is a global provider in the field of special machine construction with around 3,000 employees. As an established player on the international market, the company develops customer-specific automation solutions for a wide range of industries - from semiconductor production and the pharmaceutical industry to packaging technology. In the past, the focus was strongly on technical excellence in the individual disciplines. Due to the increasing complexity of the overall systems and rising requirements for process integration and system networking, the decision was made to introduce SE as a strategic development approach.

Thesis Mas- ters is introducing systematic qualification planning in order to meet the increasing demands with regard to the complexity of customer requirements and interdisciplinary collaboration. The company's aim is to further professionalize the existing SE processes and roles and to anchor them throughout the company. The planning is based on the methodology presented in this thesis.

5.2.1.2 Analysis phase for Thesis Masters GmbH

In the first step, the company assesses the maturity of the existing SE processes. This is based on the typical processes of ISO 15288, including the processes of project planning, risk management, requirements analysis and system architecture design. The evaluation shows that the SE roles and processes are not yet sufficiently defined. For this reason, Thesis Masters would first like to sensitize managers to the topic in order to enable company-wide introduction. When choosing the other archetypes, the company opts for **a pilot project orientation**. This decision was justified by the fact that this would allow for practical application and immediate added value. The project management also hopes that this will lead to greater acceptance through direct integration into the work processes.

When deciding on the training of a trainer, Thesis Masters GmbH decided to train a trainer internally, as the qualification was to take place over a long period of time. An experienced colleague who already has a strong understanding of the process was selected for this purpose.

The roles at Thesis Masters are diverse. At various conferences, the management has noticed that the role descriptions in the company differ greatly from other companies. In order to enable the evaluation using the competence identifier, the roles in the company are asked to assign themselves independently to the role clusters.

The roles at Thesis Masters GmbH can be divided into the role clusters as follows:

- Technical project manager=> Project manager
- Lead mechanical designer=> Specialist developer
- Software Manager Control=> System Developer
- System Coordinator Mechatronics=> System Developer
- Sales engineer with customer contact=> Customer representative

5.2.1.3 Requirements phase for Thesis Masters GmbH

In the next step, Thesis Masters carries out a comprehensive skills analysis. The aim is to determine the current level of competence of the relevant role clusters in the company. The role clusters considered are project managers, specialist developers, system developers and customer representatives. The analysis is based on the 16 competencies defined as relevant in this work, including, for example, requirements management, system architecture design, communication and collaboration.

The skills assessment is carried out separately for each defined role cluster. This ensures that it can be determined individually for each cluster whether the respective competencies reach the desired level. Table 5-1 shows the results of the competence assessment of the role cluster system developer in tabular form as an example.

Table 5-1 Competence assessment of system developers at Thesis Masters GmbH

Competence	SE qualification archetypes			
	ACTUAL	Goal (Role)	Goal (archetype)	Training needs
Requirements management	2	4	4	Yes
System architecture design	2	1	4	yes
Communication & Collaboration	2	1	4	yes

Legend

1	**Know**
2	**Understand**
4	**Apply**
6	**Mastery**

The decision on the required modules is made individually for each role cluster. This ensures that the training measures are precisely tailored to the specific requirements and skills needs of the respective clusters. Company-specific learning objectives are derived from the generic learning objectives for the necessary modules on the basis of the competencies identified for the individual role clusters. An excerpt of the learning objectives for the system developer role cluster is shown in Table 5-2.

5.2.1.4 Rough design phase Thesis Masters GmbH

As no further module selection is necessary with the **orientation** archetype **in the pilot project**, the previously created learning objectives are not used to select modules. However, the learning objectives can be used to check learning progress.

Table 5-2 Selection of learning content for the learning modules for Thesis Masters system developers

Competence	Definition	1 Knowledge	2 Understanding	4 Apply
Requirements management (process, method)	The competence to analyze the needs and expectations of stakeholders and to define requirements for a system on this basis.	**Process**: The participants can differentiate between needs, stakeholder requirements, system requirements and system element requirements . They know the importance of traceability and understand why tools are necessary for this, **Method**: The participants know the basic process of requirements management. This includes identifying, formulating, deriving and analyzing requirements	**Process**: Participants understand how requirements sources are identified, how requirements are derived and written. They know the different types and levels of requirements **Method**: Participants can read requirements documents or models (links etc.). They can read and understand context descriptions and interface specifications	**Process**: The participant can independently identify sources of requirements, derive requirements from them, write them, document them in requirements documents or models, link them, derive them, analyze them. **Method**: Participants can independently document, link and analyze requirements documents or models. They can create and analyze context descriptions and interface specifications
Requirements management (tool)		**Tool:** Participants know that there is a tool for requirements management.	**Tool:** Participants can read, view and comment/review requirements in the requirements tool.	**Tool:** Participants can define, link and analyze requirements in a requirements tool.
System architecture design (process, method)	The competence to define the elements belonging to a system, their hierarchy, as well as their interfaces or their behavior and the associated derived requirements for the development of an implementable solution.	**Process**: The participants know the purpose of architecture models. They can roughly categorize them in the development process. **Method**: Participants know that there is a dedicated methodology and modeling language for architecture modeling.	**Process**: Participants can understand why architecture models are relevant as inputs and outputs of the development process. **Method**: Participants can read architecture models and extract relevant information from them.	**Process**: The participants know relevant process steps for architecture models and know where their inputs come from in the development process and what outputs they produce. **Method**: Participants can create architecture models of average complexity. They are able to reproduce relevant information in accordance with the method and modeling language.
System architecture design (tool)		**Tool:** Participants know that there is a dedicated tool for viewing and, if necessary, editing architecture models.	**Tool:** Participants can view and comment/review architecture models in a tool.	**Tool:** Participants can create and analyze architecture models in a tool.
Communication & Collaboration	The competence to communicate constructively, efficiently and consciously, also across domains, and to recognize and take into account the feelings of other people as well as to build sustainable and fair relationships with colleagues and superiors.	Participant knows the necessity of these competencies	Participant recognizes and understands the relevance of this competence, especially with regard to the application of SE	Participant is able to communicate constructively and efficiently while being empathetic towards his/her communication partner.

5.2.1.5 Detailed design phase Thesis Masters GmbH

The project management defines the following steps for the detailed design phase:

First of all, the objectives of the qualification are to be discussed together in an initial kick-off. This will be followed by a workshop on IBM DOORS and how this tool can support the elicitation of requirements. To this end, real requirements from current projects will be examined. Initial modeling attempts will then be made in a modeling workshop with the Cameo Systems Modeler. Architectural decisions and the definition of interfaces will be accompanied by an expert. During the course of the project, reflection rounds are planned at regular intervals in order to monitor progress and collect best practices.

At the end of the training measure, interviews are conducted in the company to evaluate the training. If necessary, further training measures are planned and adapted to new requirements on the basis of the feedback.

The project management assesses the qualification as successful. The definition of requirements and the improved coordination between mechanics and software were particularly positively emphasized. The SE qualification is to be continued in further projects using the methodology.

5.2.2 Application at NovaTech GmbH

In the following, the fictitious company NovaTech GmbH is presented in more detail and then the implementation of the methodology is described.

5.2.2.1 Company description NovaTech GmbH

NovaTech GmbH is a medium-sized company based in southern Germany. With around 850 employees, NovaTech develops and produces intelligent sensor systems and control units for use in the automotive, aviation and energy industries. The company's focus is on the combination of electronics, software and mechanical integration. Due to the growing product portfolio and the increasing system complexity in customer projects, previous development processes are increasingly reaching their limits. Particularly in interdisciplinary projects, there is often a lack of standardized methods for requirements analysis, system structuring and interface definition. In order to systematically address these challenges, No- vaTech has decided to introduce SE and implement a qualification-based introduction.

5.2.2.2 Analysis phase for NovaTech GmbH

The first step was to assess the company's level of maturity with regard to SE processes and their application. The evaluation of the SE roles and processes revealed that documented processes exist in individual areas, but without uniform application within the company. The scope of the rollout was assessed as low, as SE approaches have so far only been used in the area of embedded software, while other specialist areas such as electronics and mechanics have not been systematically integrated. This combination results in the **project-oriented training** archetype with the help of the decision tree.

For the long-term introduction of SE, NovaTech also decided to set up an internal trainer in parallel. An experienced senior engineer with a high level of methodological expertise was chosen to accompany the training and continue it in further projects.

In preparation for the skills analysis, the roles involved in the pilot project were assigned to the standardized role clusters:

- High-voltage control project manager=> Project manager
- Electronics developer Hardware=> Specialist developer
- Software architect=> System developer
- Lead test engineer=> V&V
- Product manager customer integration=> Customer representative

5.2.2.3 Requirements phase for NovaTech GmbH

In the subsequent competence analysis, the defined role clusters were systematically evaluated with regard to the 16 SE core competencies. For the system developer role cluster, training needs were identified in the areas of system architecture design, requirements management, integration, verification and validation, among others. For the specialist developer role cluster, deficits were identified in particular in the consideration of life cycle phases, configuration management and information management.

Based on the target levels of the selected archetype, specific learning objectives were taken from the learning objectives table and adapted to the company's tool landscape. For example, the learning objective for requirements management was adapted to the IBM DOORS tool, while PTC Windchill was named for configuration management. The other learning objectives included the use of Enterprise Architect for architecture modeling, an understanding of life cycle phases and structured approaches to documentation and traceability of information in the development process.

5.2.2.4 Rough design phase at NovaTech GmbH

As the archetype "needs-based project-oriented training" was chosen, a targeted selection of suitable training modules was made on the basis of the learning objectives. The modules were individually assigned to the competence fields and target levels. These included, among others: "Applying system architecture design", "Applying verification & validation", "Applying requirements management", "Applying information management" and "Understanding system life cycle phases". A need for qualification was also identified for configuration management. However, as the NovaTech Academy already offers training courses for configuration management, these can be integrated into the qualification.

Specific topics were then defined on the basis of the learning objectives. Care was taken to ensure that the content was practice-oriented and role-based. For example, the "Applying system architecture design" module covers the modeling of technical interfaces with Enterprise Architect, while the "Understanding system life cycle phases" module provides an overview of typical phase models and their impact on system development. Formats were defined for the specified topics at the end of the rough design phase. Online workshops were chosen for conceptual content such as lifecycles and architecture concepts. For tool-related content such as IBM DOORS or PTC Windchill, face-to-face training sessions with practice phases were planned.

5.2.2.5 Fine-tuning phase at NovaTech GmbH

The training modules were carried out over a period of ten weeks. The training was carried out in hybrid form, partly online and partly in person by the internal trainer. Parallel to the formal training, the interdisciplinary project team was supported by accompanying SE coaching. The content was applied directly as part of the development of a sensor system for e-mobility.

At the end of the training series, the learning objectives were evaluated using practical tasks and feedback from the participants. The evaluation showed a significant improvement in the definition and tracking of requirements and in interface communication between the disciplines. System verification was also prepared and carried out more systematically. The project management considered the measure to be successful and is planning to extend it to other product areas. The internal trainer is to coordinate and supervise further training sessions in future.

5.3 Validation of the methodology

Fraunhofer IEM employees were asked to validate the methodology of this work. The individual steps of the methodology were explained with the help of a concept board and supplemented by the company example NovaTech GmbH from chapter 5.2.2. A questionnaire created using Microsoft Forms was used for validation. The questionnaire can be found in the appendix in Figure A- 1 and Figure A- 2.

The validation was carried out by three Fraunhofer IEM employees who were already familiar with the methodology during the preparation of this thesis. This meant that no extensive introduction to the methodology was necessary, as the employees were already familiar with it.

The experts agreed that the process of the methodology is clearly structured and comprehensible. The simple and logical sequence of the individual steps was particularly emphasized. The decision tree for selecting the archetypes was rated as understandable in principle, but some experts did not realize that it is also run through several times during planning and only serves as a decision-making aid. This must be given greater consideration in the further development of the methodology. The feasibility of the methodology in practice was rated as realistic by all participants. The comprehensibility and structure of the methodology was particularly emphasized. Even employees with little training could easily apply the methodology thanks to the structured approach. The lack of clarity regarding the various maturity levels in the company valuation was criticized. It needs to be made clearer which maturity assessments lead to which decision. The specific output of the methodology was criticized by one employee as unclear, which may be due to the large number of methods used.

The experts agreed that the methodology used in this work met the requirements for the analysis and consideration of maturity. Two experts fully agreed and one agreed. According to the experts, the iterative adaptation to company needs was partially fulfilled. Two experts agreed, while another was neutral on this point. This may be due to the lack of clarity that the process can be run through several times. The consideration of change management was rated as neutral by all employees. Further development needs to take place here in order to give more consideration to the aspects of change management. The experts agreed that the methodology can support the definition of learning objectives; all three experts agreed. Regarding the distinction between different qualification strategies, one expert fully agreed, one agreed and another was neutral about the fulfillment of requirements. This may be due to the lack of clarity in the assessment of the maturity levels. Figure 5-1 summarizes the results of the survey once again.

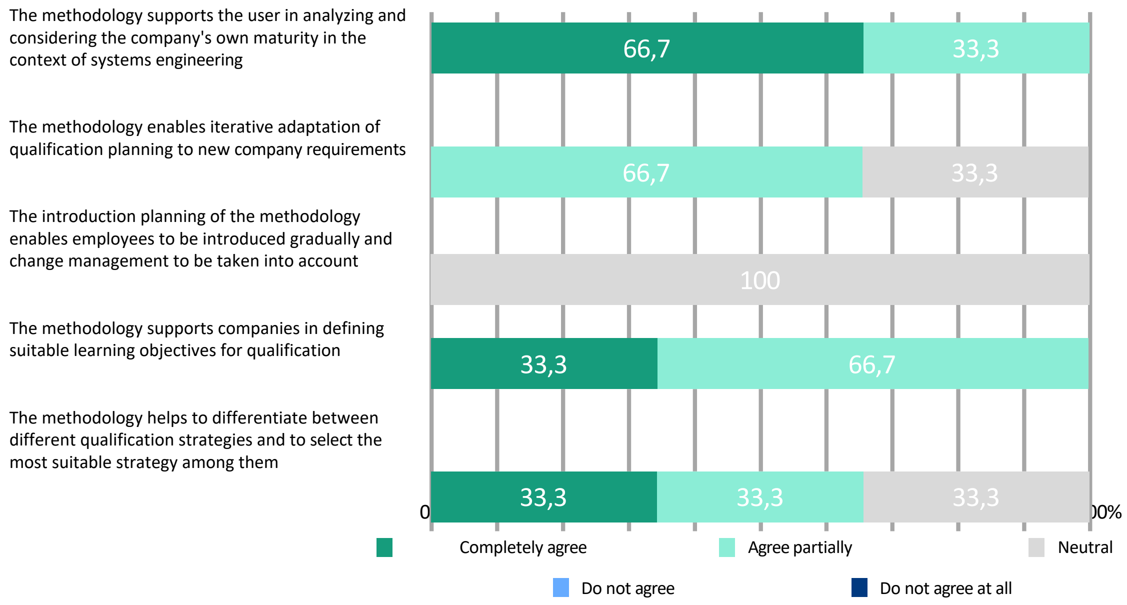

Figure 5-1 *Results of the validation of the requirements*

6 Summary and Outlook

In this work, a methodology for planning maturity level-specific engineering training projects was developed. The starting point was the analysis of the increasing complexity of technical systems and the associated challenges for companies. SE was identified as a suitable approach to meet these challenges. At the same time, it became clear that the successful introduction of SE depends heavily on the targeted qualification of employees.

Based on a comprehensive literature review, existing approaches to measuring maturity and qualification planning were examined. From this, requirements for a practice-oriented methodology were derived. The methodology developed takes into account the specific maturity level of a company, summarizes diverse role profiles in a standardized way using role clusters and evaluates the necessary competencies using a competence scale.

The application of the methodology in an example company showed that it can be used to implement tailored qualification planning. In particular, the linking of company maturity levels, role profiles and competence profiles makes it possible to design individual learning paths for different target groups. This ensures that both basic training courses and specialized further training measures can be offered in line with demand. The integration of change management approaches also supports the acceptance of the measures introduced, but must be given greater consideration within the methodology.

The application has so far been tested using fictitious example companies with ChatGPT. The applicability in real companies must be examined separately in the future. The aspects of change management in particular need to be tested in real examples. In addition, the integration of digital learning platforms offers potential for implementing the modular structure of the qualification even more flexibly and efficiently.

The individual steps of the methodology are currently carried out manually. In a next step, after a more detailed validation, the methodology could be digitized. In a similar way to the competency assessor, the individual steps can be summarized in a single tool to better clarify correlations. Combining the content can improve the usability of the methodology. The effects of the individual decisions can be better understood through additional context-dependent information.

List of abbreviations

e.g.	for example
SE	Systems Engineering
INCOSE	International Council on Systems Engineering
MBSE	Model-Based Systems Engineering
AI	Artificial Intelligence
ASPICE	Automotive Software Process Improvement and Capability dEtermination
BPMN	Business Process Model and Notation

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Appendix

A1 Breakdown of the qualification modules

A1.1 Breakdown of the qualification modules (1/5)

Table A- 1 Breakdown of the qualification modules (1/5)

Competence	Definition	1 Knowledge	2 Understanding	4 Apply
Requirements management (process, method)	The competence to analyze the needs and expectations of stakeholders and to define requirements for a system on this basis.	**Process**: The participants can needs, Stakeholder requirement, system requirements, and system element requirements differentiate between requirements documents. Know them the importance of traceability and understand why tools are necessary for this, **Method**: The participants know the basic process of requirements management . This includes identifying, formulating, derive and analyze of requirements	**Process**: The participants can understand how requirements sources identified, requirements derived and written become. You know the different types and levels of requirements **Method**: Participants can read requirements documents or models (links etc.). They can read and understand context descriptions and interface specifications	**Process**: The participant can independently sources of requirements identify requirements, requirements derive, write, convert into requirements documents or models document, link, derive analyze. **Method**: Participants can independently document, link and analyze requirements documents or -document, link and analyze requirements documents or models. They can create and analyze context descriptions and interface specifications. create and analyze
requirements management (tool)		**Tool:** The participants know that there is a tool for the Requirements management gives.	**Tool:** The participants can in the requirements tool reading and requirements view and comment/review.	**Tool:** The participants can in a requirements tool define requirements, link and analyze.
System architecture design (process, method)	The competence to a system associated elements, their hierarchy, and their interfaces or their behavior and the therefore related derived requirements for the development of a implementable Define the solution.	**Process**: The participants know the purpose of architecture models. They can roughly categorize them in the development process. **Method**: The participants know that there i s a dedicated methodology and modeling language for architecture modeling.	**Process**: The participants can understand, why architecture models as a inputs and outputs of the development process are relevant. **Method**: The participants can create architectural models and use them to relevant information extract.	**Process**: The participants know the relevant process steps for architecture models and know where in the development process their inputs and which outputs they produce within them. **Method**: The participants can create architecture models of average create complexity for them. They are in the position for them relevant Reproducible information and in accordance with the method and modeling language modeling language.
System architecture design (tool)		**tool:** The participants know that there is a dedicated tool for the viewing and, if necessary, the editing of architecture models.	**tool:** The participants can architecture models in a View tool and comment/review.	**Tool:** The participants can Architecture models in a Create tool and analyze.

A1.2 Breakdown of the qualification modules (2/5)

Table A- 2 Breakdown of the qualification modules (2/5)

Integration, verification & validation	The competence to integrate a set of system elements into a verifiable or validatable unit or to provide objective evidence that a system fulfills the specified requirements (validation) or achieves its intended properties in the intended operating environment (validation), to perform.	The participant knows the objectives of verification and validation and is familiar with different types and procedures of V&V.	The participant can read and understand test plans, test cases and test results.	The participant can create test plans. They will be able to carry out and document tests and simulations.
Operation, service and maintenance	The competence to commission and operate the system and maintain its capabilities/functionalities over its lifetime .	The participants know the lines of the operation, service and maintenance phase. They know that these are already taken into account during development and that there are activities in the respective phase.	Participants understand how the operation, service and maintenance phases are taken into account in development. They are able to name the activities that are necessary in the life cycle.	Participants understand how the operation, service and maintenance phases are taken into account in development. They will be able to manage the phases and identify improvements for future projects.
Agile method competence	The ability to apply methods that support agile values in the project context and enable parallel work. enable parallel work	**Method:** The participant knows the agile values and the relevant agile methods	**Method:** The participant understands the basics of agile working methods and understands how agile methods can be applied in a development process.	**Method**: The participant can work in an agile environment. They are able to apply the necessary methods.

A1.3 Breakdown of the qualification modules (3/5)

Table A- 3 Breakdown of the qualification modules (3/5)

Self-organization	The ability to organize oneself and work on tasks work on tasks	Participants know the concepts of self-organization.	Participants understand how the concepts of self-organization influence their everyday work	Participants are a b l e to carry out projects, processes and tasks in a largely self-organized manner. in a largely self-organized manner.
Communication & collaboration	The ability to communicate constructively, efficiently and consciously, including across domains, and to recognize and take into account the feelings of other people, as well as to build sustainable and fair relationships with colleagues and superiors. with colleagues and superiors.	Participants know the necessity of these skills.	Participants recognize and understand the relevance of this competence, especially with regard to the application o f SE.	Participants are able t o communicate constructively and efficiently while being empathetic towards communication partners.
Leading	The competence to select suitable goals for a system or system element, to negotiate them if necessary and to achieve them efficiently with a team and, if necessary, to support team members in solving problems. team members in solving problems to guide team members in solving problems.	The participants know the necessity of these competencies	Participants understand the relevance of defining goals for a system and can define them in a way that is understandable for the entire team	Participants are a b l e to negotiate objectives with the team and find an efficient way to achieve them.

A1.4 Breakdown of the qualification modules (4/5)

Table A- 4 Breakdown of the qualification modules (4/5)

Project management (process, method)	The competence to identify, plan, coordinate and adapt activities to deliver a satisfactory system, product or service with appropriate quality, budget and time.	**Process**: The participant knows the subject area of project management and can organize his activities in a project plan **Method**: The participant knows the common methods of project management.	**Process**: The participant understands the project assignment and can categorize project management in the context of systems engineering. **Method**: The participant can independently create the relevant (project) plans and generate corresponding status reports (with regard to Q-K-T).	**Process & method:** The participant is able to define a project assignment and framework conditions, create complex project plans and generate meaningful reports. He is practiced in communicating with stakeholders.
Project management (tool)		**Tool**: The participant knows the relevant tools for project management. (e.g. Microsoft Project)	**Tool**: The participant understands why project management tools are used.	**Tool:** The participant is able to carry out planning in the respective tool.
Decision management	The competence to identify, characterize and evaluate an objective set of alternatives in a structured and analytical manner, taking risks and opportunities into account. opportunities	Participants are familiar with the main decision-making bodies and know how decisions are made. They know the basic methods for decision-making	Participants learn about decision support methods and understand which decisions they can make themselves and which are made by committees etc.	Participants are able to prepare decisions for their relevant scopes or make them themselves and document them accordingly. They can apply methods of decision support.
Information management	The ability to address all aspects of information for specific stakeholders in order to provide the right information at the right time and with the right security. security.	The participant knows the advantages of established information and knowledge management.	The participant knows the main platforms for knowledge transfer and knows which information needs to be passed on to whom.	The participant knows the main platforms for knowledge transfer. He is able to define filing structures and documentation guidelines for projects and can make the relevant information available in the appropriate place.
Configuration management (process, method)	The ability to harmonize system functions, performance and physical properties over the life cycle and ensure consistency.	**Process:** The participant understands the necessity of configuration management	**Process:** The participant understands the procedure for defining configuration items. He is able to recognize the configuration items relevant to him and to form an integer configuration for his relevant scopes.	**Process:** The participant can define meaningful configuration items. He is able to recognize the configuration items relevant to him and to create an integer configuration for his relevant scopes.
Configuration management (tool)		**Tool:** The participant knows in which tools configurations are to be created.	**Tool:** The participant is able to create configuration items for his scopes in the tool(s)	**Tool:** The participant is able to define configuration items in the tool(s) and create them for their scopes

A1.5 Breakdown of the qualification modules (5/5)

Table A- 5 Breakdown of the qualification modules (5/5)

Systemic thinking	The competence to apply fundamental concepts of systems thinking in systems engineering and to understand the role of one's own system in its overall context. context.	The participant knows the interrelationships of his/her system and the associated system boundaries.	The participant understands the interaction of the individual components that make up the system.	The participant is able to analyze their existing system and derive continuous improvements from it.
System modeling and analysis	The ability to provide accurate data and information using cross-domain models to support technical understanding a n d decision making. support decision making.	Participants know the basics of modeling and its benefits.	Participants understand how models support their work. They are able to read models easily.	Participants are able to independently define their own system models for their relevant scope. They are able to differentiate between domain-spanning and domain-specific models,
Consideration of system life cycle phases	The competence to consider the life cycles other than the operational phase in the system requirements, architectures and designs during the realization of a system. into account.	The participant knows the life cycle phases of his system	The participant understands why and how all life cycle phases must be taken into account during development.	The participant is able to identify, consider and evaluate the relevant scope of all life cycle phases
Customer-benefit orientation	The competence to place agile values / customer benefits at the center of development. development.	The participant knows the basic principles of agile thinking.	The participant understands how agile thinking can be integrated into everyday working life	The participant is able to develop a system according to agile thinking and to f o c u s on customer benefit.

A2 Questionnaire for validation

A2.1 Questionnaire for validation (1/2)

Validierung der Methodik zur reifegradspezifischen Qualifizierungsplanung

* Erforderlich

Verständnis der Methodik

1. Ist der Ablauf der Methodik für Sie nachvollziehbar strukturiert *

- ◯ Ja
- ◯ Nein
- ◯ Teilweise

2. Begründen sie *

Ihre Antwort eingeben

3. Wie bewerten sie den Entscheidungsbaum zur Archetypauswahl *

- ◯ Gut verständlich
- ◯ Verständlich
- ◯ Unklar
- ◯ Zu komplex

4. Begründen sie *

Ihre Antwort eingeben

5. Ist der Ablauf für die Planung von Qualifizierungsmaßnahmen realistisch Umsetzbar? *

- ◯ Ja
- ◯ Ja mit Einschränkungen
- ◯ Nein

Figure A-1 Questionnaire Understanding the methodology

A2.2 Questionnaire for validation (2/2)

Validierung der Methodik zur reifegradspezifischen Qualifizierungsplanung

* Erforderlich

Erfüllung der Anforderungen an die Methodik

10. Bewerten sie die Erfüllung der Anforderungen an die Methodik der Arbeit *

	Stimme voll und ganz zu	Stimme zu	neutral	Stimme nicht zu	Stimme überhaupt nicht zu
Die Methodik unterstützt den Anwender bei der Analyse und der Berücksichtigung der eigenen Reife des Unternehmens im Kontext des Systems Engineerings	○	○	○	○	○
Die Methodik ermöglicht eine iterative Anpassung der Qualifizierungsplanung bei neuen Unternehmensbedürfnissen	○	○	○	○	○
Die Einführungsplanung der Methodik ermöglicht es, Mitarbeiter schrittweise einzuführen und das Change-Management zu berücksichtigen	○	○	○	○	○
Die Methodik unterstützt Unternehmen dabei, geeignete Lernziele für die Qualifizierung zu definieren	○	○	○	○	○
Die Methodik hilft dabei, zwischen verschiedenen Qualifizierungsstrategien zu unterscheiden und unter diesen die am besten geeignete Strategie auszuwählen	○	○	○	○	○

11. Haben sie sonstiges Feedback zur Methodik? (Freiwillig)

Ihre Antwort eingeben

Figure A-2 Questionnaire Fulfillment of requirements