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Systems engineering in design practice: a guideline for development service providers

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Abstract

To handle the increased complexity within the automotive industry, this paper introduces a guideline, which aims to support development service providers to examine the introduction and if applicable support the introduction of systems engineering. The initial verification was performed through applying the guideline at Porsche Engineering as an exemplary service provider. As a result, the success factors "knowledge basis" and "knowledge transfer" have been improved by two points on a 1-5 Likert-scale by introducing a SE process-specific knowledge platform and a defined knowledge transfer.

Keywords: *systems engineering (SE), service-oriented design, development service provider, knowledge management, case study*

1. Introduction

The traditional wristwatch was originally invented as a piece of jewellery for women in the 19th century. Shortly after, it was used as a practical tool, especially for pilots, to easily keep track of the time during a flight. These very complicated watches consist of about 1500 individual parts today and still adorn the wrists of many people. But the share of people wearing a traditional wristwatch has fallen from 46 percent (2020) to 39 percent (2021). At the same time, the share of smartwatch wearers rose from 15 to 24 percent. This example underlines the hypothesis that hardware is hardly sold without software anymore (McKinsey & Company, 2022). The introduction of software into hardware products, as the wristwatch introduced above, leads to complicated products turning into complex products. Thousands of lines of code lead to different functionalities, which were originally not part of the product. The very same phenomenon is visible in the automotive industry. Cars are built with about 10.000 individual hardware parts of different materials. But nowadays, millions of lines of code need to be implemented to add different functions in the multimedia system or driver assistant system. This results in a more and more complex development process to address the customers' needs.

One industry that has been working with this complexity for a long time is the aerospace industry (Gausemeier *et al.*, 2013a). Here, the systems engineering method is used to continue to develop functioning products in a complex environment. The trend towards systems engineering can also be observed in the automotive industry, as from the fact that many original equipment manufacturers (OEMs) are introducing or have already introduced the method in their development areas. However, this change in development methodology not only has an impact on the OEM itself, but also on the supplier and service provider network. Especially the latter of development service provider has not yet been investigated, which is why this paper aims to develop and initially verify a guideline that will enable development service providers to examine the introduction of systems engineering and, if applicable, to support the introduction through the investigation of success factors. To do so, the paper first presents the state of research regarding systems engineering and a definition of development service providers. Following, the research objective and the methodical approach are described. Subsequently, to create a guideline, decision attributes and success factors are initially derived from a literature review. Finally, the guideline is validated in an industrial application and discussed to give an outlook on the topic.

2. State of research

2.1. Systems engineering

The origins of systems theory, which lie in antiquity, were summarized as general systems theory by the biologist Bertalanffy in the 1930s (Bertalanffy, 1969). Central element of this system theory is the realization that characteristics of higher levels cannot be explained by the isolated consideration of the sum of the characteristics of their components. Therefore, not only the components, but especially the relations between them must be considered. This approach showed the potential to develop a cross-disciplinary theory that allows the integration of existing, isolated disciplines.

In the context of engineering, this general systems theory has taken on a form of describing technical products and their creation processes (Pulm, 2004). It is referred to as "Systems Engineering"(SE) or "systems theory of engineering". Referring to this, the International Council on Systems Engineering (INCOSE) defines SE the following:

> *"Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods." (INCOSE, 2023)*

To be able to decide about the introduction of SE, benefits of SE and challenges in the introduction of SE need to be considered. In the following, four main benefits of the application of SE are described. First, the method supports in handling the complexity of the development task (Huth and Vietor, 2020; Bursac *et al.*, 2016) and complex product requirements (Bretz, 2021). Second, the comprehensive system understanding is seen as a benefit of SE, because errors can be detected early and corrected in a cost-efficient manner (Dumitrescu *et al.*, 2021). In addition, communication and clear interfaces are encouraged, what benefits the parallelization of development tasks. Moreover, the system understanding improves the design of innovative and customer-oriented solutions. Third, SE improves the traceability and transparency of the development task for example by the documentation of technical connections, which than can be comprehend in later development phases (Dumitrescu *et al.*, 2021). Fourth, Haberfeller *et al.*, (2019) mention agile SE, the synthesis of agile working methods and application of SE as a benefit of the introduction of SE. In this way, while developing complex systems, the development process can be adjusted more flexible and at short notice to changing requirements.

However, the introduction of a new development methodology such as SE also presents challenges. Therefore, employees must accept the change and be trained accordingly (Dumitrescu *et al.*, 2021; Bretz, 2021; Huth and Vietor, 2020). In addition, processes, methods, and tools must also be adapted to the new development methodology (Dumitrescu *et al.*, 2021). Furthermore, a successful introduction of SE is only possible if the mindset of the entire company changes and the complexity of the development task is acknowledged (Gräßler and Oleff, 2022). Related to this, the necessity of SE for the company's own products must be recognized (Gausemeier *et al.*, 2013b).

2.2. Definition of development service provider companies and business strategies

Development service providers (DSPs) are active in the field of research and development (Antje Blöcker, 2016; Berylls Strategy Advisors, 2015). They are characterized by the fact that, unlike (Tier X) suppliers or original equipment manufacturers (OEMs), they do not develop their own products. Instead, they take on project orders for industrial customers in the form of service contracts or work contracts and so-called employee leasing. Therefore, development service providers are not bound to a

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specific contractor or a specific phase within the product development process. As the automotive industry, one of DSP's largest customers in Germany (Antje Blöcker, 2016), is in a state of structural transformation (Leffers *et al.*, 2020), DSPs have to deal with various challenges. These include increased price pressure (Berylls Strategy Advisors, 2015), changing competencies (Fintl, 2021), increasing internationalization (Berylls Strategy Advisors, 2015), but also flexible and agile ways of working (Leffers *et al.*, 2020; Gilgen, 2020). To cope with those challenges (Leffers *et al.*, 2020) are presenting three strategies for DSPs. First, "**Commodity** - the generalist in the development supermarket" with a focus on cost-efficient standard development services at so-called best-cost locations. Second, "**New Tech** - the specialist for sophisticated niches" with the focus on being a technology partner for differentiation technologies of the customer like advanced driver systems or complex electric/electronic systems. Third, "**Complete Vehicle** - the development supporter for newcomers" with the focus on offering the existing complete vehicle knowledge in cooperation with an emerging OEM. Conclusively, to examine the introduction of SE within a DSP, the strategy is an important factor.

3. Research objective and methodology

Many experts such as Sandrin, (2019), Ohlsen, (2019), Berylls Strategy Advisors (2015), and Leffers *et al.*, (2020) agree, that the automotive industry is working through a structural transformation. This is often linked to the increasing complexity of development tasks (McKinsey & Company, 2022). Therefore, a methodology must be found that enables the developer to work within this complexity (Albers *et al.*, 2010). According to a study by Dumitrescu *et al.*, (2021) there is agreement among the respondents that SE has a special strategic significance in order handle the increased complexity and to improve the performance of the development of innovative market services in the future. However, according to, Schasse *et al.*, (2016) there are only a few research studies to date that explicitly deal with development service providers.

For this reason, this paper aims to develop and initially verify a guideline that will enable development service providers (DSPs) to examine the introduction of SE and, if applicable, to support the introduction through the investigation of success factors. This is operationalized by the following research questions:

1. What determines the suitability of introducing SE to a DSP and what are the success factors to consider when introducing SE to a DSP?
2. How should a guideline be designed that supports the evaluation of introducing SE within DSPs and the introduction of SE itself?
3. What added value can be demonstrated when applying the guideline at Porsche Engineering Services GmbH as an example of a DSP?

The presented research follows the Design Research Methodology according to Blessing *et al.*, (2009). In the first descriptive study, attributes to evaluate the introduction of SE and success factors that needs to be considered when introducing SE are deducted by a literature review. In the following prescriptive study, a guideline to support the process of examination and introduction of SE is presented. In the second descriptive study, initial results using this guideline are described, by using the research environment of Porsche Engineering Services GmbH. Porsche Engineering is a German DSP with their head office in Bietigheim-Bissingen employing around 1700 people at their locations in Germany, Czech Republic, Romania, Italy, China, and the United States. The company stands for innovative, customer-centred solutions not only in the automotive industry but overall mobility industry.

4. Determination decision attributes and success factors for the application of SE

To examine what decision attributes and success factors exist for the introduction of SE, a systematic literature review was conducted. Therefore, the platforms google scholar and ResearchGate were used with the search words "Entwicklungsdienstleister" "Systems Engineering" "Einführung von Systems Engineering" "development service provider" "introduction and application of systems engineering", "automotive industry". Doing so, 38 scientific papers, reports and books were identified by reading the regarding abstracts. A final number of ten sources were used after reading the complete scientific work to derive the following six decision attributes and success factors clustered in five fields of action.

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Based on the chosen strategy (see chapter 2.2), the following six decision attributes must be considered to examine the introduction of SE, as it needs to be compared if the introduction of SE supports the realization of the characterization of each attribute. For each strategy, there are different characteristics of these attributes As an example, some of these characteristics are described below, by using the following literature: (Bihr *et al.*, 2017; Krieg *et al.*, 2018; Sandrin, 2019; Leffers *et al.*, 2020)

- **Expertise** must be built up especially in the complex and new areas for example driver assistant systems or electric/electronical components to implement "New Tech" strategy. In terms of "Commodity" and "Complete Vehicle" it is more important to strengthen the existing knowledge.
- **Processes & tools** need to be optimized or tailored. Example given, for "Complete Vehicle" it is important to have overall process and tool support in the development. For "New Tech" and "Commodity" it is more important to handle the processes and tools of the customer.
- There are several **working methods** divided in classic or agile methods. For agile methods the Scrum framework seems to be the most famous one, what also seems to be the most applicable for the strategies "New Tech" and "Complete Vehicle".
- For **development methods** there are two most relevant methods. First, the stage-gate method and second the VDI-Guidance 2206 for development of mechatronic systems. Again, it seems most applicable for "New Tech" and "Complete Vehicle" to use the development method VDI-Guidance 2206.
- **Overarching competence** means to not only control the main development process but also supporting process as project management or supplier management. This is most important for the "Complete Vehicle" strategy. Nevertheless, it should not be ignored for "New Tech" and "Commodity" strategies.
- The **selection of location** is quite specific for each strategy. For "Commodity" it is important to choose so called best-cost-countries to lower the costs. For "New Tech" the adjacency to the customer the DSP wants to be technology partner for is essential. This applies also for "Complete Vehicle" strategy. Here the areas of USA and China seem to be superior to other areas, as there are the most upcoming OEM in recent years.

Based on the presented challenges of the introduction of SE, the five fields of action in Figure 1 could be derived from the following list of literature: (Bretz, 2021; Dumitrescu *et al.*, 2021; Gausemeier *et al.*, 2013b; Gräßler and Oleff, 2022; Haberfeller *et al.*, 2019; Huth and Vietor, 2020)

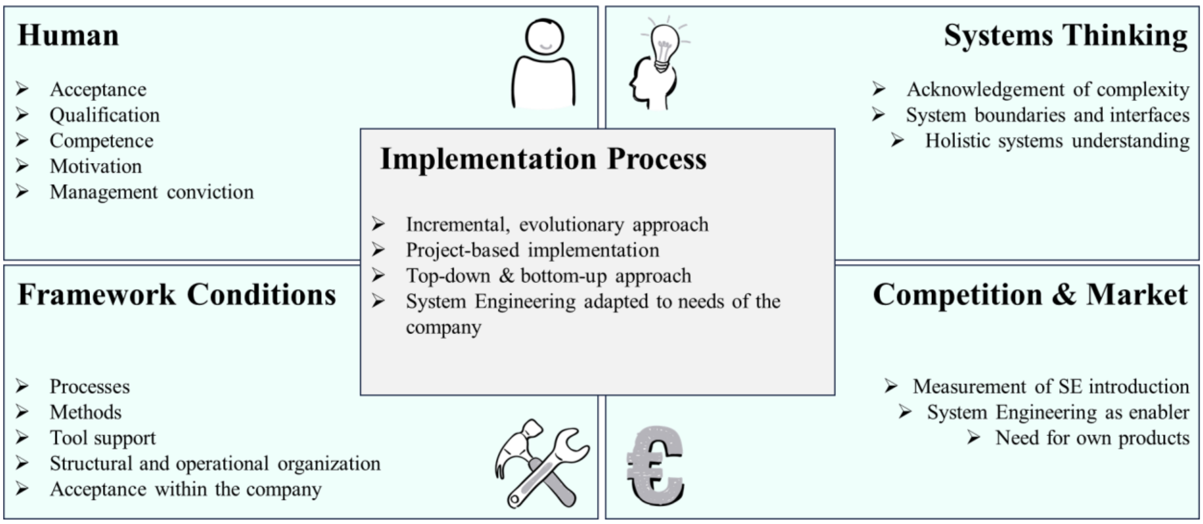

Figure 1. Presentation of action fields and success factors

Thereby the field of action "Implementation Process" is located central, overlapping with every other action field as it describes the general procedure for the introduction of SE. This includes some basic

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measures for fulfilling the success factors of the other fields of action. In the following the idea behind the other four fields of action are described:

- The field of action **Human** focuses on qualification, motivation and acceptance by the employees and management of the DSP.
- **Systems thinking** includes the mindset of the company as well as understanding the systems, which are developed including boundaries and interfaces. Here, it is most important that the employees and managers acknowledge the complexity of the development task.
- **Framework conditions** contains for example processes, methods, tools, and the structural & operational organization. In addition, the acceptance with all those framework conditions is part of this field of action.
- **Competition & market** represents the success factors of SE within the market. Currently, SE is often seen as an enabler to gain a greater market share. Therefore, it is important to first recognize the need of SE for the products the company provides on the market.

5. A guideline to evaluate and support the introduction of SE within DSPs

To support DSPs in the process of evaluating the introduction of SE and the introduction of SE itself, the guideline in Figure 2 was developed. The guideline is based on standard problem-solving models. In addition, the guideline has been supplemented by recurring steps and the identified decision attributes and success factors (see chapter 4) in the literature on the introduction of systems engineering.

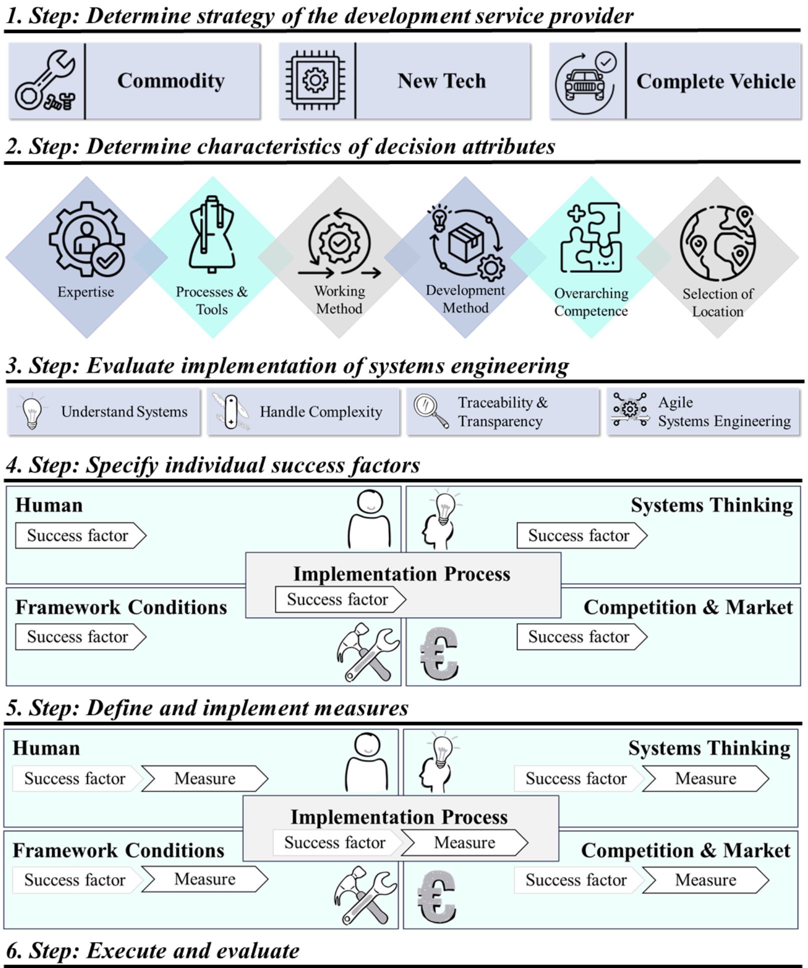

Figure 2. Presentation of the guideline to evaluate and support the introduction of SE within DSPs

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In the following, the content and activities within that guideline are explained.

- First step is to **determine the strategy of the DSP.** Here, the three main strategies were presented in chapter 2.2. It is possible that a company is choosing more than one strategy.
- Second step is to **determine the characteristic of each decision attribute** in context of the chosen strategy.
- Based on those characteristics the **evaluation of implementing SE** can be done as a third step. Therefore, the benefits of SE can be compared to the characteristics of the decision attributes. If the benefits do support the characteristics, SE is applicable and should be introduced to support the development tasks of the company.
- In accordance with that decision, as the fourth step, the action fields and success factors presented in chapter 4 are to be **specified according to the individual needs of the company.** The information in Figure 1 can be used as input for example in workshops to determine what the most relevant action fields and success factors withing the company are.
- Subsequently, as step number five, **measures are defined and implemented**. In addition, variables to fulfil each success factor and to validate the performance of each measure must be quantified.
- As final step number six, the **measures are executed,** and the **criteria are evaluated**.

In general, the presented activities should be done in an iterative manner. To do so, two options are available. First, the explorative iteration. In that case, all steps are done within one iteration and even the strategy decision itself is challenged after evaluating the performed measures. Second, the exploitative iteration. Here, only the steps 4-6 are done within one iteration. The decision about the strategy and applicability of SE is not challenged. Therefore, the action fields and success factors are reviewed as a first step of each iteration and the possible measures can be adapted by the performance of previous iterations.

6. Application of the guideline within the research environment Porsche Engineering Services GmbH

As an initial verification, the results of the presented guideline to evaluate and support the introduction of SE within a DSP in chapter 5 are presented in the following (see Figure 3). This figure shows the time schedule for the application of the guideline at Porsche Engineering.

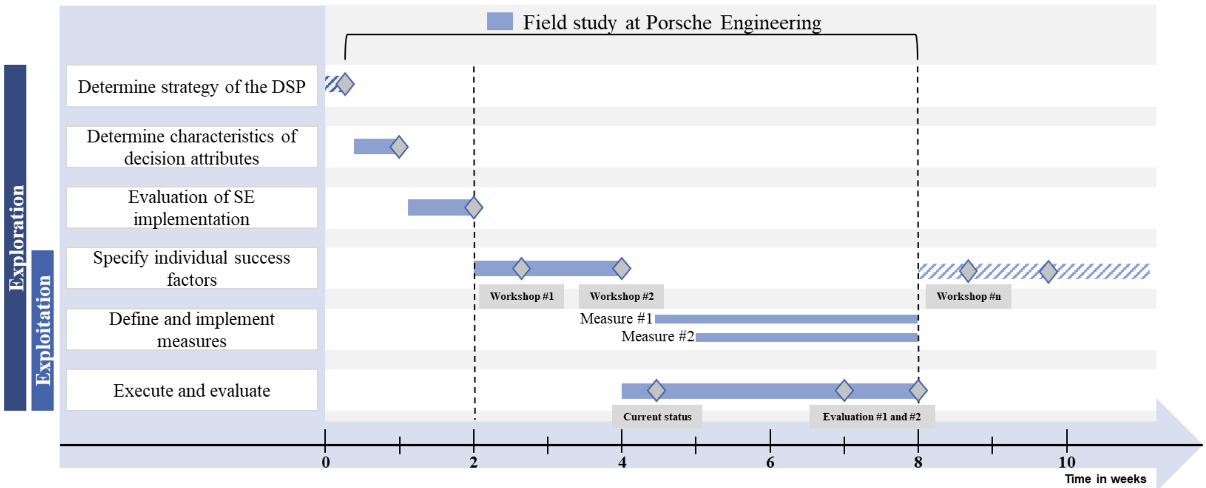

Figure 3. Time schedule of the application of the guideline at Porsche Engineering

As it can be seen, the strategy itself was not created or decided within that time but was given as an input factor to the study. Therefore, for the first three steps roughly two weeks were needed in the field study of Porsche Engineering. Afterwards, two workshops were conducted to identify success factors and measures. The implementation and evaluation of those results took about four weeks. Afterwards it

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was decided to keep on doing exploitation iterations with 4-6 weeks of time for each iteration, which are not part of the presented study.

1. Step: Determine strategy of the DSP

As a first step, the strategy choice of Porsche Engineering is derived from an interview of Porsche Engineering CEO Markus-Christian-Eberl (Damköhler, 2023). By that, the focus on the strategies "New Tech" and "Complete Vehicle" has become apparent.

2. Step: Determine characteristics of decision attributes

As the second step, each characterization of the decision attributes is given in the following, as they are compared to the benefits of the introduction of SE in step 3. In terms of expertise, it is very important to build up knowledge in complex topics, such as advanced driver systems or electric/electronical systems to be able to serve as a technology partner of the customer. On the other side, for the "Complete Vehicle" strategy, it is important to strengthen the knowledge in the field of complete vehicle and tailor it specifically to the customer needs. For processes and tools, it is again important to gain knowledge in the tools the customer needs in terms of "New Tech" strategy. For the "Complete Vehicle" strategy, it is more important to build up a company-wide standard toolchain which then can be used to provide trans-divisional development services. An iterative working method such as the Scrum framework are applicable to both strategies, to cope with short development cycles and fast-changing requirements. As a development method the presented VDI-directive 2206 should be adapted as it is the state of art in the automotive industry. Especially in the strategy of "Complete Vehicle", a broad knowledge is needed to implement those processes. In the strategy of "New Tech", it is more important to have a good basic understanding of the development method, so one can quickly adapt to different customers. The overarching competence is very important in the "Complete Vehicle" strategy and less important in the "New Tech" strategy. But nevertheless, to be a true technology partner, it is unadvisable to ignore overarching competencies. Last, the selection of location is always customer oriented. Therefore, in terms of "Complete Vehicle" locations in China and USA are beneficial, as the most upcoming OEMs are located there. Those characteristics are further used to evaluate if SE is applicable for implementation at Porsche Engineering.

3. Step: Evaluation of SE implementation

As the third step, the decision about implementing SE can be made. Therefore, the benefits of SE are compared to the characteristics of the decision variables. All four benefits (see figure 2) do support the introduction of SE at the Porsche Engineering, as SE supports to handle the complexity of the development tasks regarding the "New Tech" strategy. In addition, for both strategies, it is highly important to have a traceable and transparent development process. Furthermore, the holistic system understanding is especially important for the "Complete Vehicle" strategy but also for "New Tech" in terms of knowing the interfaces of the sub-system to be developed. Last, agile SE does support the characteristics of the variable working method and developing method.

4. Step: Specify individual success factors

As the decision is made towards SE, the fields of action and success factors are now specified to the specific needs of Porsche Engineering. Therefore, two workshops were conducted with a total number of 11 employees including the roles team leader, technical project manager with electric/electronical, software development, and thermal management expertise, requirements engineer, process engineer, and quality manager. Each workshop took around 90 minutes of time and was moderated in a semi-structured way. For the documentation of the workshops the tools "MS Whiteboard" and "Power Point" were used. This was especially helpful as the workshop was conducted in a hybrid way and people in the meeting room and online could interact easily and share their notes. To do so, one author of the paper was present as moderator and presented the action fields without any success factors. The moderator introduced each field of action with a question to start the discussion of the attendees. The following questions were used:

- What are your experiences with SE/by using SE?
- Is systems thinking already established at Porsche Engineering?
- Are the boundary conditions changing at Porsche Engineering by introducing SE?
- Does the competition on the market change for the PE by introducing SE?

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Doing so, the success factors for each action field were discussed and as one example the results for the action field "human" are shown in Figure 4. The discussion focused first on the basic knowledge about SE itself. Here the attendees agreed that the overall qualification in terms of SE knowledge needs to be increased to successfully introduce SE. In addition, for the SE-specific processes such as requirements management it was discussed that a process-specific knowledge basis and the regarding transfer of that knowledge are important success factors. Therefore, the employees can use and transfer the knowledge gained in one project to other and future projects within the team. This is also in accordance with the success factors "incremental approach" and "project-based implementation" for the implementation process itself (see Figure 1).

5. Step: Define and implement measures

As final step of the workshop**,** possible measures for the success factors were collected and discussed as it can be seen in Figure 4. Afterwards, the measures "install knowledge platform to create basis" and "define knowledge transfer actions" were decided to be the most applicable to implement as an initial verification of the guideline.

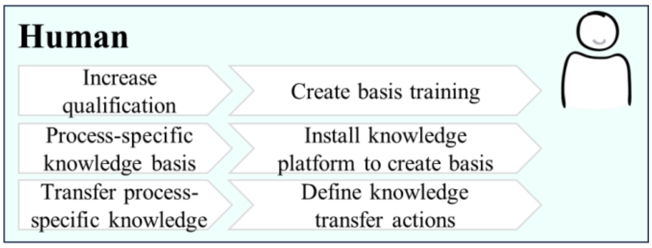

Figure 4. Presentation of the success factors and measures for the field of action "human"

As reference to Figure 3, measure #1 is the installation of a knowledge platform and measure #2 is the definition of knowledge transfer actions. As the platform will be part of the transfer actions it is started after the first evaluation of the knowledge platform.

6. Step: Execute and evaluate

In accordance with the results of step 5**,** a questionnaire was sent to the requirements management team of Porsche Engineering to verify those results. At the time of the study the team was newly founded and consisted of 12 people located in Germany and Romania. The questionnaire contained the following questions, that could be answered by a 5-point Likert scale with the options "Fully disagree (1)", "Disagree (2)", "Neutral (3)", "Agree (4)", "Fully agree (5)":

- 1: A structured knowledge base and a possibility to transfer knowledge are success factors for the introduction of SE in terms of requirements management
- 2: Currently, I feel supported in the documentation of my knowledge regarding requirements management.
- 2a: What adjustments would you like to see - where is there room for improvement?
- 3: Currently, I feel supported in transferring my knowledge from previous projects/experiences regarding requirements management.
- 3a: What adjustments would you like to see **-** where is there room for improvement?
- 4: Currently, the knowledge base and knowledge transfer activities do support me when onboarding new employees in the requirement management team.

The questions 2a and 3a could be answered without any restrictions and not based on the Likert scale. As the field study was conducted around the Christmas time only ten people of the team were able to answer the questionnaire due to holidays. The mean value of the answers to question #1 is 4**.**8 with a variance of 0**.**11, what shows that the team agrees that a structured knowledge basis and a possibility to transfer knowledge are success factors in the introduction of SE. The results to the questions #2, #3 and #4 can be found in Figure 5. As the results to question #2, #3, and #4 do also show low values (3.1, 2.4, 2**.**5) with variances smaller than 0.5, the "Evaluation #1" before introducing the measures shows the need to improve in knowledge basis and knowledge transfer. Therefore, a workshop within the requirements management team of Porsche Engineering was conducted. The target of the workshop was to specify the measures and decide on re-doing the questionnaire after the measures are in place.

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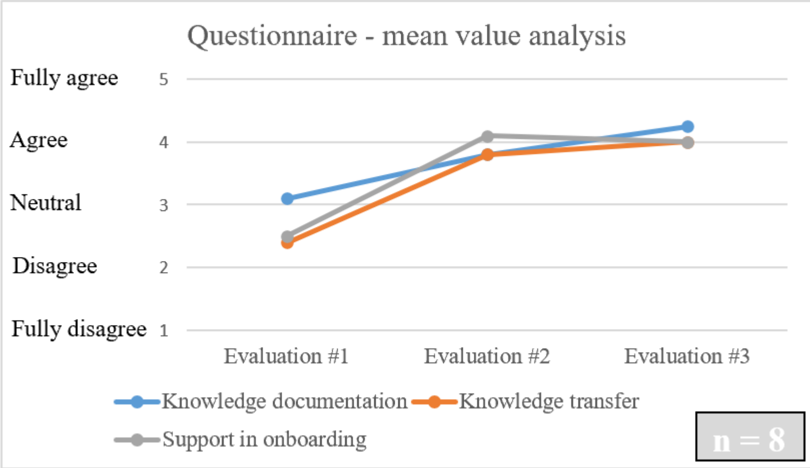

Figure 5. Results of the questionnaire

The following measures were decided on:

- Create and maintain a knowledge base in Confluence page, so the knowledge of every team member can be documented and accessed by the team easily.
- Do a regular international expert meeting so every team member has to possibility to transfer the gained knowledge with guidance from the whole team (for instance, from previous projects)

In the following, the questionnaire was re-done after 3 ("Evaluation #2") and 4 ("Evaluation #3") weeks. The value of each answer increased (Evaluation #2: 3.8, 3.8, 4.1 and Evaluation #3: 4.25, 4, 4), which shows the applicability of the measures. In addition, the team members had different improvement ideas within the evaluation. For instance, in "Evaluation #2" it was decided to also introduce a glossary to the SharePoint page to improve the translation of German terms.

7. Discussion, summary, and outlook

As the complexity of development tasks rises within the automotive industry, a guideline was introduced, which aims to support DSPs to examine the introduction and if applicable support the introduction of SE. SE supports in handling the complexity of the given development tasks such as developing (sub-) systems of vehicles. By the example of the Porsche Engineering, an initial verification was performed by a first application of the guideline. Here it could be demonstrated, that, by introducing a process-specific SE knowledge platform and a defined knowledge transfer, the success factors "knowledge basis" and "knowledge transfer" have been improved by 1.15 and 1.6 points on a 1-5 Likert scale. In addition, an application model of the field study of applying the guideline was created, which can be used as a reference model for further studies. Furthermore, it could be derived, that the introduction of SE is applicable for the DSP with strategies "New Tech" and "Complete Vehicle" in the example of Porsche Engineering. Nevertheless, the verification could only be done initially and as a field study. Therefore, the results lack objectivity and reliability. They are not transferable to different development situations or development tasks. In addition, the results lack of objective measurement criteria. It is therefore important to further verify and validate the given guideline. In a first step, this will be done by doing more explorative iterations within Porsche Engineering to cover the complete introduction of SE. As further steps, the guideline is to be validated within different companies with different strategies and a toolbox to improve the application of the guideline. In conclusion, subsequent research activities will address the further development by the validation of the given guideline in different context and research areas.

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