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Systems, Software and Services Process Improvement

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Preface

This textbook comprises the proceedings of the 30th Systems, Software and Service Process Improvement and Innovation (EuroSPI) Conference, held during August 30 – September 1, 2023 in Grenoble, France.

Earlier conferences were held in Dublin (Ireland, 1994), Vienna (Austria, 1995), Budapest (Hungary, 1997), Gothenburg (Sweden, 1998), Pori (Finland, 1999), Copenhagen (Denmark, 2000), Limerick (Ireland, 2001), Nuremberg (Germany, 2002), Graz (Austria, 2003), Trondheim (Norway, 2004), Budapest (Hungary, 2005), Joensuu (Finland, 2006), Potsdam (Germany, 2007), Dublin (Ireland, 2008), Alcala (Spain, 2009), Grenoble (France, 2010), Roskilde (Denmark, 2011), Vienna (Austria, 2012), Dundalk (Ireland, 2013), Luxembourg (2014), Ankara (Turkey, 2015), Graz (Austria, 2016), Ostrava (Czech Republic, 2017), Bilboa (Spain, 2018), Edinburgh (UK, 2019), Düsseldorf (Germany, 2020), Krems (Austria, 2021), and Salzburg (Austria, 2022).

The EuroSPI conference series (and book series) was established in 1994 as a leading conference in the area of Systems, Software, and Service Process and Product Improvement and Innovation with contributions from leading industry and leading researchers. SOQRATES as a working group of leading German and Austrian industry partners started in 2003 and has been moderated by the chair of EuroSPI since 2003 and the working group contributes to the thematic workshops organized at EuroSPI, to define the state of the art in system design, safety and cybersecurity, assessments, quality management, agile processes, standards, etc. The EuroSPI academy started in 2020 (based on the EU Blueprint project DRIVES concept of a learning compass for the European automotive industry) and within a year had many hundreds trained, and on the DRIVES learning portal we now have more than 2000 MOOC trainees. The exam systems originally developed to support ECQA are now adapted and integrated to support a Europe-wide certification and exams systems under the European System, Software, Service Process Improvement EuroSPI Certificates & Services GesmbH. All the activities are being integrated into a EuroSPI Certificates & Services GesmbH under one umbrella.

EuroSPI is an initiative with the following major action lines (http://www.eurospi.net):

- Establishing an annual EuroSPI conference supported by software process improvement networks from different EU countries (https://conference.eurospi.net).
- Establishing a Europe-wide academy with online training for qualifications related to the content discussed in the EuroSPI conference series (https://academy.eurospi.net).
- Establishing an exam and certification system for all the trainings offered in the EuroSPI academy (https://www.iscn.com/projects/exam_portal/index_asa.php).
- EuroSPI entered a strategic partnership with ASA (Automotive Skills Alliance) in Brussels which includes the association of all car makers and all suppliers in the automotive industry in Europe, and EuroSPI certificates are issued in cooperation with ASA. Also EuroSPI has had a special ASA representative as a conference board member since 2022 (https://automotive-skills-alliance.eu/).

- EuroSPI runs its own social media and YouTube Channel (https://www.youtube.com/channel/UCIQfOm8-ycv8gY2BuuhKDMQ/videos).

EuroSPI has had a cooperation with the ASA (Automotive Skills Alliance) from 2022 onwards, and the ASA is the result of the EU Blueprint for Automotive project DRIVES (2018–2021) where leading Automotive organizations discussed and presented skills for the Europe 2030 strategy in the automotive sector.

EuroSPI has a cooperation with the EU Blueprint for Battery Systems ALBATTS (2020–2023) where leading industrial organizations discuss and present skills for the creation of battery production in Europe for cars, ships, planes, industrial plants, etc.

EuroSPI established the SPI Manifesto (SPI: Systems, Software and Services Process Improvement) at EuroSPI 2009 in Alcala, Spain, and this manifesto still provides a framework for improvement and innovation in organizations.

From 2013 onwards, new communities (cybersecurity, Internet of Things, Agile) joined EuroSPI[2] and the meaning of the letter "S" extended to "System, Software, Service, Safety, and Security", and the letter "I" extended to meaning "Improvement, Innovation, and Infrastructure (Internet of Things)".

In memory of our dear friend and long-term EuroSPI conference series editor, Rory O'Connor of Dublin City University and Lero (the Science Foundation Ireland Research Centre for Software), the committee has in collaboration with ISCN, ASQ and Lero, established the Rory O'Connor Award for Research Excellence. On an annual basis, the individual presenting the highest quality work to the conference audience, especially in areas of major importance to our field, is awarded this honor.

A typical characterization of EuroSPI is reflected in a statement made by a company: "... the biggest value of EuroSPI lies in its function as a European knowledge and experience exchange mechanism for SPI and innovation."

Since its beginning in 1994 in Dublin, the EuroSPI initiative has outlined that there is not a single silver bullet with which to solve SPI issues, but that you need to understand a combination of different SPI methods and approaches to achieve concrete benefits. Therefore, each proceedings volume covers a variety of different topics, and at the conference we discuss potential synergies and the combined use of such methods and approaches.

These proceedings contain 48 research and industrial contributions under nine core themes:

- I: Emerging and Multidisciplinary Approaches to Software Engineering
- II: E-Mobility, Digitalisation of Industry, and Infrastructure
- III: Good Process Improvement Practices
- IV: Functional Safety, Cybersecurity, ADAS, and SOTIF
- V: SPI and Agile
- VI: International Standards and Norms
- VII: Sustainability and Life Cycle Challenges
- VIII: SPI and Recent Innovations
- IX: Virtual Reality and Augmented Reality

For the contributions, only the highest-quality research submissions were accepted. Theme I presents eight papers related to emerging and multidisciplinary software engineering paradigms. Theme II presents nine papers about e-mobility, digitalisation of industry, and infrastructure. Theme III presents three papers about good process improvement practices, while Theme IV contains six papers on functional safety, and cybersecurity. Theme V includes five papers focused on Agile software development and SPI. Theme VI presents five papers about international standards and norms. Theme VII presents five further contributions related to sustainability and life cycle challenges, and Theme VII presents five further contributions focused on recent innovations. Finally, Theme IX contains two contributions focused on virtual reality.

To encourage synergy between best academic and industrial practices, the various core research and industrial contributions to this conference were presented side by side at the conference under the nine key themes identified for this EuroSPI edition.

September 2023

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Recommended Further Reading

In [1], the proceedings of three EuroSPI conferences were integrated into a single book, which was edited by 30 experts in Europe. The proceedings of EuroSPI 2005 to 2022 inclusive were published by Springer in [2–19], respectively.

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Contents – Part II

Contents – Part I

SPI and Agile

The Future of Agile Coaches: Do Large Companies Need a Standardized Agile Coach Certification and What Are the Alternatives?

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Abstract. Agility has become a necessary mindset for companies facing new challenges, and the role of the agile coach is becoming increasingly important in the agile transformation. But how can companies train and find the right agile coaches?

Two decades after the introduction of agile, this study employs a survey of DACH30 companies to examine how modern organizations can identify and access the most suitable agile coaches for their business. The research investigates the present state of agile coach training and offers insights from the agile community how companies could get more agile by adapting the training concept.

This study contributes to the practice of large corporations by recommending to adapt the experience of the DACH30 agile community, which suggests that external agile industry certifications in an isolated manner are not an effective approach to fostering a strong agile culture within an organization. Furthermore, this research advances current knowledge by proposing that a new phase in agile education has been reached, and industries using agile methodologies must explore alternative approaches to attain the next level of agility.

Keywords: agile · certification · agile coach · agile mindset · spi manifesto

1 Introduction

The constantly changing and volatile business environment, often referred to as VUCA, has made agile orientation a necessity for companies to succeed in the future [1, 2]. Prior to the COVID-19 pandemic, digitization [3] and the New Work approach in human resource management, which have parallels to agile values and principles, were considered the drivers of agility [4]. However, crisis has highlighted the fact that companies, regardless of their cause or direct entrepreneurial context, can face challenges, which has

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made agile companies better equipped to respond to changing environmental influences. The Future Organisation Report (2020) confirms that agile companies' employees felt better prepared for the crisis period than non-agile companies [5].

Agile companies' competitive advantage is characterized not only by their ability to react and adapt quickly to externally triggered changes but also by their managers' and employees' mindset [6]. This mindset is at the centre of organizational maturity and is closely linked to the organizational mindset and corporate culture [7]. As companies need to anchor agility in their organization for long-term survival, the need for agile coaches has arisen [8, 9]. However, many companies rely on external agile coaches who primarily implement widely used agile frameworks during their assignment, neglecting the sustainable anchoring of the agile mindset [10]. Moreover, the need for agility is commercially exploited, which leads to criticism of the implementation and approach of agile orientation, missing the added value and core ideas of agility [11].

2 Literature Review

The term "Agile Coach" is not legally protected, and there are no legally prescribed guidelines and specifications regarding the acquisition of the necessary competencies, role definition, and use of the title [12]. Nevertheless, companies recognize the value of the Agile Coach for agile transformation processes, which has led to various Agile Coach certifications in the training market [12–14]. Companies tend to use different agile frameworks in combination to suit their organization and teams [8, 14], raising the question of whether they should establish their own certification body [14] or unit [15] and adapted set of rules for the Agile Coach role [13–15].

It surveys the DACH 30 members using a questionnaire on Agile Coach certifications offered in German-speaking countries to obtain company-relevant results. The goal is to provide decision-making aids for establishing one's own agile organizational unit, as well as one's own and adapted certifications. Theoretical research aims to clarify the connection between agility, the Agile Mindset, and the role of the Agile Coach and its relation to the Shu-Ha-Ri approach.

This section outlines existing literature around agile coaches and the DACH30 minimum standards around agility. The identified gap in the literature review generates the research questions. This research builds on the SPI Manifesto (2009), in particular the section on the learning organisation as well as the use of dynamic adaptable models as needed.

2.1 The Agile Coach

The Agile Coach has enjoyed increasing popularity since the success of Spotify [16]. The high demand from companies for professionally feasible agile transformations is accelerating the need and thus the rapid rise of Agile Coaches [8, 13]. The need as well as the advantage of Agile Coaches is due to the fact that they facilitate Agile transformation in organisations, often referred to as facilitators [13, 17]. In addition, they help to minimise the risk of failing in the Agile transformation [14]. Agile coaching is seen as a subset of the coaching spectrum [14]. Although the role is well known among practitioners, empirical knowledge about the Agile Coach is sparse [13]. In addition, although there are many providers offering training including certification as an Agile Coach [8, 11], the job description and the designation “Agile Coach” are as mentioned not legally protected [12]. Furthermore, the role is seen as one that develops from experience and practice, so that certification is not mandatory, but can be helpful in improving understanding [13, 14]. On a scientific level, this role has also attracted the attention of researchers to concretise the role [13], the tasks [17] as well as the added value [14] in the context of recent scientific works and articles.

Agile coaches are employed in companies as internal permanent employees or as external consultants [8, 9, 14]. Depending on the employment relationship and scope, the Agile Coach is divided into two types, the full-time and part-time Agile Coach [14]. The full-time Agile Coach is characterised by being firmly anchored in and coaching one team, whereas the part-time Agile Coach works for several teams [14]. An internal, organisationally anchored Agile Coaching unit is advantageous for the sustainable Agile development of companies as well as Agile Coaches, as this unit can ensure the holistic correct application and implementation of Agile practices, needs as well as the development of a mindset [15]. As the job description is not subject to standardisation, the role, tasks and necessary competences can only be derived from the literature and previous scientific research and articles [9, 12].

According to this, agile coaches have social competences (soft skills) in addition to professional competences [13, 14]. The main tasks of the agile coach include team building with the aim of supporting and developing the team in agile processes, techniques and self-organisation [18]. This way, they support the teams as well as the organisations in implementing agile practices and help them to acquire the entrepreneurial and agile mindset [8, 18]. In addition to teams and the specific agile roles such as the Scrum Master and Product Owner, employees in various functional areas as well as the management level and top management are trained and supported in the transition [8, 18]. Agile coaches monitor the effectiveness of the agile implementation by identifying and discussing potential problems, offering solutions to those affected and thus actively shaping the change process [18]. Another task is the contextual approach in relation to the organisation [18]. Thus, the agile coach has the task of introducing and adapting agile processes, frameworks and techniques that fit the organisation [13, 14, 18]. This in turn requires the Agile Coach to develop an understanding of the organisation and its requirements and needs [13, 14, 18]. In addition, Agile Coaches work with management to develop roadmaps, goals and shared values that define the organisational vision for the organisation and how to achieve it in the future [18]. They also create guidance for software teams and develop guidelines for the widespread introduction of agility [18]. Furthermore, the Agile Coach is responsible for removing obstacles that affect productivity and teamwork [9], collecting data and developing metrics that show the status of the teams’ activities [9], and selecting pilot projects during the Agile transformation [8, 14, 18]. Other skills and knowledge that Agile Coaches have are leadership skills, project management skills, communication skills, teamwork, team dynamics and team building, and conflict management [18].Leadership skills in particular are of great importance in fulfilling this role, as Agile Coaches build trust in the teams [13, 18] and ensure psychological safety and create a learning culture. Since agile transformations are also change processes that primarily affect people directly, soft skills are indispensable qualities that distinguish agile coaches [13]. These include empathy, consistency, person orientation, the ability to listen and diplomacy. In order to realise the full potential of agile coaches, the mandate and the support of the management levels are absolutely necessary [8, 17, 18].

In the context of the agile transformation, the DACH 30 members have formulated a manifesto based on their experience so far, which, among other things, also covers the learning path of the team facilitator, which, depending on the level of competence, can be equated with the agile coach [19].

2.2 The DACH 30 Minimum Standards

The DACH 30 working group "Transition to Agile" is an association of change agents, transformation managers and agile coaches from large companies and corporations in the DACH region [20]. The working group pursues the goal of successfully shaping the agile-lean transition in companies and offers a basic pattern for agile working that allows companies freedom of design in its characteristics [19]. The idea arose from experience with agile transformations and projects as well as the realisation that standard market certifications are not sufficient for agile change and transformation in companies, as they are no guarantee of success for the project. Another point of criticism to which the DACH 30 draw attention is the recertifications due to the limited validity of certificates issued, which do not offer any additional added value and thus show a commercial aspect of certification providers. Furthermore, the DACH 30 notes that, for example, proven best practices from start-ups are not always compatible with the structures of large companies.

With the formulation of the DACH 30 minimum standards, which were presented for the first time at the *Agile Conference 2019* [19], the DACH 30 presented a manifesto that is intended to serve as a basic pattern for agile working. Thus, the DACH 30 formulates a standard in the form of the qualification portfolio for agile working [21]. In its product vision, the DACH 30 addresses all employees and managers in companies who have the need to develop themselves further in lean and agile and who would like to help shape the change in companies towards an agile and customer-centred organisation [21]. The DACH 30 working group is not alone in its observation. With the rising popularity of agile management approaches that go beyond pure software development, voices are also increasingly being raised that question the commercial and incompatible aspect behind agile certifications as well as the available frameworks. For example, the involvement of consultancies in the introduction as well as the promotion of new management approaches, both on the conceptual and the sales side, is highlighted as one of these aspects [11]. According to certain authors, the commercialisation in the form of certifications leads to an inflationary perception and meaning of the term agility, so that the core idea disappears and only a buzzword remains [22].

"Influence factors, such as commercialization of agile certifications directed the agile mindset towards what is today. Nowadays, agile has become a buzzword for "having fun at work, while simultaneously performing better than before" [23].

In addition to the inflationary aspect, Gelmis et al. (2022) [10] came to the conclusion in the form of expert interviews that the commercialisation of agility prevents organisations from "being agile" [10]. They also found that common agile frameworks need to be adapted in relation to corporate culture and needs [10]. Furthermore, it was scientifically proven that theory or trainings alone are not sufficient to implement scaled agile frameworks in companies, for example, as the literature does not provide a guide for implementation [22]. The competency levels of the DACH 30 Minimum Standards correspond to the Shu-Ha-Ri principle, which was developed in the Japanese martial arts doctrine of *Aikido* and describes the cycle of a student's progress throughout their learning path [24]. Shu-Ha-Ri can be applied as a model for any kind of learning [25]. The first stage, *Shu,* means to preserve, protect, maintain or care for [25]. In this stage, the student learns the technical basics as they are taught by copying them without modification or questioning [25]. The Shu stage helps to build a lasting technical foundation upon which the deeper understanding of the art can be built [25].

The following stage *Ha* means detachment [25]. In the Ha stage, the student detaches from the teacher's traditions and reflects on the meaning and significance of what has been learned [25]. The process of reflection provides a deeper understanding of the teaching rather than mere repetition of it [25]. Furthermore, due to the mastery and absorption of all techniques, the student can question and holistically evaluate the background of these techniques [25].

In the last stage, *Ri,* transcendence takes place [25]. In the Ri stage, the former student is now a practitioner and develops original thoughts on the teaching beyond the background knowledge he has gathered so far, testing them against his conclusions, the available knowledge and the demands of everyday life [25]. In this stage, the teaching becomes to a certain extent the practitioner's own creation and is thus subject to change [25]. The transitions between the stages are controlled and timed by an instructor. The Shu-Ha-Ri model must be closely accompanied by an instructor [25].

2.3 Research Questions

The literature review emphasises the importance of agile transformations in the context of the VUCA world. This has resulted in new roles such as the agile coach or facilitator, which at the same time provide a basis for discussion regarding the need for certification. Summarizing the details above, the following research questions are to be answered:

- (RQ1) Is certification as an Agile Coach necessary for employees of the DACH30 members?
- (RQ2) Should DACH30 corporations set up their own certification?

3 Research Strategy

Quantitative Online Questionnaire. With regard to the collection of primary data, the questionnaire method based on the structured, written survey [26], in the form of a quantitative online questionnaire (self-administered questionnaire) was selected for the collection of information [26, 27]. Due to the efficiency of the procedure, the online survey is one of the most important fully structured survey techniques with regard to private-sector market and social research as well as basic academic research [26, 27].

Online surveys offer a variety of advantages, including the user-friendly design of the questionnaire, simple filtering, which automatically ensures that certain questions are skipped [27]. In addition, the results can be exported and evaluated relatively easily in digital and structured form after the survey phase has been completed [17] and the redirection to the survey digitally by e-mail can be done easily by providing the survey link [26, 27]. The questions shown in Table 1 were deducted from the research questions and asked to the participants.

Table 1. Questions asked and their relationship to the research questions.

Question of survey
Have you completed further training incl. certification as an Agile Coach? (Deducted from RQ1)
Do you think that certification as an Agile Coach is necessary? (Deducted from RQ1)
Is agile coaching or agility organisationally anchored in your company (e.g. role and job description, separate department, corporate centre)? (Deducted from RQ2)
Do you think that companies should offer their own training programmes or certifications for agile roles, such as agile coach, based on their own company structure, needs and culture? -Should they offer their own training programmes or certifications for agile roles? (Deducted from RQ2)
In your view, is the organisational establishment in a central division by means of an agile competence centre necessary for companies, e.g. corporate groups? (Deducted from RQ2)

Analysis. For the content analysis, the process model of summary content analysis according to Mayring was used [28]. According to this, the material to be analysed is paraphrased in the context of the text passages that carry the content in such a way that a concise form describing the content remains [28]. The next step is to determine the level of abstraction for the first reduction so that a generalisation is made possible, which enables inductive categories to be derived in the second step of the reduction [28].

The level of detail and comprehensibility of the questions as well as the acceptability of the number of questions were elicited in a pre-test. Pre-tests are designed to identify and correct sources of error [26]. With the help of a DACH 30 member, the link to the online survey was sent by email to 67 DACH 30 members, who in turn forwarded it to other members. The anonymous online survey was conducted between 01 November 2022 and 18 November 2022.

4 Results

4.1 Overview

A total of 109 accesses to the online survey were registered (total sample gross), of which 52 actually started the survey (net participation) [29]. Of the 52 participants, 48 completed the survey. A total of four dropouts were recorded, which occurred at different points in the survey, so that a dropout tendency with regard to a specific question cannot be determined. For this reason, only complete data sets were considered for the evaluation, which amounted to 48 (N = 48). Of the 48 participants, 18 turned out to be non-certified Agile Coaches, who were selected by means of a filter option. From the third question onwards, this results in a base of 30 (n = 30) complete and relevant data sets that are the subject of the results mapping. The answer to question 9 was also subject to a filter and was not evident for those participants who answered the previous question 8 with "None", so that question 9 was answered by n = 26 participants. Question 18 was also subject to an exclusion filter and was only visible for those participants who answered question 17. Thus, a total of n = 21 answered question 18.

4.2 Results Regarding Research Question 1: Is Certification as an Agile Coach Necessary?

The first questions served to verify that only agile coaches were reached with the survey, so 100% (n = 30) stated that they work as an Agile Coach in a permanent position. Question 2 should give more background and revealed, that for 63% of the respondents, agility is organisationally anchored in the company through roles, job descriptions and corporate centres. For 37% of respondents, it is not.

The question "Do you think that certification as an Agile Coach is necessary?" was asked to answer directly research question 1. It was answered in the affirmative by 47% of respondents, while 53% disagreed (Fig. 1). The answers could be completed with reasons. Since the reason was not given as a compulsory field, 14 who answered "Yes" and 12 who answered "No" gave a reason.

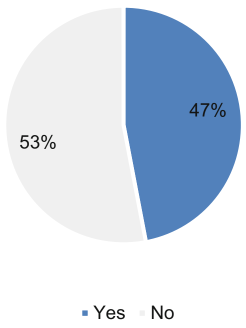

Fig. 1. RQ1 - Do you think that certification as an Agile Coach is necessary?

Fig. 2. RQ1 - Reasons for yes answers by category

The reasons with "yes" resulted in a total of 9 categories (K), those with "no" in 10 categories (K). The reasons given by those who are of the opinion that certification is necessary vary, so that a tendency cannot be explicitly identified. All details can be found in Fig. 2. For example, 14% are of the opinion that certification as an Agile Coach is necessary, as this serves as proof of competence, quality assurance and proof of training for cooperation with stakeholders. A further 14% are of the opinion that certification ensures compliance with agile working standards and legitimises role standardisation. The remaining justifications (7% each) range from the justification that certifications build knowledge to the views that a holistic approach is conveyed with the help of certifications, and that agile role delimitations and role-specific knowledge acquisition are made possible.

Fig. 3. RQ1 - Reasons for no answers by category

A certain tendency can be derived from the reasons given for the answer option "No" as shown in Fig. 3. Among those who are of the opinion that certification as an Agile Coach is not necessary and have also formulated this, justify this with the fact that the mindset and soft skills are more important than certification (17%). A further 17% are of the opinion that competence development takes place in practice. In each case, 8% justify their answer with the fact that certifications give no indication of practical applications, are no proof of the knowledge learned and of good coaches. A further 8% each have an aversion to certifications and are of the opinion that no competences can be proven with slips of paper and that this is inflationary due to the lack of protection of the job description of coach. Furthermore, 8% each stated that soft factors on the personality level and experience are more important and that personality and experience are more decisive than certification.

4.3 Results Regarding Research Question 2: Should Corporations Set Up Their Own Certification?

Regarding Research Question 2 the question "4.Do you think that companies should offer their own training programmes or certifications for agile roles "was asked. Most respondents (80%) are of the opinion that companies should offer their own training programmes or certifications for agile roles, such as the agile coach, based on their own corporate culture, needs and culture, whereas 20% of respondents are not of this opinion.

Among the reasons given by respondents who answered "yes", the categories, exchange with colleagues and networking as well as the specification to the company context predominate. Among the reasons given by respondents who answered "no", no tendency is apparent. For example, it is stated that the internal offer depends on the size of the target group, that the internal structure is not economical or that agility could be misinterpreted. Further individual justifications can be found in.

Additional details are received from the 5th question "In your view, is the organisational establishment in a central division by means of an agile competence centre necessary for companies, e.g. corporate groups?" which was answered in the affirmative by 70% of the respondents. Those who answered question in the affirmative see added value in the organisational establishment of agile organisational units in the promotion of the agile mindset with 90%, no loss of knowledge through external agile coaches with also 90%, and with 86% each in the support of human resources with necessary leadership skills and the holistic organisational orientation. Figure 4 shows all the information on added value.

5 Findings and Discussion

The aim of this research was to explore how Agile Coaches in the DACH30 companies are judging on the need for Agile Coach Certifications or if alternatives need to get discussed and how those could look like.

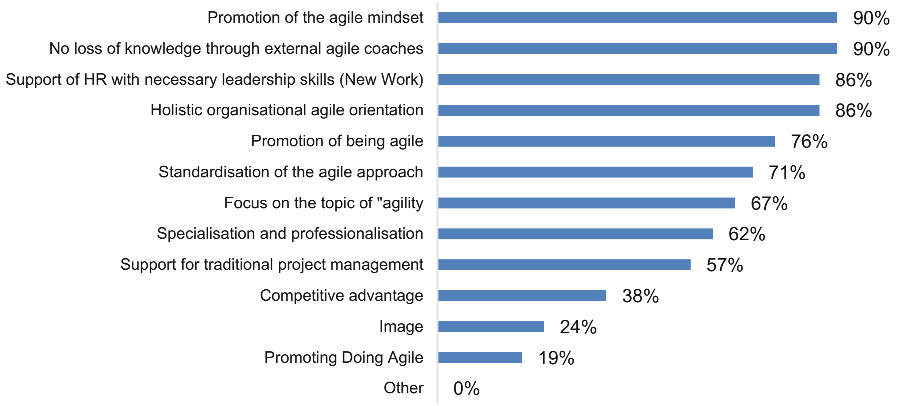

Fig. 4. Question 18 - In your view, what added value does the organisational embedding of agile organisational units (e.g. agile competence centres or departments) offer?

5.1 (RQ1) Is Certification as an Agile Coach Necessary?

The results of the reveal interesting facts for theory and practice. On the practice side 53% of respondents believe that Agile Coach certification is not necessary, and that certification is not sufficient to perform the role of Agile Coach (80%). This result raises another question for research purposes regarding the need for certification in general and its impact on professional opportunities and development. As this question is not the subject of this paper, it cannot be answered, but is suitable for future research. Another finding is that agile coaching is firmly anchored in the organisation of 63% of the respondents, this finding is also reflected in the theory. Thus, for the sustainable application of agile practices and the development of companies, internal units specialising in agile coaching are recommended. The organisational establishment of an agile competence centre in companies is considered necessary according to the research regarding research question 2. The added value that results from organisational embedding is very multifaceted and extends across a holistic approach. This includes, among other things, the promotion of the agile mindset, no loss of knowledge through external agile coaches, support of HR with necessary leadership skills (New Work), holistic organisational agile orientation, standardisation of the agile approach as well as other aspects that can be taken from Fig. 4.

5.2 (RQ2) Should Corporations set up Their own Certification?

Organisations are also developing certification programmes to standardise the qualification process. This is also evidenced by the online survey, which shows that 30% of respondents have completed an internal Agile Coach certification. Furthermore, agile practices are no longer limited to software development. In the context of the VUCA world, organisational agile transformations are necessary, which also have an impact on the corporate culture. This need is also reflected in the fact that 80% of respondents are in favour of company-owned training programmes and certifications that align with the company structure, culture and needs (Fig. 4). This suggests that the answer is ‘yes’ to research question two, which asks if companies should setup their own certification.

6 Conclusions and Outlook

6.1 Conclusions

The online survey showed that certification as an Agile Coach is not relevant for the exercise of the role but can only contribute to a better understanding. One reason for this is that the role develops out of practice and thus experience and expertise are more decisive than a certificate. From the online survey, another research question for future research has also emerged, questioning the link between certifications and professional development and opportunities.

Furthermore, our research revealed that internal company certifications for Agile Coaches are already in use and the majority of the DACH 30 members are in favour of this. The main reasons for this are the exchange and networking within the company with colleagues as well as the specification to the company context. In addition, the following reasons are also mentioned: Clarification of internal role understanding and coaching support, work relevance through internal offers and direct examples, training adaptation for agility outside of IT, shared vision as well as company-specific needs. Aspects that speak against internal company certification are the negation of the use of agility, the dependence of the offer on the target group, the possible misinterpretation of agility as well as the danger of mixing agile basic principles with the company culture. It could be determined that the organisational establishment of an agile competence centre for companies such as corporations is felt to be necessary by the majority. The necessity of a separate organisational agile unit is predominantly based on the promotion of the agile mindset, avoidance of knowledge loss through external agile coaches, support of human resources with leadership skills and the holistic agile orientation.

6.2 Outlook

Agility is no longer limited to software development but has become an essential management concept in today’s volatile and fast-changing business environment. The COVID-19 pandemic has highlighted the importance of agility in the success of companies. However, many companies make the mistake of equating agility with the application of specific frameworks, such as Scrum and are training their agile coaches according to standard certifications. They neglect the mindset and organizational structure that underpin agility. The failure of agile transformations is often due to mindset and corporate cultures that resist change. The Shu-Ha-Ri approach, which promotes a transition from doing to being agile, can be helpful in establishing an agile mindset.

Throughout the last years the established certification as agile coach helped large companies like the DACH30 to their doing of agile. The suggestion of the current research to practice, that companies should no longer build on standard certifications but build their own agile practice with their own agile training raises the question if companies need a new training strategy for agile coaches to be able to reach the being agile status

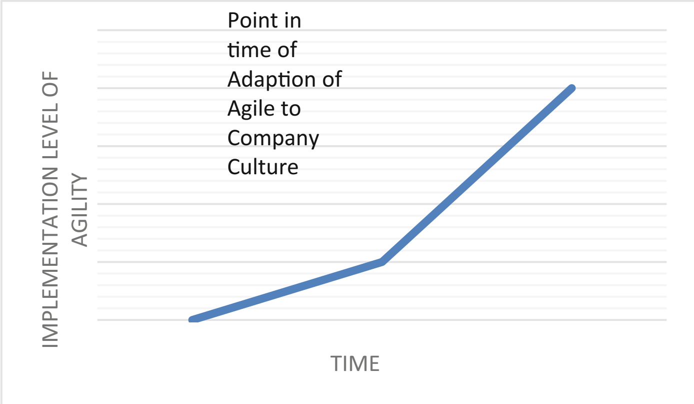

Fig. 5. Agility Level a company can reach over time

as suggested by Shu-Ha-Ri. Figure 5 is showing how the recommendation of the current research could influence the evolution of companies using their own agile enablement instead of continuing the current model of external certifications.

Agile coaches play a significant role in promoting agile transformations and require soft skills, human-centred management styles, leadership qualities, and empathy. A company-internal agile organizational unit and internal certifications can be an opportunity for companies to promote the agile mindset and sustainably pursue the agile transformation to the next level.

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Agile Teamwork Quality – Reflect Your Team While Playing and Identify Actions for Empowerment

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Abstract. Agile working is based on teams. To perform their tasks each team has to find ways to establish and improve the way they work. Agile Teamwork Quality is an approach to reflect and improve the teamwork capability systematically. To reflect the current team quality level a gamification approach is proposed. The game can be part of the cyclic retrospectives or other team events. The game presents typical scenarios respectively cases which can happen. The team has to argue why this also can happen or not in their team. These case discussion promote awareness about the team' current situation. The awareness is used to initiate improvement actions in real world after the game. The presented case study of the Volkswagen Group IT shows the facilitation of the teamwork quality.

Keywords: agile teamwork quality · gamification · efiS® framework implementation · retrospective · IT quality management

1 Introduction

The improvement of teamwork quality is often not systematically established in organizations. Furthermore, established agile approaches like Scrum [1] or SAFe® [2] do not offer systematic reflection and improvement of the agile teamwork quality, too. To improve the situation approaches are needed which are fitting into the modern agile instantiations. Gamification is one of the current approaches to access and engage teams. To realize this option the aTWQ approach [3] is transferred into a game. The game can be part of a retrospective or another team event or ritual. Important is that the team members are reflecting their current status-quo and can initiate improvement actions where needed. Important is that the game is based on some reference scenarios and derived cases with a rating respectively points in the game. This helps teams to get a better common understanding about their maturity. During the initial phase of utilizing the agile Team-Work Quality (aTWQ) questionnaire, it was observed that the absence of example cases and reference ratings could result in a broad spectrum of interpretations. While the absence of example cases and reference ratings may be acceptable for relative improvement purposes, it is insufficient for comparing teams in large-scale programs. To enable effective team comparisons, a process of "calibration" is necessary. The gamification

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approach, incorporating predefined cases and ratings, facilitates this calibration within the team. Often teams are assembled by skills etc. to develop products and services. The teams have to build their own team culture and maturity. This is a process which can systematically facilitated. One approach to do this is using the efiS® framework [4] and its empower pillar. One building block of the empower pillar is the agile Team-Work Quality (aTWQ) approach [5]. The initial versions are centered around a questionnaire that teams can utilize to provide ratings. This questionnaire oriented checklist can be used by the teams to reflect their current state against the aTWQ aspects in the questionnaire. This approach works fine for a rating of one team. The team can use the last evaluation and compare it with the current evaluation and see improvement progress. However, when dealing with larger programs involving numerous teams, the ratings provided have limited comparability. This is driven by the relative rating of the team against their views and values. The questionnaire does not standardize the ratings. This makes it difficult for large programs with many teams to see were additional support is needed from the program level to improve the selected team quality. One approach is to make formal assessments or reviews [6] with team-external assessors respectively reviewers. This is cost-intensive, not scaling and not good fitting with the autonomy mindset of agile – this is a good practice, e.g., in the context of compliance checks but not for daily work and improvement. Another approach is to have something which fosters critical reflection by the team against pre-rated reference cases. The team can get a good "calibration" about their maturity state, if the reflection is mapped to their current team state. To make this critical reflection a game can be an useful tool. Because the game mechanic can reward individuals for critical reflections and ratings of the team against the cases. Important is that the final game setting can be used as starting point for real world improvement actions for the team. With the presented aTWQ gamification approach this gap in standardization of the ratings should be addressed.

Based on these observations the following research questions are derived:

- RQ1: What are the generic scenarios that can be incorporated into an aTWQ game, and what are the various cases that can be used as rating references to obtain comparable ratings?
- RQ2: How can be defined a game with its mechanics etc. to make the play interesting and adaptable in play-time and difficulty to keep it long-term interesting?
- RQ3: How it can be realized that the final state of the game can be used as an indication for improvement actions in real world?

The work to answer these questions is structured as followed: Section 2 gives an introduction into the literature, Sect. 3 describes the methodology of the taken approach and details the chosen solutions, Sect. 4 presents an evaluation of given results, while Sect. 5 is elaborating the question of dispersion and rollout of given results. Section 6 discusses the restrictions and limitations of the first set of results. Finally, in Sect. 7 a summary and an outlook are given.

2 Literature Review

2.1 Game Design Principals

The first academic reflection to define a game came from Ludwig Wittgenstein [7], He was an Austrian philosopher. He said that elements like play, rule and competition are not enough to describe games. There is more that he described as family resemblances. This all influences the game speech and that is the main aspect for a game.

A further approach to define games came from the French sociologist Roger Caillois [8]. He described that a game should have the following characteristic:

– fun: the activity is chosen for its light-hearted character
– separate: it is circumscribed in time and place
– uncertain: the outcome of the activity is unforeseeable
– non-productive: participation does not accomplish anything useful
– governed by rules: the activity has rules that are different from everyday life
– fictitious: it is accompanied by the awareness of a different reality [9]

2.2 Teamwork Quality Approaches

Teamwork aspects are under investigation in literature from different point of views. In context of assessment of teamwork skills in computer engineering [10] and science education [11]. In the literature you will also find analysis in the context of feedbacks for teamwork and engagement [12]. aTWQ explicitly like in agile contexts will be addressed by some of the previous work [13] or innovation teams [14]. There are also some approaches which also propose organizational models fostering TWQ like [15] with the spiral dynamics model, which distinguishes team maturity characteristics. A systematic questionnaire is developed in [16] to determine TWQ. There are three most promising structured teamwork approaches:

– The first is the TWQ [14], which focus on quality indicators of teamwork.
– The second is the Team Climate Inventory (TCI) [17], which has been developed and established over years and evaluates team indicators related to the teams' working structures for innovation and
– the third is the Group Development Questionnaire (GDQ) [18], which addresses both team development and maturity. The investigated works propose differently sized generic questionnaires, which are typically moderated by experts to assess teams. To summarize, there isn't a ready to use approach to address the expectations of autonomous teams to elaborate their TWQ in a self-service way for continuous improvement in the existing literature. This leads to the need to bundle existing elements and building blocks to a holistic approach that is usable in industry.

2.3 Gamification in Agile and Related Work

There are a lot of approaches which investigate gamification in agile. Which influence gamification has, is described in [19]. An Framework called "Fraggle" is developed in [20]. How gamification can be used to deliver software solutions in agile teams shows

[21]. Another approach discusses the software agile management process and gamification [22]. Some authors also discuss gamification as an aspect of software process improvement [23]. A study which presents a comparison among the different gamification elements that can be applied to create a teamwork, reducing its integration time, and therefore, improve its performance is described in [24]. An overview from a little bit more theoretical way of use gamification principals mechanics, dynamics, and emotions (MDE) is described in [25].

3 Methodology

3.1 General Objective

To ensure applicable outcomes an Action Research (AR) approach [26] is chosen. From our point of view it is the best approach for combining theory and practice. With the design and evaluation iterations which are observed the design team gets feedback for improvement. The design team terminates the iterative improvement loops at the point on which no significant improvement is identified by the feedbacks and observations. The design team of the aTWQ game is formed by a diverse team of experts from quality management, agile coaching and software engineering.

Objective is the development of an approach to measure the current state of the teams to make decisions based on local views with current facts to generate in each context relative effects within a before/after state, after identified actions take place in the team. Additionally, the standardized approach offers the possibility to get an overview about the teams from an organizational perspective. Furthermore, the game should be playable online and in-person to address the new work with its "switch options". To keep the game setup lean no specific software beyond typical available browsers, e.g. Firefox, and Office tools, e.g., O365, should be needed.

3.2 Development of Generic Scenarios and Derived Rated Cases

The core of the game is the transformation of the aTWQ questionnaire into game scenarios. This will address RQ1 by the definition of an adequate set of scenarios. The definition was realized by identifying realistic real-world cases. The identification was realized by accessing the experience of agile coaches of the Group IT from the Agile Center of Excellence (ACE) and LACE:HUB. This over years grown experience of the facilitators was used to extract scenarios and cases and rooted by real world relevance. The methodology to identify scenarios was to go step by step through the aTWQ questionnaire and reflect each questions with the experience of the agile coaches respectively facilitators. The identified scenarios were structured by addressing following requirements:

- Fits the scenario direct to the question? (keep focus on the question and avoid ambiguous cases)
- Is the scenario generic respectively context independent? (it is clear for all teams without specific knowledge or experience beyond basic agile professional experience in an IT context)

– Is it possible to derive rated case from the scenario? (to build a deck of cases addressing all maturity levels related to the question)

For each aTWQ question at least 3 scenarios fitting the three requirements were identified. The limit of 3 was set to have a few scenario around a questions and avoid too much options and complexity for the first version of the game.

Each selected scenario was instantiated with 3 cases. One case for a low maturity, one for typical maturity and one for high maturity teams. However, it is important to note that the terms “low,” “typical,” and “high” should be interpreted as three rating categories that are not dependent on detailed word specifications. The concept is to have the generic scenario and the case adjusts only a few words to make the rating to one of the three levels. The definition of three cases per scenario was driven by the reduction of complexity of fine granular variants and the overall amount of options by the multiplication of the questions with the 3 scenarios and 3 cases. Figure 1 presents 3 cases of a scenario. In this example the Scrum Master (SM) – Franzi – and a developer (Dev) – Daniela – are part of the scenario which is instantiated in the 3 cases. In the right down corner are meta information such as to which of the five teamwork areas the card belongs (p: participate) and which scenario of the area it is (no. 2) and the case type (g: perfect, o: ok and r: improvement).

3.3 Design of the Game with its Goals and its Mechanics

A base set to “handle RQ2” to define a adequate game setup and mechanic to address the issue that team often have no common baseline for a rating their maturity in the context of team work quality.

Purpose: identification of improvement areas for the team in the real world setup. Evaluation respectively a rating of the team in the context of aTWQ is an outcome, too.
Game Design: the main way the player interacts with the game is argue about the cards why the described case from a card fits to the team or not.
Basic Gameplay: optimize own rewards for each played card and minimize rewards of other players played cards to become winner by having the highest reward points.
Game Mechanics option 1: round robin every player put a card and argues for the case, were possible, about why this fits to the team to get the reward points. All other players argue why this card case does not fit to the team. Arguments are based, e.g., on past examples around the case of the scenario happened in the team. The objective of the card player is to realize the rewards and the objectives of the others is to avoid this. Progress happens by the iterations during the round robin. Different tactical and strategical behavior can be applied by the player to put cards on the desk and realize respectively collect their reward points depending on the competencies of the player. The player gets direct feedback about the card and can earn reward points. Reward points are assigned to the case types. Low maturity cases get the highest reward (4 points) to motivate the players to discover issues in the team and the high maturity cases get the lowest reward (2 points). One point is also given for cards which are not applicable in the game teams’ context– each round should be “positive” counting.

Franzi (SM) and Daniela (Dev) think in daily scrum the team has the focus to inform each other. They talk about details and knew who to ask for information.

p2g1

Franzi (SM) and Daniela (Dev) think that the team talks sometimes a lot in daily scrum. But at the end many developers have sometimes the feeling that they are not informed about important things to do their work efficiently. Frequently they have no idea where to get the information.

p2o1

Franzi (SM) and Daniela (Dev) think that the team talks a lot in the daily scrum. But at the end the developers have the feeling that they are not informed about really important things to do their work efficient.

p2r1

Fig. 1. Example scenario with its three cases.

Game Mechanics option 2: use all cases from one scenario to play and start the discussion with the team, which card fits best. Start the talk with the team when there is a common understanding about the content.
Game Mechanics option 3: chose one of the 5 categories (defined in the aTWQ questionnaire: 1- participate, 2- support innovative, 3- vision, 4- task orientation and 5- coordination) which you want to investigate at the moment. Play mechanic option one or two.

Game dynamics are driven by competition about the highest reward points as an individual player. However, cooperation with other players can be useful to avoid selected other players to push their amount of reward points. An example for cooperation could be that players confederate against the current high score player(s). This leads to dynamic coalitions or confederations. By design each scenario has to fit with one case which ensures progression of the game. In some scenarios two cases can be rewarded, if the team sees itself borderline between two cases of a scenario. Based on this game dynamics it is ensured that always the state of the game goes forward (primary dynamics) but not always the players state (reward points) is changed (secondary dynamics).

The **formal structure** of the game involves electing or defining the game moderator, determining the topics within scope by selecting or deselecting scenarios, and establishing the game duration based on the number of selected scenarios. The game ends if all cards are played. To keep a time box for the entire game play it is possible to define for each case argumentation and discussion a time box, too. This can be realized by setting for example 30 s. per card play (with 10 s. for argumentation and 20 s. for discussion respectively contra-argumentation).

Core-loop of the game is that round robin each player tries to put a card on the board with highest possible reward (points). For putting a card on the specific place on the board to get the associated rewards the argumentation for the card case must be committed by the other players.

Boundaries in the game are also information that is available to the players and what they can do with it. Depending on the selection of the cards different information about the competition to realize the reward about scenarios exists. For the game setup in which all scenario cases are played the strategy and tactic is different to a setup in which by definition it is not clear respectively known by the players that all cases per scenario are in the game play.

To keep the game interesting and engaging, not all objectives of all players are always transparent. For example, a real world Scrum Master could be more interested on the overall reusable improvement ideas after the game than on winning as person in the game. So this person can play strategies to gain more "meta information" for the improvement actions.

Game components are:

- Board (Fig. 2) to put to cards on (base for post-game improvement actions derivation)
- Cards (Fig. 1 gives an example for one scenario with its three cases) to describe the cases of the scenarios
- Randomizer for card-selection respectively assignment to players
- Timer defines time box for argumentation respectively discussion about card fitting
- Counter for reward points of the players

Rules are:

Define one moderator (final discussion decision, timekeeper), all others are players
Define scope and play length (deselect scenarios respectively cases to fit constraints)
Define time box for each card play (argumentation and contra-argumentation)
Randomize cards and distribute the cards to the players
Play one card per player per round to the board round robin up to all cards are played

Count rewards (point) per player
Winner is the person with the highest count at the end

Fig. 2. Prototype board to discard cards to the associated case g/o/r or n/a if not applicable.

3.4 Impact the Real World with the Game

The business objectives (legitimates the time for having fun by playing during working hours, too) of the game are to identify a status-quo of the team maturity and make strengths of the team transparent and discover opportunities for teamwork improvement. To decouple the objective from the game play the final state of the game is used for the business objectives. The game play itself and the winner etc. are not relevant and used – only the final state of the game is relevant for the maturity rating and potential improvement activities. This underpins to play the game without the permanent reminder that each action in the game is business-driven action. The game is the game and can be played to win by each player. After the game the business scopes comes back. The final state of the cards on the board shows based on their position the rating for each of the five areas of the aTWQ approach. Also positions of cards in low maturity areas are good points to think about improvement actions in this context. However, the initial setup of the game has an influence, what kind of outcome in the final state can be expected. The initial definition of the game setup, for example which cards respectively scenarios and cases are selected and relevant for the status-quo view and potential improvement actions.

Potentially, it is possible to have meta-game running between different teams about their team maturity, if they compare their finale states to compete to become the most mature team.

The aTWQ-game is delivered as a Self-Service Kit (SSK) [27] to ensure scaling within large organizations. Important on the SSK approach is that a SSK can be used independent as a SSK "unit" and be part of a bigger respectively comprehensive thing based on a set of SSKs [28].

RQ3 is answered with the preparation phase, which influences the game-play by selection of scenarios and the opportunity to use the final game state to get a status-quo rating of the team. Additionally, the final game state is the base for the improvement actions.

4 Evaluation

4.1 Environment

The Volkswagen Group IT is the research respectively evaluation environment. It is a large and distributed environment with many different projects, programs, product and service teams. The aTWQ approach is mostly applied in agile teams setup. The evaluation is made in a large SAFe® program with over 10 teams and one DevOps team setup. In all cases, the teams have at least some experience with the aTWQ questionnaire.

4.2 Instantiation

To play the game in-person respectively offline or online two variants are available. The variants are developed iteratively to version 1.0 of the aTWQ-game. In a first phase the game was evaluated in-person by voluntary people of a team which are assigned to the same organizational unit. This phase contains three steps respectively iterations to improve the cards and board and defines easy and more complex game-play scenarios. During this phase, the players are the same to compare the effects between the improvement iterations. For the online setup and evaluation the team evaluates different facilitations like randomizers to "select" cards and stop-watches to keep pace. Also the template with the game-card and cards was optimized to keep pace and flow without to much switching of screens respectively pages. After additional three iterations a good setup was identified. With the working in-person and online version the release v1 was defined and the evaluation in the "field" started.

4.3 aTWQ-game v1 Setup

As described earlier, an early adopter was a large program of the Group IT with more than 10 teams.

Started by the Scrum of Scrum (SoS) team and rolled out to the teams. The program teams applied aTWQ based on the questionnaire in the past. Integration into PI and Improvement-Sprint was the next planned step by the SoS team members. With this train-the-trainer approach the scaling into large programs was realized, too.

Observation: The SoS-team had problems to transfer the team orientated scenarios to their work in that team. For example, they hadn't defined a scrum master for them so the card, which described to dos for the scrum master was not applicable. Another example is, that they didn't work with a backlog. But some scenarios described the work with this artifact, but the team couldn't transfer their list of requirements.

Learning: For special teams it could be an option to create more general cases to make the transfer easier or create cards with special scenarios for the given teams.

A second adopter was a DevOps team of a cloud service. The team applied aTWQ based on the questionnaire in the past. The team selects the factor 4 of cards than for the planned play rounds are needed. The aTWQ-Game was played in the retrospective. All roles – incl. Product Owner - of the team actively played.

Observation: after a short introduction the game starts. The first round was a little bit slower as expected. But speed came up fast about the argumentation for cards. At the end the team feedback was positive and the decide to play it cyclic in a 6 to 8 week frequency during retrospectives. The most valuable positive point was, that each scenario triggered a reflection of the team and the cases helped by the rating. Overall one hour was used for the initial introduction into the game (approx.. 5–10 min), the game play (approx.. 30-40min) and the derivation of improvement actions (approx.. 10–15 min). A short personal feedback about the aTWQ-Game was given by the players at the end, too.

Learning: However, the high "overprovisioning" of cards leads to the point, that often only one case of a scenario was played. And this case was not fitting the team. So the scenario did not bring the right case to the board for selecting the case for improvement actions. It is recommend to not overprovision the cards to much to have a high rate of scenarios which are rated in the game as base for improvement actions.

Both teams got an anonymous online-survey for feedback – additional to the personal feedback at the end. The questionnaire contains the following questions:

- The game was?
  - Response span: boring to amusing
- The gameplay was?
  - Response span: easy to complicated
- I recommend the game to colleagues:
  - Response span: 0 to 100%
- For me is clear after the game what are out team improvement areas:
  - Response span: no or yes
- Select the improvement area(s): [aTWQ topic area list]
- Give general game improvement ideas/feedback: [text field]

The questions are used to derive ideas for further improvement of the game for future aTWQ-Game versions.

5 Communication and Rollout

For the communication within the LACE:HUB two facilitators of SAFe® transitions were engaged with the aTWQ game development respectively evaluation during their program facilitation. The objective is to have the approach in the "tool-box" of the SAFe® transition facilitators. Additionally, the game was integrated into the Agile Toolbox which is available via Group Wiki. Furthermore, in the Agile Community of the Volkswagen AG, the aTWQ game was presented in the online variation. In a Community of Practice (CoP) all interested people were able to play the aTWQ game. Based on these direct communications additional channels were used like Volkswagen internal wikis and social media.

For rollout, the integration into the efiS® framework as building block in the empower pillar is useful to offer an alternative to the aTWQ questionnaire. In addition to LACE:HUB facilitator communication the establishment is made by the implementation roadmap mapping. This mapping uses the SAFe® implementation roadmap and maps the efiS® framework building blocks to the right position(s) on the implementation roadmap. Furthermore, the initial usage of the aTWQ game becomes part of the transition facilitation by the LACE:hub. This ensures professional introduction at the right point on the implementation roadmap under experienced facilitators. However, it is possible to use the aTWQ game independent, like in a retrospective.

6 Discussion

6.1 Restrictions

A limitation is that no long-term experience is available to measure especially the effects of the improvement actions. However, the improvement actions are the post-game phase and its performance depends like in the questionnaire based aTWQ approach from the team and its environment. A long term observation can focus on the "creativity" of the improvement actions like is the game driven derivation too much oriented on the scenario and case or is also an adequate transfer and adaption to the team specific setup realized. On the other hand, is the questionnaire based approach finding also in not "creative" teams the relevant "standard-actions" for improvement?

Another restriction is, that no peer-groups are defined like in A/B-testing to see how much more or better the game or questionnaire based approach works. However, as we identified this A/B approach will not work as expected. Depending on the teams, some people are more or less game affine. Our observation goes more in the direction that each team should try both approaches and chose the "better fitting" one to the team culture and attitude to the offered methods to perform the aTWQ approach.

Furthermore, it is not clear how the approach fits to non-IT teams. Currently only Group IT teams performed the aTWQ-Game. However, the Scrum of Scrum (SoS) team with only Scrum Masters is not strongly depending on IT related SAFe® programs etc. So there should no big difference between the IT evaluation and non-IT setups.

6.2 Contributions to Practice and Research

Continuous improvement of the team maturity can be realized by gaming. Overall the results of the evaluation of the gameplay fits to the expectations which were derived during the game development. It works online and offline and is adaptable to the time slot a team want to spend for playing. Also options about the gameplay are existing to have variation in the game.

Contributions to research:

- Demonstrate that approaches like aTWQ can instantiated with different methods like a questionnaire or a game.
- The scenario and case approach helps teams to get an idea how their maturity is standardized rated.
- The gamification is not accepted by all team in the same way – some prefer the usage of the questionnaire which they can answer private an anonymous.

Contributions to practice:

- The aTWQ-Game offers more flexibility to the teams to perform the aTWQ approach – the teams perform the preferred method and always can chose one.
- The game can be performed in person and online without large setup changes.
- The case-rating enables organizations with an multi-team setups to compare the individual team results better.

7 Summary and Outlook

The aTWQ-game is a step into more objective ratings in the context of aTWQ approach. The game can be played in-person and online which fits to the new established hybrid work. The aTWQ-game is an extension to the existing questionnaire-based SSK of the aTWQ approach. This work is a step towards a more legal obligation complete efiS® framework [29] because it facilitates an objective evaluation of the team maturity with the scenario based rated cases.

Currently, no default. Spread the gamification to other efiS® framework [30] building blocks. A potential next step is to apply the game-concept to the TTM approach [31]. Furthermore, the analysis about the contribution and still open gaps to legal obligations in the context of delegation and monitoring of agile teams is possible.

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Agile Team Autonomy and Accountability with a Focus on the German Legal Context

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Abstract. Agile teams are a growing part of the employees way of working within organizations and projects. Within agile working the autonomy is an important element of the way how agile approaches are defined and build. So it is important to look how this non-hierarchical approach, based on team autonomy, fits into an existing legal frame. In this work aspects from Germany, are focused and analyzed. To find a trade-off between specific and generic observations, the work is based on a typical enterprise scenario. The scenario is instantiated case specific to identify generic patterns. The patterns are analyzed with selected legal views to derive recommendations about the setup of agile teams from a compliance perspective. Focus in this analysis are Scrum and SAFe® in combination with the efiS® framework.

Keywords: team autonomy · responsibility · accountability · agile · legal aspects

1 Introduction

With the settlement of agile approaches in established organizations some questions are rising about how the established hierarchical structures have to be adjusted to facilitate the agile approaches or who is accountable in autonomous agile teams in the case of a compliance deviation? For example standards like the ISO/IEC 27001 (control A.18.1.2) or ISO 21434 have requirements which are more or less directly demanding a Software Bill of Material (SBOM) to ensure compliance management of, e.g., intellectual property rights of, e.g., Free/Open Source Software (FOSS) components. In agile setups often "the team" is responsible to do something like building a complete SBOM and maintain it. But what will happen in the case that a security breach occurs, because no one maintained the SBOM and therefore vulnerable components were implemented, which led to a root-cause for the security breach? Is the issue bigger in scaled agile setups in which more teams are involved? Is it better to have DevOps teams with an end-to-end responsibility instead of the hand-over to an Ops-team?

From a legal perspective the question is always who is accountable. Is an entire agile team accountable with all its members, or a dedicated person, who had been assigned with the task? In agile teams especially such using Scrum principles – there will be indicators

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displaying, if the Scrum Master is "caring" for the teams' processes or respectively if the value streams are adequate and running, e.g., "Causing the removal of impediments to the Scrum Team's progress" [1]. The question here will be, if the Scrum Master is accountable for non-compliance about standards or regulations, which are typically addressing processes with their requirements?

To address some of these questions the following Research Questions (RQ) are derived for a selected scenario:

RQ1: why does an agile team has to ensure that responsibility and accountability are assigned?
RQ2: what are patterns an agile team can apply to ensure adequate assignment? RQ3: how can a transparent assignment of responsibility and accountability be realized within a team?
RQ4: who has to ensure and is respectively accountable that the assignments are adequately realized?

Not addressed is the question how an agile team can ensure that all relevant accountabilities are identified and assigned. However, some approaches for a holistic view are suggested, but without a claim for completeness.

The work is structured as followed: a literature analysis gives an overview about the state of the art, the method section describes the used approach, the analysis section develops the patterns, the discussion reflects the results and outcomes and finally the outlooks shows potential next steps.

2 Literature

Accountability
In [2] accountability is reflected in the context of distinguishable types. The types of accountability can be used to make transparent that established organization with their "bureaucratic accountability" needs a mapping to the agile organizations "personal accountability" and "profession accountability" of the teams.

Agile Contracting
Agile programming from a legal perspective with focus contracting is analyzed in [3]. Also [4] focus on agile contracts. Another work which address contracting agile development in the context of public sector is [5]. In [6] is described how Mastercard legal experts adopt agile approaches for their work.

Legal Perspective
Legal questions around temporary employment, agile process and organizational methods are being dealt with in [7]. In [8], aspects of liability in agile projects at the interface

between client and contractor are examined. However, coverage of liability matters within an organization with a direct connection to agile development is not available.

Scrum
Scrum is an agile methodology for teams. In the Scrum Guide [1] the term legal and law is not used.

SAFe®
The SAFe® framework address scaling of agile working beyond the team size with different scaling levels form essential to full SAFe®. The SAFe® [9] description uses the term legal mostly in the context of legal requirements or as function respectively service unit. However, nothing is presented how to build agile teams enabled to act accountable form a legal perspective.

efiS®
The efiS® framework [10] is driven by a quality management perspective and builds upon four pillars which are interacting together as "flywheel". The first pillar, Empower, fosters team maturity, the second pillar, Focus, analyzes the specific risks of the teams value stream, the third pillar, Integrate, ensures that regulations and standards are embedded into the value-stream and its outcomes and the fourth pillar, Scale, facilitates knowledge sharing between different value-stream teams and the organization.

Legal Cases About Agile Working
Court rulings [11] regarding agile software development are available [12] on e.g. remuneration in SCRUM procedure, withdrawal and loss of interest in contracts for agile software development as well as equivalence of management functions in environments with and without agile approach [13].

3 Method

Based on the defined scenario (RQ1) instantiations within enterprises are identified. These instantiations are the cases which are analyzed regarding similarities to derive patterns. To limit the complexity respectively the heterogeneity of the cases only Scrum [1] and SAFe® [7] based setups with the overlay options of the efiS® framework [8] are focused. The identified patterns are reflected with different relevant legal views. To limit the complexity respectively the heterogeneity the focus is on European especially on the German legal framework. Recommendations are suggested for the patterns. The participating cases reflect the suggestions about instantiation in their specific setup. The feedbacks from the cases are used to refine the suggestions for more generic and wider practical usage. This research approach is aligned with Action Research [14] and its participant collaboration in the context of change and reflection.

To keep scope the research methodology is defined by the following guidelines and propositions:

- Keep the agile setup in a well-defined but relevant methodology scope with Scrum, SAFe® and efiS®

- Keep the legal perspective in the narrowest possible angle like German law instead of European law (German law should be aligned with the European Union anyway)
- Do not address all possible aspects from the cases by selection of generic sub-sets and patterns e.g. based on identified common propositions to identify generic aspects
- Definition of one feedback loop to get the most relevant learnings and improvement but avoid micro-optimizations for specific cases

Based on the identified cases and their typical handling in projects recommendations are derived. The recommendations focus on additional tasks and dependencies. They present the options to handle the topics with agile framework approaches (e.g., methods or rituals) and recommendations which are not coming out of the box with the agile frameworks. To fill the systemic gaps of the frameworks, possible patterns are derived based on the recommendations. The patterns and recommendations are discussed in the context of legal obligations. The formal flow works top down (Fig. 1). In real world the topic and possible operational solutions are not necessarily handling the layers in the top-down order. However, the case analysis handles these five refinement stages.

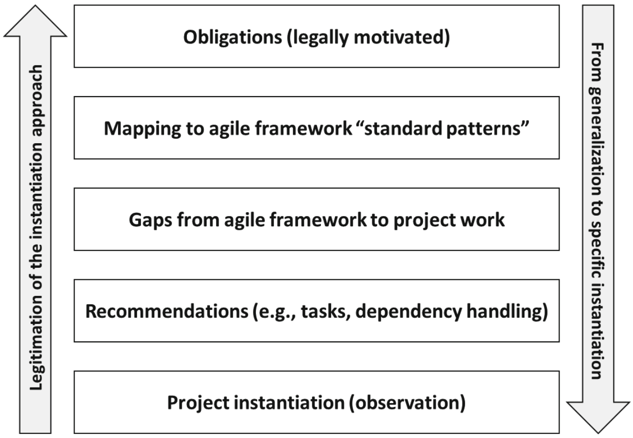

Fig. 1. Methodology to refine respectively derive legally aligned actions.

4 Analysis and Results

Based on the defined scope two types of the cases are analyzed – one is Scrum the other is SAFe®, both in combination with efiS®.

Case A: Accountability About Team Task

Let us assume the following case: How is the accountability in the agile team realized to ensure standard compliance of their development flow outcomes? To make it tangible on a typical artifact in practice: How is the completeness and timeliness of the SBOM for FOSS components realized in the team?

Practices from Scrum to realize the objective are: define a Story for each Sprint to ensure that each increment has i.e. a complete updated SBOM of the FOSS components. Also possible is to add a SBOM-check to the Definition of Done (DoD). There is the assumption that the team has the skills in an adequate level with the assumption that the team is “structured and empowered by the organization to manage their own work” [1]. However, Scrum does not ensure that a sufficiently competent team member realizes the story. In case of issues the retrospective should identify these and try to define and establish actions to avoid the issue in the future – but this is a “(too) late handling”.

Practices from SAFe® are the same as in Scrum (as it is part of SAFe®). Additionally, on Program Increment (PI) level a cross-validation by the Release Train Engineer (RTE) can be established. However, also the RTE is not explicitly qualified by its role for this task as this job is not defined by SAFe® [15]. In case of a full SAFe® implementation with luck one of the “shared service” [16] cares about the topic.

Practices from efiS® are in the Empower pillar with the building block Technical Team Maturity (TTM) [17] which makes the demanded skills about SBOM explicit to the team. Of course the TTM about FOSS management has to be defined respectively refined by the organization. Furthermore, the Integrate pillar with a Level of Done (LoD) [18] layer addresses the topic as a task for releases. For example an ISO 27001 LoD layer [19] includes this topic. Based on the TTM evaluation rating which is conducted in a cyclic manner, e.g., as part of the retrospective of the team the accountability can be assumed by the team or not. Only sufficiently skilled teams can take over the task execution with responsibility. If the skill level is not given, team-external compliance checks can be initiated before release.

Obligations from a legal perspective around the topic pertain more general expectations as to the organization of agile working, very much comparable to those regarding more conventional forms of work.

At a fundamental level and depending on the legal structure of the company, there are obligations, for example, for the board of management of a stock corporation based on the German Stock Corporation Act (Aktiengesetz). This includes the fundamental duty and concept of careful corporate management which means that the board of management is obliged to steer and monitor the company’s activities and has an organizational responsibility; both to be aligned with the fulfillment of at least the legal requirements for the company [20].

This means to comply with applicable statutory law in order to avert damage to the company which is a crucial aspect. Such binding statutory law also includes e.g. civil law with its contractual provisions, for example those on the requirements for defectfree delivery in contracts for work and services.

With regard to the above example of a completely and timely prepared SBOM, damage to the company may occur in two exemplified scenarios: (1) As a result of violating a contractual provision stating this as a required deliverable in connection with the applicable statutory provision on defect-free deliveries; as a consequence of such a violation the company may be exposed to legal claims for damages; or (2) if the SBOM is either incomplete or does not feature the correct/latest software product inventory the company may not be able to quickly enough identify vulnerable components and cannot substitute these with secure ones. In the meantime adversaries may be able to lock down corporate data or threaten to disclose sensitive information in order to carry out a ransomware attack.

Both example scenarios are to be avoided by the board of management with appropriate organizational means. Such organizational measures must have the goal of avoiding the identified or prognostically expected risks or – depending on the type of risk – at least to reduce them [21]. In the example of the complete and up-to-date SBOM, appropriate measures include that the department entrusted with the specific task is equipped with sufficiently qualified personnel, that these personnel are appropriately instructed and that they are also monitored in the execution of the task. In companies typically the Human Resources department is responsible for recruitment in accordance with the organizational obligations. The specific selection of employees for the re-quested task is then made by a supervising person. This supervising person is then usually also entrusted with the instruction of the fulfillment and execution of tasks to the employees, i.e. the what and the how.

In this context, it is important to note that work instructions in agile projects only cover the planned next development phase (sprint). They should be adapted to the development progress and are otherwise rather general [22]. Even if the responsible person does not give explicit instructions, this does not exempt other stakeholders of the company's organization or the acting personnel from legal responsibility. The disciplinary supervisor is responsible for the subordinate area and therefore in principle also for the technical instructions of the project manager. This includes rather general instructions for the execution of the tasks as well as the creation of criteria for evaluating progress and quality.

The legal obligation to carry out these instructions arises from the respective employment contract in conjunction with the applicable statutory law. If the employee – the agile team member – does not implement these instructions, although it would be required, labor law measures may be used by the disciplinary supervisor, so there should be an incentive to at least avoid these possible negative consequences [22]. Apart from exceptional cases, this forms the legal basis for ensuring that the employees, who are also supposed to create the SBOM in an agile team, keep it complete and upto-date. Finally, the supervising person along the chain of organizational duty is usually concerned with monitoring the execution of the assigned task and, if necessary, requesting corrections, for example. The type and scope of monitoring is influenced, among other things, by the risk arising from incorrect execution of the tasks and the reliability of the employee according to the experience of the supervisor. It is therefore the result of individual factors.

The overall rationale should be to provide the highest degree of autonomy possible to the teams, however embedded into applicable legal requirements.

It is proposed to teams to apply the presented practices of the frameworks. The delegation can be realized best into a highly qualified team e.g. facilitated by aTWQ and TTM without detailed working instructions. The high competency level of the teams also can be used to let them adjust their working procedures with a high level of autonomy without too many instructions from the management. Additionally, also in the efiS® setup the management has to monitor or ensure, e.g., by "external" cross-validation that the autonomous team works as expected. Additionally to the cyclic self-evaluation of the teams, e.g. with TTM the monitoring of the team has to check that enough mastery and rigor in the teams exists to assure that e.g. no trainee is responsible for critical task execution without senior supervision. This can be facilitated for example by a governance which randomized samples releases and checks the efiS® instantiation based on LoD checks as proposed in [23] and TTM evaluation reviews [17].

Case B: Product Risk Management
Let us assume the following case: A specific IT product or service is developed because no adequate solution is available on the market. The aim of the business team is to realize decided opportunities by developing the IT product or service. How are the product and service related risks corresponding to the chances adequately handled in an autonomous agile team?

The generic part of accountability is comparable with Case A. Specific practices for risk management are facilitating with guidance for the operational implementation.

Scrum practices to realize the objective are: During sprint planning and the refinement of sprint content, i.e. stories or sprint goals, the aspect specific risks to the stories and sprint goals can be reflected. However, it is not an explicit topic in the Scrum procedures. Additionally, if a risk is detected during a sprint, it can be addressed during the stand-up – transparency aspect to initiate, inspect and adapt. The retrospective should cover any risks and their realized problems. However, this is often too late – and if the risk becomes reality this will for example result in additional effort for rework. The overall concept based on an iterative and incremental approach – based on sprints with their stories – tries to reduce such (often large) efforts within a risk area. However, some specific product or service risks are not directly coupled to a specific feature of a specific sprint. It is often an incremental risk-contribution of features over the entire development with many sprints which have to be addressed to mitigate systematically inherent product or service risks with small steps. Continuously practiced transparency is needed to address this issue, but no explicit practice is recommended in Scrum for risk handling. An indirect anchor for story-related risk-management could be the Definition of Done (DoD), if the team adds some smart risk-evaluations to the DoD.

Practices from SAFe® are the same as in Scrum (as part of SAFe®). SAFe® proposes to handle implementation risks on the acceptance criteria level [24], but does not facilitate systematic identification and elaboration of risks. By applying Weighted Shortest Job First (WSJF) the risk aspect should be part of the weighting process [25], too. Additionally, the Solution Architect/Engineer's "help address through risk management" and define mitigation actions for the Backlog [26]. One approach is to handle implementation risks as ART PI Risks (without long-term focus). Furthermore, the Release Train Engineer (RTE) is a servant leader who facilitates the risk management [15]. Also the entire learning-culture cycle handles the learnings from past risks [27].

Practices from efiS® are in the Focus pillar with the Product Quality Risk (PQR) [28] building block which addresses the specific product risks and the Empower pillar with TTM to have sufficient knowledge to perform the tasks. PQR uses a risk identifying Design Thinking approach. Additionally, PQR ensures with the product respectively service specific story-template which integrates the identified PQRs that the risk awareness becomes a part of the value-stream. However, PQR only can be applied in areas in which risk handling is an acceptable option. Additionally, formal risks like compliance to regulations and standards are addressed in the LoD. To ensure that the team is able to make an adequate risk ideation and evaluation the Empower pillars building blocks are facilitating the needed methodological and technical maturity. Furthermore, learnings about risks or state of the art can be shared with Self-Service Kits (SSK) [29] with the organization to become better in the future as entire organization. Obligations from a legal perspective around the topic must include the relevant goods and interests that may be at risk to be violated. Risks to public goods and rights (physical integrity of persons and property of third parties) as a result of the placing on the market of the corresponding work product of agile software development require that the legal evaluation on the one hand again includes contractual aspects and on the other hand the principles of product liability and producer liability. Both aspects need to be adequately organized by the board of management of e.g. a stock corporation in order to manage product and service-related risks and to avoid damage to the company on the basis of e.g. court decisions [30].

As stated above under Case A., the company's board of management also has the possibility, and within limits the obligation, to control the prevention and mitigation of product and service-related risks [18]. As described, such control takes place on the basis of relevant regulations on the establishment of organizational managers in HR departments, the respective direct superiors and their instructions in connection with the employee's employment contract in the agile team.

It is conceivable that the work of the agile team is used to fulfill a contract; e.g. a software supply contract with a third party [31]. In this case contract law requires the software to be created in accordance with the terms of the specific agreement between the parties and additionally on statutory law, insofar as the agreement does not stipulate them. Should there be no limitations on liability, the software development is expected to produce no defects in the software to be delivered.

However, neither the statutory provisions on the contract for work and services, which is generally relevant in such cases, nor the contracts typically concluded for this purpose contain specific requirements for the organization of the contractor for the provision of the contractual service. In this respect, the legislation assumes an independent entrepreneur whose freedom of organization is to be interfered with only to the extent necessary (e.g. by the above mentioned Stock Corporation Act).

However, due to the specific character of agile development planning of the development process can be expected to be part of the contractor's performance and part of the contractually required work [32]. Moreover, since such work results cannot be described comprehensively and conclusively in advance, in addition to the express agreement on the planning of the development process on the part of the parties, the qualification required for the provision of services should also be contractually described [33]. Product liability and/or producer liability were largely developed around § 823 Bürgerliches Gesetzbuch (German Civil Code) and represent a multi-layered model of individual obligations as far as the placing on the market of products is concerned. The obligations generally include the avoidance of development errors, design errors, manufacturing errors and instruction errors [34]. For agile development mainly the first two categories may be relevant. By contrast, manufacturing defects are, by their nature, related to physical products, of which even individual pieces of a series may have a defect due to improper manufacture; a circumstance that is not relevant for software. Each error is characterized by the specifics of its respective setting and liability regarding one product may occur on each of these layers simultaneously.

Preventing development errors requires that, according to the state of scientific and technical knowledge, no one was able to discover the defect at the time of placing the product on the market [35]. The manufacturer must use all possibilities of knowledge available to him to choose an approach that avoids this error [35]. A design error exists if the product's concept does not meet the applicable safety standard [36]. The manufacturer must take the measures that are practically operational according to the latest scientific and technical developments [36]. He does not have to implement solutions that are still being tested [36]. Simply implementing industry-standard solutions or applicable technical standards is not enough if technical development is already advanced; however, both must be observed as a minimum standard [36]. The manufacturer, i.e. the company's board of management, must use all the information available and ensure that it is also made available to the developing personnel, in this case the agile team.

Instructions and control of the organizational and procedural requirements to avoid these errors are again part of the duties of the company's board [21]. The procedural requirements may include that the legally created and judicially formulated error patterns are processed in such a way that the employees entrusted with the specific tasks are enabled to avoid errors in the execution of their tasks. As described under Case A., the board of management can and must create the personnel and organizational requirements in the company in particular or have them created, agile adequate work instructions together with the respective employment contract and the statutory provisions form the basis for the employees to implement the company's structure to avoid the aforementioned errors.

The overall rationale should be to see "everything" which is relevant as autonomous team with the facilitation of the organization.

It is proposed to teams to apply the presented practices of the frameworks. None of the analyzed agile frameworks offer an approach for an explicit and systematic monitoring of the state of scientific and technical knowledge. An up-to-date TTM is a good base for a minimum scientific and technical knowledge in the team. Also with SSKs knowledge can be made transparent to all team members and the organization. If no full monitoring is possible a risk management to focus on critical areas can be an approach to manage the issue. Still in the efiS® setup with a systematic PQR a risk can be described as a state in which not all relevant aspects about the deliverables (products or service) are defined and identified related to the state of scientific and technical knowledge. This issue can best be supported by a servant governance and competence center like the Shared Services or CoP with experts as proposed in SAFe® because the typical agile teams are too small to know, foresee and monitor "everything".

Case C: Compliance with Regulations and Standards

Let us assume the following case: An agile team shall develop a product or service in a regulated domain. How is compliance with product and service relevant regulations like GDPR and standards like ISO 9001 and ISO 27001 ensured for a specific product or service?

The generic part about accountability is comparable with the case A. Additionally, specific practices about identification and managing of compliance requirements are facilitating with guidance for the operational implementation.

Practices from Scrum to realize the objective are: “if the Definition of Done for an increment is part of the standards of the organization, all Scrum Teams must follow it as a minimum” [1]. But the intention of a DoD is not to handle all requirements of regulations and standards for the product. This shows that the topic is not sufficient addressed by Scrum.

Practices from SAFe® are “During backlog refinement and PI Planning, the Feature’s size and scope include all of the work, including quality and compliance activities” and give some abstract suggestions to address security requirements [37]. However, a systematic approach to identify and integrate compliance aspects is not represented. Compliance is also part of the Enterprise Solution Delivery [38], but also not explicitly instantiated and delegated to be addressed by a Quality Management System (QMS). It is recommended to automate compliance activities [39] within the ART [40] and Solution Train [41] as part of the Solution Intent [42] as well in the Architectural Runway [43]. This motivates roles to assign compliance to the Solution Architect [44] and enabler capabilities to handle compliance or to establish Shared Services or Communities of Practice (CoP) for the topic. Additionally, in the Solution Management requirement, compliance is assigned [45] and driven by Non-Functional Requirements [46] or as enabler Story. Last but not least, compliance is part of Release on Demand [47]. This shows the aspect compliance is everywhere but not dedicated and explicitly handheld. However, SAFe® does not present an explicit approach to handle regulation and standard requirements. Additionally, in the extended SAFe® guidance documentation an outdated 4.6 document from 2017 exists about achieving regulatory and standard compliance [48]. With all the distributed contributions to realize compliance it looks like that the Product Owner (PO) “regularly evaluates progress toward story acceptance criteria, including compliance”. So he could be addressed as accountable person and as last instance to accept the implementation [49]. However, the PO can try to move responsibility to the “Business Owners” as a small group of stakeholders who have the primary business and technical responsibility for governance, compliance”[50]. This shows that each SAFe® implementation or organization has to find a way to establish compliance, because in SAFe® the topic is not addressed in a reliable manner.

Practices from efiS® are to establish the LoD and ensure that the related tasks to check the LoD “points” are made by the value stream team. In mature organizations LoD layers for the relevant regulations and standards are existing and can be used directly. In mature organizations the LoD layers are maintained by the experts of the regulation or standard as a kind of enablement facilitation. In less mature organization or in case of new regulations like for the upcoming the EU AI Act the “first user” has to build the LoD layer together with some experts (i.e. legal, data scientists, etc.) and share the LoD layer together with a SSKs to the entire organization. The LoD is used in the value stream team to ensure that nothing about the compliance is forgotten. External compliance checks can be conducted against the from experts of the application domain defined LoD or selected LoD layers depending on the audit scope.

Legal answers to the question raised are mainly based on what was stated above on Cases A and B. The explanations on the observance and organizational implementation of binding rules for the exemplary stock corporation are valid here again.

For the example of the GDPR, this means that the board of management must also have implemented all requirements relevant to the specific project of the agile team under consideration in an appropriate form. These include here i.e. to observe a lawful basis for the processing of personal data, to implement data protection by design and default and to limit the transfer of personal data to places outside the European Union to cases where appropriate safeguards are in place [51].

With regard to ISO standards and comparable non-statutory regulations or parts thereof, the company may also be obliged to implement them if compliance with the specific standard is required for projects of the respective type and in comparison with companies in the same industry, e.g. to prevent the violation of safety requirements for a product. This example was already indicated above in Case B. In such a case, a statutory act forms the bridge for non-statutory requirements. It is also possible that the work result of the agile team should serve as part of the fulfillment of a contract with a partner. In such a contract, the parties may, for example, agree on the application and fulfilment of a standard, even if this is otherwise not prescribed by law. In this way, the parties can agree on certain requirements, the implementation of which they need, for example, due to their own quality specifications.

Insofar as the board of management has created the necessary organizational prerequisites for the implementation of the regulations, the responsibility for the implementation in the specific project is in turn passed on to the agile team on the basis of work instructions, contracts and laws.

The overall rationale should be to ensure that all relevant statutory and non-statutory requirements are identified and handled.

It is proposed to teams to apply the presented practices of the frameworks. However, also in the efiS® setup with its LoD layers it is difficult to ensure that all relevant requirements are identified. The identification and updates of the LoD layers can in the best way be supported by the in SAFe® proposed Shared Services or CoP with the experts because the typical agile teams are too small to know "everything".

5 Discussion and Limitations

The presented three cases are addressing three areas of accountability within product and service development. The pivot is the management level on which the switches happen from the hierarchical to the agile organization. Here the delegation to or instruction of the team has to be realized adequately by the management and a sufficient monitoring has to be established. As agile teams are typically handling complex work [52] it is often not possible to define top-down the work in detail. This makes it important that a delegation of the what and how into the agile team is possible – this demands high mature agile teams about the work objective respectively deliverable outcomes. The mature teams can adjust their procedures if needed and define quality characteristics to perform in the complex work environment which has to be supervised by the management. To handle these areas of delegation and monitoring obligations systematically the proposed generic patterns are:

- Team safety, support & information, vision alignment, coordination,
- Task definition
- Task assignment
- Task fulfillment
- Task output validation
- Outcome validation

From the analyzed agile frameworks perspective efiS® supports these aspects in the best way with the teamwork capability support with the Empower pillar. With a TWQ and TTM the team empowerment is realized, with the LoD formal respectively obligated tasks are assigned, with PQR specific risks are identified, and with the LoD explicit check tasks for output validation can be defined.

A compliance capability to statuary and non-statuary obligations can be realized with the efiS® framework building blocks LoD and LoD layers and the empowerment pillar to ensure sufficient awareness respectively qualification for the topic in the team. Neither Scrum nor SAFe® does explicitly ensure systematic compliance handling. However, a kind of objective "self-monitoring" by an autonomous team is not given within the efiS® framework building blocks. This demands an establishment of a team-external "monitoring" by the management respectively organization.

Delivery specific risk-management handling is possible in Scrum and SAFe® but only efiS® offers by design explicitly risk handling on the product or service level. The efiS® framework makes product risks explicit with PQR. The compliance risks are mitigated by the LoD layers and their instantiation of the relevant regulations and standards for the specific product respectively service setup. The Empower pillar ensures that the team has sufficient maturity to adequately handle risks. However, the organization has to check in a cyclic manner that efiS® is adequately implemented.

Compliance capabilities to regulations and standards are not explicitly addressed in Scrum and not systematicly assigned in SAFe®. The efiS® framework with LoD respectively LoD layers can be used to facilitate the identification and instantiation of product and service relevant compliance requirements in the value stream teams and facilitates to audit the compliance or maintain LoD layers by experts for a specific regulation or standard. However, also in the efiS® setup the team empowerment for the awareness and accountability regarding compliance has to be established for an autonomous agile team.

The technology capability (scientific and technical knowledge) is partly addressed in the efiS® framework Empower pillar with TTM. The Empower pillar should at least foster a systematic reflection of the team on their capabilities. The capabilities should be the enabler to reflect the used technologies about valuable outcome creation contribution and enables the team to initiate adequate actions if needed. However, methods like technology assessments or IP management are not explicitly integrated. Scrum and SAFe® did not add something to improve to the situation. In case that this is needed it has to be added by the delivery team explicitly.

The identified aspects of the discussion of the cases A to C can be summarized in Fig. 2. The frameworks support with many practices the key capability areas. However, there is no philosopher's stone in one framework which fits all legal aspects – some business risk is not completely mitigated. There is no framework or combination of the analyzed frameworks which ensures the completeness about the state of scientific and technical knowledge and all relevant statutory and non-statutory requirements.

Limitations are that all cases only reflect one aspect without the real world complexity about contracting, global sourcing of delivery teams or global distributed team members. Additionally, the cases are analyzed only against three agile frameworks and other potential better approaches are not in scope. The selection of other cases or other frameworks respectively combinations of them can lead to other results. Although this evaluation is realized with focus for German law only – it is possible to transfer results to the EU because many laws are harmonized by EU regulations, but not all are transferable to other global legal areas; this should be considered by the transfer of these insights. Over and above all the analysis are interpretations because a final decision is only made by judges for cases handled by courts.

Furthermore, the frameworks are evolving and in the future they can address the research topics with the identified issues. However, SAFe® v6 does not significantly amend its framework around the discussed topics from the previous versions.

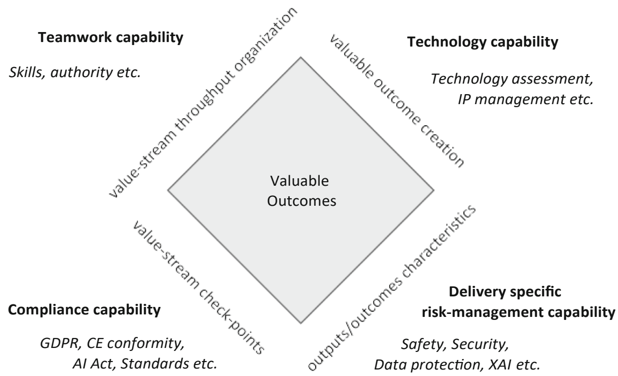

Fig. 2. Key capability areas of accountability for valuable outcomes.

6 Conclusion and Outlook

This analysis of Case A to C shows that none of the three analyzed agile frameworks or a combination of the frameworks can completely mitigate the business risks.

The key contributions *to practice* can be summarized by the following aspects:

– The efiS® framework facilitates best the analyzed cases
– 6 patterns are identified to address accountability.

The key contributions *to theory* can be summarized by the following aspects:

– The literature is patchy about the topic "agile team accountability" with relation to legal aspects
– The key areas of accountability are proposed.

Future research has to focus on how to ensure that more completeness about the state of scientific and technical knowledge and all relevant statutory and non-statutory requirements can be realized. Furthermore, research has to focus to ensure that all relevant risks can be systematically identified.

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Foster Systematic Agile Transitions with SAFe® and efiS® Oriented Team Evaluations

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Abstract. Agile transitions are complex changes within organizations and their employees. Typically, established frameworks are used as a kind of implementation target picture for the first milestones of transitions. To evaluate the progress of the adoption of the target frameworks the organizations with their teams need feedback. The proposed approach address these feedback for transitions with a SAFe® and efiS® framework focus. This includes Scrum with the SAFe® Scrum derivation. The approach was designed to facilitate the transition journey of product teams and organizations in large enterprises. The presented case study of the Volkswagen Group IT shows the facilitation of the journey in direction to a more agile and product oriented organization.

Keywords: agile transition · SAFe® implementation · efiS® implementation · IT governance · IT quality management

1 Motivation and Introduction

1.1 Motivation

In large organizations many agile projects and programs are often delivered and developed simultaneously. In the case of an organizational transition towards more agility often specific agile frameworks are used. Frameworks [1] can help organizations to define a common language and establish a consistent and standardized delivery approach through fixed roles [2]. The management of an organization wide transition requires transparency about what is reached and what is still needed. To get an objective status quo of agile transitions reviews, evaluations or assessments are required. It is necessary to make a comparison between the planned implementation and the organizational expectation and find the right alignment [3]. To find the best suited approach it is recommended to let the agile teams run an assessment which the teams can carry out themselves or by external staff.

Taking this into account, an approach has to be developed which is re-using established building blocks and combine them with the demands of large enterprises. Large enterprises have at least two views: the internal team-view, like the teams of a value stream or an Agile Release Train (ART) and the entire organization in with multiple the ARTs.

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1.2 Introduction

In large enterprises the systematic instantiation of the selected agile framework during the transition towards an agile organization is often realized by professional agile coaches. Theses coaches are organized in internal competence centers like Lean Agile Center of Excellence (LACE). On large organizations Scrum [4] needs some additional structures to ensure inter-team cooperation. To address this demand scaled agile frameworks like Nexus [5] or SAFe® [2] are designed. However, not all of these scaled frameworks have an implementation roadmap or assessment approach to evaluate the current state of the transition. Especially, the assessment is useful as long agile is seen as a mindset which leads to journey which goes beyond the instantiation of a framework.

To facilitate teams to reflect their agile journey it is important that the assessment works as self-assessment and is available and applicable every time the team wants are evaluation. However, the organization also want an appraisal approach to conduct them with a performance and alignment objective. To avoid different approaches a holistic evaluation approach is needed to address assessment respectively appraisal. The benefit is that teams are measured internal and external with the same focus and rating approach. This makes it easier to transfer ratings and compare the results of conducted assessments and evaluations within the entire organization.

The aim of this stud< is to develop a combined assessment and appraisal approach which addresses the use cases self-assessment and external appraisal of agile teams and their value streams. In this context the word evaluation is used as synonym were the word (self-)assessment and appraisal can be used.

1.3 Research-Questions and Outline

Based on these observations the following research questions have been formulated:

- RQ1: What are relevant key design aspects to identify the progress of the implementation respectively instantiation of the agile framework?
- RQ2: How can these aspects be effectively measured?
- RQ3: How can these measures be analyzed for further usage respectively improvements in the teams and on organizational level?

The work to answer these questions is structured as followed: Sect. 2 gives an introduction into the literature, Sect. 3 describes the methodology of the taken approach and details the chosen solutions, Sect. 4 presents an evaluation of given results, while Sect. 5 is presenting the communication and rollout of given results. Sect. 6 discusses the restrictions and limitations of the first set of results. Finally, in Sect. 7 a summary and an outlook are given.

2 Literature Review

The summary of the literature review starts generic with Agile assessment approaches, refines to agile framework assessment and evaluation approaches and deep dives into the selected frameworks SAFe® and efiS®.

2.1 Agile Implementation Assessment Approaches

In [6] a generic assessment approach for agile is suggested. The assessment approach derives from the agile principles clusters. For example the principle Human centricity is split into 6 clusters. In [7] different assessment approaches are identified. The purpose of this study is to evaluate existing agility assessment tools to provide an overview about potential uses, advantages and drawbacks. They uses 9 criteria to compare and analyses 11 tools. A further interesting investigation is a survey about Metrics used in agile organization [8]. With this survey they collected data to find answers how organizations use specific agile metrics with different characteristics, such as size, industry sector, and agility level.

2.2 Framework Assessments and Evaluations Approaches

Most of the existing agile frameworks does not come with a dedicated assessment approach. In [9] are artefacts of scaling agile frameworks like Nexus, LeSS, SAFe, AgilePgM and Scrum@Scale are compared. It concludes that emphasis is on cooperation or delivery.

A wider approach, how to start with evaluation of agile maturity is described in [10]. The author described, how to Measuring Agile Maturity with Assessments – Agile Adoption.

2.3 SAFe® Implementation Approaches and Measures

The SAFe® framework defines its own assessment approach with Measure and Grow. The assessment approach look stable because no changes were made between v5.1 [11] and v6 [12] of the SAFe® framework checklists. The overall Business Agility Assessment is based on 7 sub-domains called core competencies: Team and Technical Agility (TTA), Agile Product Delivery (APD, Enterprise Solution Delivery (ESD), Lean Portfolio Management (LPM), Lean-Agile Leadership (LAL), Organizational Agility (OA) and Continuous Learning Culture (CLC).

2.4 efiS® Implementation Approaches and Measures

The efiS® framework [13] does not incorporate an assessment approach to evaluate its instantiation in the core framework. The efiS® framework offers indicators about successful implementations like the flywheel [14] to demonstrate successful implementations. The efiS® framework "does not yet explicitly guide the teams during instantiation and adaption of elements of the framework based on different scenarios."[14] However, the framework does offer evaluation tools, such as agile TeamWork Quality (aTWQ) [15] and Technical Team Maturity (TTM) [16], which can assess the current state of teams and their adoption of agile practices.

None of the literature analysis proposed approaches solves the demand. However, some of them are building-blocks for the development of a solution fitting the demand.

3 Methodology

3.1 General Objective and Basic Requirements

To ensure applicable outcomes an Action Research (AR) approach [17] is chosen. With the design and evaluation iterations which are observed the design and development team gets feedback for improvement. The design team terminates the iterative improvement at the point on which no significant improvement potential is identified by the feedback and observations. The design and development team of the approach for the evaluation kit – which can be used in the context of external evaluations and self-assessments – is formed by a diverse team of experts from quality management, agile coaching and software engineering.

Initially, an analysis was conducted which agile frameworks are mostly used respectively recommended by the organization. This information is useful to build an approach which is compatible with strategic and operational used agile frameworks and lever synergy effects were possible if the evaluation approach can directly use indicators produced by the agile frameworks. Another important factor is that the evaluation approach can be designed to use well-known wording for the self-assessment questionnaire and give helpful examples fitting to the instantiation. This fitting helps also to measure progress of the agile framework instantiation. The common wording helps to identify the relevant indicators more easy. However, the evaluation approach has to address also aspects beyond typical artifacts from the agile framework to have a chance to detect for example Scrum theater. So the indicators have to address mindset, methods and techniques. Furthermore, it is helpful to have the opportunity to evaluate only relevant respectively focused aspects and not everything of the evaluation approach to be more efficient and enable the teams to do the self-assessment during one or more retrospective time-slots.

The identified key aspects addressing RQ1 and are the requirements for further development of the self-assessment and evaluation approach.

3.2 Analysis of State-of-the-Art Approaches

Currently the most used agile frameworks are Scrum and SAFe® [18]. Furthermore, SAFe® uses Scrum on the team-level, too. As identified in [13] both frameworks have a weakness in systematic quality management on organizational level – to address this, also aspects for the efiS® are integrated to have a holistic enterprise view. Scrum does not offer any kind of systematic evaluation approach about the instantiation of Scrum or agile working in general. SAFe® offers with Measure and Grow a modularized assessment framework. The assessment approach is not elaborated like CMMi [19] or automotiveSPICE [20] but fits the wording of the SAFe® and mostly with Scrum, too. The missing part are the efiS® framework related indicators.

To avoid similar indicators coming from SAFe® and efiS® it is useful to analyze which evaluation aspects and indicators from the SAFe® assessment can be "re-used" with an efiS® framework view. This approach is chosen to respect that SAFe® is "more established" and first defines a questionnaire. However, only from an efiS® framework perspective the questions would be defined more focused to the efiS® objectives. But, each additional question is an overhead which should be avoided in lean thinking. Table 1 presents the identified questions from the SAFe® Measure and Grow assessment which are correlating with the efiS® framework. In the table the questions have as prefix the structure of the Measure and Growth questionnaire to have a traceability to the source. The questionnaire is based on the SAFe® v5.1 and v6 Measure and Growth version. This reduces the questionnaire set which has to be developed explicit for addressing efiS® framework related indicators.

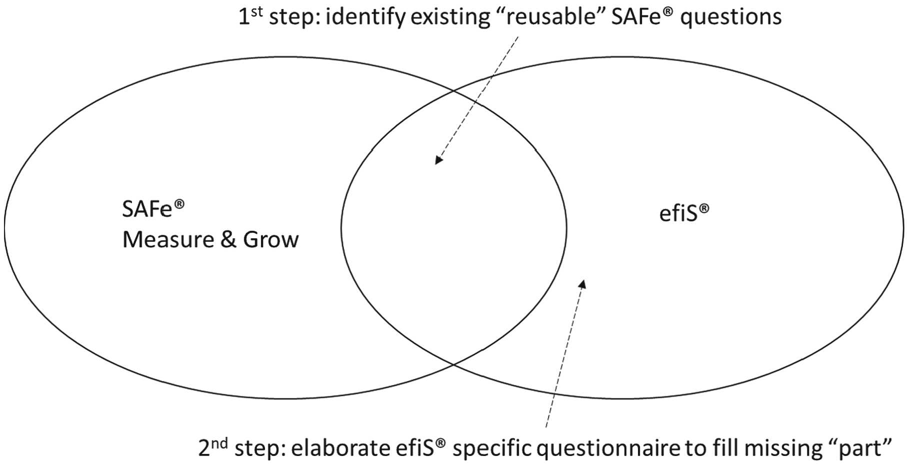

Fig. 1. Relation of the Measure & Grow questionnaire to the comprehensive questionnaire.

The described approach addresses RQ2 with the existing SAFe® Measure and Grow which is extended by the missing efiS® framework aspects (Fig. 1). The efiS® framework is based on four pillars. The Empower pillar addresses aspects of the value stream team development. It focus on capability and maturity improvement on the generic agile working level and on product and service specific technical level. The Focus pillar has a product and service scope. Many frameworks are focusing on chances and offer many approaches and methods for the elicitation and engineering of product and service requirements – on the other side the product and service specific risks are not explicit and systematic handled. The Focus pillar fills this gap by explicit and systematic risk ideation and handling within the value stream. The Integrate pillar addresses requirements of regulations and standards. The building blocks of the Integrate pillar facilitate the "selection" of relevant requirements and bring them into the value stream by mapping them to the adequate hand-over points to facilitate compliance with the requirements on team, program and organization level. The Scale pillar facilitate learning beyond an individual value stream team. It can be applied within a program or on organization level. These four pillars can applied to small teams, e.g, during a project setup phase or to large programs. With focus on empowerment and teamwork quality [21] a flywheel-effect is initiated by the four pillars of the efiS® framework: teams grow in their maturity and mastery, mastery leads to autonomy, autonomy leads to self-responsible decisions and actions, actions lead to insights, and insights lead to learnings that can be scaled and make other teams more mature.

Table 1. Lists all Measure and Grow questions related to the efiS® framework.

efiS pillar	Related Measure and Growth question
Empower	Team and Technical Agility – Agile Teams – Agile Teams: Teamwork - Our team is goal-oriented
	Team and Technical Agility – Agile Teams – Agile Teams: Teamwork - Our team operates in an environment of psychological safety
	Team and Technical Agility – Agile Teams – Agile Teams: Teamwork - Our team is empowered to make decisions on how best to do our work
	Team and Technical Agility – Agile Teams – Agile Teams: Teamwork - Our team has all the skills necessary to deliver our work
	Team and Technical Agility – Agile Teams – Agile Teams: Teamwork – Our team operates at a sustainable pace
	Team and Technical Agility – Agile Teams – Agile Teams: Teamwork – Our team addresses conflict in a constructive way
	Team and Technical Agility – Agile Teams – Agile Teams: Teamwork – Our team holds each other accountable for meeting our commitments
	Team and Technical Agility – Agile Teams – Agile Teams: Value Delivery – Our team understands how our work aligns to the strategy
	Team and Technical Agility – Agile Teams – Agile Teams: Value Delivery – All of our team's work comes through the Team Backlog
	Team and Technical Agility – Agile Teams – Agile Teams: Value Delivery – Our team delivers predictably on our commitments
	Team and Technical Agility – Agile Teams – Agile Teams: Value Delivery – Our team is responsive to change
	Team and Technical Agility – Agile Teams – Agile Teams: Learning and Improving – We continuously improve our ways of working as a team
	Team and Technical Agility – Agile Teams – Agile Teams: Learning and Improving – We support each other to develop T-shaped skills
	Team and Technical Agility – Agile Teams – Agile Teams: Learning and Improving – We incorporate feedback from both customers and stakeholders throughout development
	Team and Technical Agility – Agile Teams – Agile Teams: Learning and Improving – We continuously improve the flow of value
	Continuous Learning Culture – Learning Organization –Teams defer group and personal goals for the greater good of the organization
	Continuous Learning Culture – Innovation Culture – Leaders create an environment that supports creative thinking, curiosity, and challenging the status quo

(*continued*)

Table 1. (*continued*)

efiS pillar	Related Measure and Growth question
	Continuous Learning Culture – Innovation Culture – The organization promotes learning and exploration through experimentation without fear of failure
	Continuous Learning Culture – Relentless Improvement – Individuals and teams are given the time and resources to identify and solve problems
	Continuous Learning Culture – Relentless Improvement – Teams at every level of the organization pause regularly to reflect and improve
Focus	Team and Technical Agility – Built-in Quality – Built-in Quality: Quality Practices – Our team adheres to well-defined quality standards
	Team and Technical Agility – Built-in Quality – Built-in Quality: Customer Satisfaction – Our Solution(s) meet appropriate performance, security, and usability standards
	Enterprise Solution Delivery – Lean solution and systems engineering – Fixed-variable solution intent evolves system requirements, designs, and compliance data
	Continuous Learning Culture – Innovation Culture – The organization cultivates the courage and aptitude for innovation and encourages employee risk-taking
Integrate	Team and Technical Agility – Agile Teams – Agile Teams: Value Delivery – Our team has clearly defined acceptance criteria for our work
	Team and Technical Agility – Agile Teams – Agile Teams: Value Delivery – Our team delivers increments of value each Iteration
	Enterprise Solution Delivery – Lean solution and systems engineering – Compliance activities are performed in small batches and automated in the continuous delivery pipeline where possible
	Organizational Agility Self-Assessment – Lean Business Operations – Development and operational value streams are defined and understood
	Organizational Agility Self-Assessment – Lean Business Operations – Development teams understand the operational value streams they support
	Organizational Agility Self-Assessment – Lean Business Operations – Development teams apply customer-centricity with internal and external customers
	Organizational Agility Self-Assessment – Strategy Agility – Reorganizing around value creation is normal and fluid
	Continuous Learning Culture – Relentless Improvement – Improvements optimize the end-to-end flow of value
	Lean Portfolio Management – Agile Portfolio Operations: Foster Operational Excellence – We integrate compliance activities continuously throughout development

(*continued*)

Table 1. (*continued*)

efiS pillar	Related Measure and Growth question
Scale	Continuous Learning Cultur – Learning Organization – The organization invests in the growth of employees
	Continuous Learning Culture – Learning Organization – The organiza tion continuously creates, acquires, shares, and transfers knowledge
	Continuous Learning Culture – Learning Organization – The organization encourages employees to challenge the status quo
	Continuous Learning Culture – Learning Organization – The organiza tion empowers employees to gain knowledge and experience in multiple disciplines
	Continuous Learning Culture – Learning Organization – The organization invites employees to share in and contribute to a common view of the future
	Lean Portfolio Management – Agile Portfolio Operations: Foster Operational Excellence – We share improvements in how we work across the Portfolio

3.3 Gap Handling

Not addressed aspects of the efiS® framework within Measure and Grow are addressed by a new set of evaluation aspects. Objective is to keep the additional questionnaire as short as possible. Table 2 presents the extension.

Table 2. List of the dedicated efiS® framework indicators represented by questions.

efiS pillar	Additional question – not addressed by SAFe®
Empower	Team development is explicit oriented on the deliverables (products and services) to address needed technical skills and the ways of work to address the needed agile skills
	Team development is oriented on the specific skill and capability profile of the deliverables
	Team development is part of the improvement journey which is reflected cyclic to identify improvement potentials for the team maturity (and deliverables)
	Team development is seen as maturity indicator and used to grant autonomy based on the maturity profile
Focus	For risk-handling – especially for deliverables – a systematic approach is established for identification and mitigation of risks
	Risk-handling is part of the value stream flow
	Risk-handling is aligned with compliance (e.g. regulations) and the teams capabilities (respective their autonomy)
	Risk-handling is reflected cyclic to adjust it (e.g., to new insights or changes) when needed

(*continued*)

Table 2. (*continued*)

efiS pillar	Additional question – not addressed by SAFe®
Integrate	Value streams are mapped to hand-overs (or interfaces) to ensure clear responsibilities to each value stream stage
	Compliance requirements are systematically identified for the value stream
	Compliance requirements are assigned to value stream stages
	Compliance to identified requirements is evaluated cyclic and actions initiated when needed (ensure establishment)
	Market is observed respective evaluated cyclic about new compliance requirements (update/get new requirements respective adjust existing setup)
Scale	The organization especially management enables and fosters individuals to share their knowledge
	The organization facilitates a prosumer approach in involve everybody in the organizational learning/improvement journey
	The organization establishes a way to share learnings asynchrony, over teams, and value streams

The teams of products and services can apply the self-assessment questionnaire by selecting a subset or all questionnaires. A subset is useful for the case that specific potential areas have to be addressed or a fitting into a retrospective time-slot is needed. In retrospectives the relevant questions can be used sequential. This allows to start with the priority questionnaire and improve its main findings. Step by step the teams works based on the priority on the derived improvement actions.

To facilitate the work, the full questionnaire is offered as self-service. To support also remote work the entire questionnaire is available online via a survey tool. This helps to get a more comprehensive evaluation, too. Each person realizes a "private rating" of the questions to avoid influencing each other (often the first rating proposal attracts respectively provokes similar ratings – a typical team dynamics). This online-tool support opens the range of ratings and gives smart analysis charts to work with the results to identify the most relevant areas for improvement.

This implementation approach directly contributes to RQ3 because it facilitates to focus on usage scope and the organizational scope, too.

4 Evaluation

4.1 Environment

The Volkswagen Group IT is the research and evaluation environment. It is a large and distributed environment with a heterogenic portfolio of projects, programs and organizational units. The Agile Center of Excellence (ACE) and the Lean ACE (LACE) facilitates the transitions of the programs and is responsible for the agile alignment checks within the organization supported by other cross functional shared services such as IT quality with the Test and Quality Assurance (TQA) team. Different programs within a SAFe® instantiation initiative are analyzed with the new evaluation approach.

4.2 Instantiation

Some programs were selected by the LACE to conduct the evaluation. As some programs have more than 10 teams the chosen approach was that the teams have to perform a self-assessment first. Than the external LACE and QA team members analyzed the program and the team self-assessments with focus to identify "cross-check" aspects such as variation in ratings. After this pre-analysis some teams were selected by the appraisal team to make their evaluations with their team-external independent view. The evaluation rating was cross-validated with the self-assessment rating results. The appraisers focused on questions with a high variation within a team or over teams within a program to investigate why this divergent rating occurs. Figure 2 presents the generic process flow.

Fig. 2. Process of instantiation

Two reason for this variation were identified by the appraisers cross checks a) teams are different affected by some evaluation aspects and this lead to the different rating of the same question within one program b) the perception of teams and team-members differs – some are more self-critical than others. This shows that the self-assessment is useful for a relative improvement but the ratings of teams and programs only be compared after "normalization" by the objective appraiser team. However, also appraisals have variation [22], too. In the case of one organization the number of appraisers is limited and they can discuss rating "challenges" to ensure no divergent ratings depending on appraisers.

4.3 Cases

Early adopters were the selected SAFe pilot programs. Different version of application respectively instantiation were applied. One was the usage of a spreadsheet questionnaire. In this program there are only little deviations about the teams. Figures 3 and 4 shows the Business Agility Assessment results for the first instantiation step. The application of the questionnaire leads to a positive image of the team. As a team pressure the question-set is interpreted more positive.

The enhanced version was with the online-questionnaire which was rated "private". Each team member has to rate each question by its own impressions. Only after rating the result of other team members is visible. This avoids that the team rates aligned with the first (often positive) rating. With the enhanced version the variation of each question of the questionnaire within a team growths. High variation is an indicator that something is to improve – it should have similar focus than low rated questions in general.

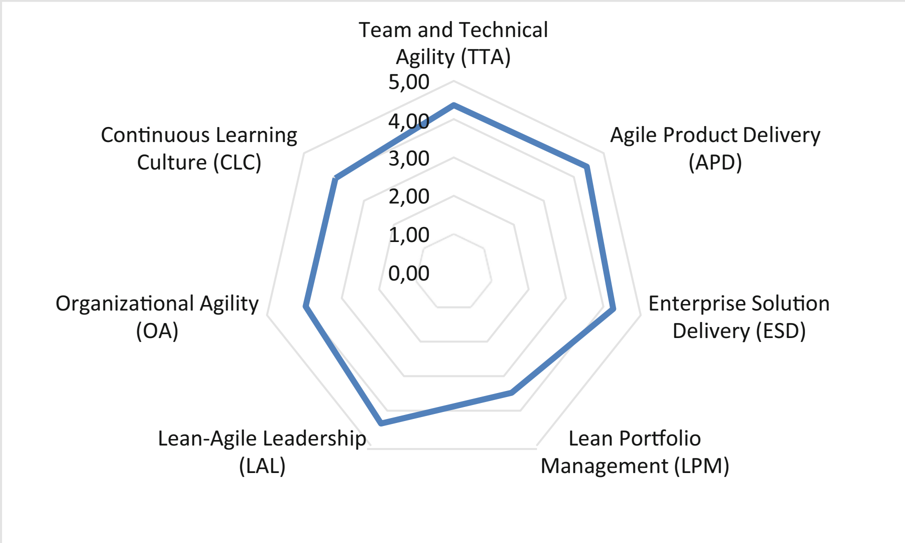

Fig. 3. Results of team A in program 1.

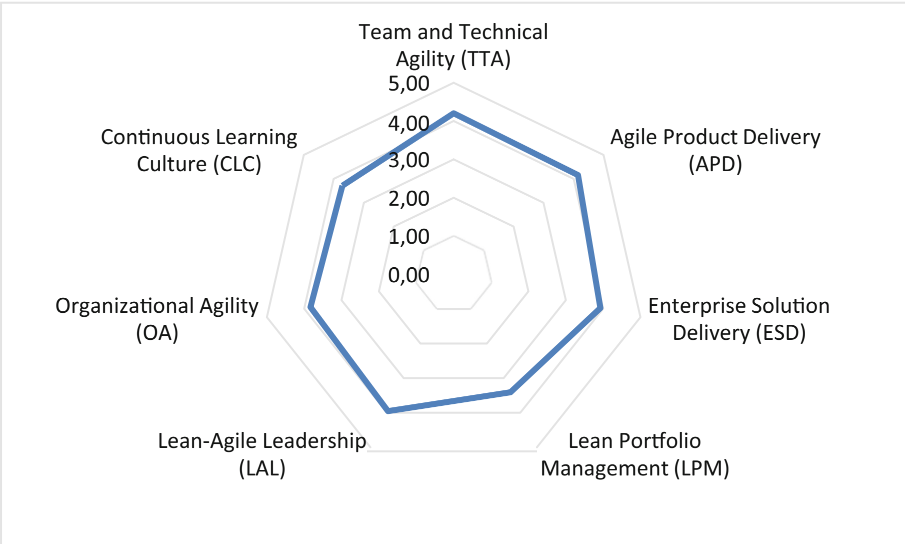

Fig. 4. Results of team B in program 1.

Both approaches are possible, but the personal rating in the online questionnaire is the preferred approach for future usage. This is motivated by the rating of each team member – no person is "hidden in the group". Also the variation gets transparent to the team and is usable for appraisals, too.

For the cross-validation also high variation over teams are interesting to identify what are the reasons for the different views in one program. Also the cross-validation is used to check the general rating attitude in a program – some large programs have their one culture which can have for example a trend to see things positive and leads to more positive ratings – as base to compare different programs

5 Communication and Rollout

5.1 General Communication Approach

For the communication within the LACE:Hub (orchestrates SAFe® instantiations) the approach was developed and applied with coaches of selected pilot SAFe® programs. The engaged coaches have the role to multiply the approach and especially set the "level" for the cross-validation checks to ensure high comparability between different programs. Furthermore, communication within the LACE was initiated to ensure that all coaches have the awareness about the importance of the objective of the developed and performed evaluation approach. As coaches are more facilitators than assessors the cross-validation is conducted in a teams with quality experts. This setup ensures that agile respectively SAFe® specific aspects are rated rigor over different evaluations to have a base to compare and derive trends.

5.2 Rollout

In addition to LACE:Hub communication the establishment is made by the Transition Roadmap mapping which defines dedicated points to conduct the self-assessments and the initial cross-validation to have at the end of an initial program transition a baseline to compare this result with future evaluations and ensure that all programs have the basic skills to perform continuous improvement based on the evaluation approach.

6 Discussion

6.1 Restrictions

A restriction is the dependency to the Measure and Growth approach of SAFe®. For the case, that in the future the questionnaire is adopted the efiS® framework related questions have to be checked and if needed to be adjusted, too. However, this is a design decision to explicit build on the Measure and Growth approach to minimize double work in the teams by handling similar questions. Also this approach makes transparent which areas are partly covered by SAFe® and which are not addressed. For example the version updated from SAFe® 5.1 to 6.0 did not triggered some adjustments because the Measure and Growth questionnaire is the same in both versions. This dependency also implies that some questions would be different to reduce a little the amount of questions if they only focus on efiS® related aspects. But, this restriction is accepted because the overall synergy effect is still high.

A limitation is that no long-term experience is available to measure especially the effects of the systematic evaluation and their derived improvement actions. Also the application was in one large IT organization which does not guarantee that the evaluation approach works in other enterprises, too.

Another restriction is that the proposed approach is only applied in teams which are using Scrum, SAFe® and efiS®. No results about other agile frameworks like Nexus are existing. Especially the mapping of the working to other agile frameworks could be become a relevant aspect to transfer the questionnaire into teams with other framework experience. No analysis about incompatibility with other agile frameworks is conducted. It exists a risk that some agile frameworks can have incompatible aspects. Also the evaluation of the synergy effects of reduced questionnaire size are missing.

Furthermore, the presented agile transition evaluation approach is not a tool to address all aspects of an agile transition. Especially the soft factors are only limited evaluated. But often the soft factors like are important for successful transitions on a long- term agile journey.

6.2 Contributions to Practice and Research

The presented questionnaire to evaluate the efiS® framework instantiation is based on two parts. One part levers synergy effects with Measure and Growth to reduce similar questions which have to be handled by the teams. The second part addresses missing aspects of the Measure and Growth approach which are not part of SAFe®. This work is a step towards a more legal obligation complete efiS® framework because it facilitates the obligation of the monitoring of delegated or instructed work of agile teams. With the two use cases of using the evaluation approach the high maturity of the team is fostered with the self-assessment and its improvement actions and by the team-external appraisal the monitoring obligation is addressed [23].

Contributions to research:

- Identification of relevant key design requirements for the evaluation of agile teams in their transition
- Proposal of an evaluation approach for large enterprises Contributions to practice:
- Evolvement of the existing agile review approach to a combined self-assessment and external appraisal as evaluation approach
- Facilitation of team and organization level status-quo with presented evaluation approach

7 Summary and Outlook

7.1 Summary

The presented evaluation approach can be used by the agile teams as a self-assessment and as appraisal initiated by the organization. The evaluation focus on the instantiation of agile working oriented on the SAFe® and efiS® framework. The self-assessment is facilitated by an online-questionnaire as part of a Self-Service Kit.

The proposed evaluation approach fosters systematic agile transitions with SAFe® and efiS® oriented team evaluations. This is realized by an extension of the existing Measure and Grow approach of SAFe® with the missing aspects from the efiS® framework to get a holistic view.

7.2 Outlook

Future research goes into direction of management of the different evaluation results to establish a systematic improvement within large organizations. This should help to allocate support of resources and expertise as part of facilitation.

Additionally, the long-term trend of the agile transitions of teams will be part of the research to identify further actions to facilitate their journeys.

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Identifying Agile Practices to Reduce Defects in Medical Device Software Development

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Abstract. Medical Device Software (MDS) defects have caused death of patients and continue to be the major cause of recalls of medical devices in the US and Europe. Despite various approaches proposed to address defects, dealing with defects in MDS is an increasingly difficult task as MDS has become more complex to support a growing number of functions. To increase quality in any software development project, it is essential that defects are identified and addressed quickly in the early stages of the software development life cycle. Agile methods have been advocated to increase software quality by minimising defects through their agile practices. However, agile methods on their own are deficient in satisfying the regulatory requirements for the MDS domain. Instead, the common approach is to integrate agile practices into the plan driven methods. Consequently, frameworks have been developed to help developers in the MDS domain to accrue the benefits of agile development while fulfilling regulatory requirements. Despite the adoption of agile practices in MDS development, it is still unclear as to which agile practice(s) is effective and how it is applied to address MDS defects. The purpose of this research is to identify agile practices that can assist in addressing defects in MDS development. This will help MDS developers to select the appropriate agile practice(s) to address defects.

Keywords: Medical Device Software · Agile Practices · Medical Device Software Defects · Software Faults · Medical Device Recalls

1 Introduction

In the medical domain, software is used to diagnose illness and assist health personnel to perform numerous activities related to patient health. Software used in the medical domain and that performs its functions as a medical device is termed as Medical Device Software (MDS) [1, 2]. MDS allows medical devices to accomplish complex functionalities that would otherwise not be possible. For example, MDS allows medical devices to be utilized in diverse applications, such as regulating the amount of medication that patients receive, tracking patients' vital signs, and alerting caregivers about

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harmful drug incidences [3]. It is particularly vital that MDS must be of high quality and reliable as any software quality issues can have significant detrimental effects on a patient's recovery, health, and well-being [4]. The difficulty in developing reliable and safe MDS is evidenced in the recalls of numerous medical devices by the Food and Drug Administration (FDA) due to software defects [5]. Reliability mainly considers three characteristics: fault avoidance, fault removal, and fault tolerance [6]. It is very difficult to achieve reliable software considering that all software development techniques have limitations, and none can guarantee overall software reliability [7].

Delivering high quality software is a key element in MDS domain. However, some MDS is released with defects which only manifest when the software is used. There are many factors that can cause systems to fail including hardware failures, and software failures [8]. Software-related failures could be traced to different phases of the software development lifecycle.

The purpose of this research is to identify agile practices that could help to address defects in MDS development. We reviewed each of the agile practices individually to gather evidence of their use and potential to address defects in the General Software Domain (GSD). We reviewed studies in the MDS domain to identify which agile practices were used in MDS development, including those used to address defects.

The aim of this study is to help practitioners to select and apply the most suitable agile practice(s) to address defects in MDS development. The remainder of the paper is organized as follows, Sect. 2 covers the background and the state of the art to software defect identification, Sect. 3 covers agile practices used in MDS development and agile practices that could be used to address defects in MDS development, Sect. 4 covers future work and concludes the paper.

2 Background of Medical Device Software Development

2.1 Medical Device Software

In healthcare, the increase in diseases prevalence and shortage of caregivers has necessitated the drive for faster and more innovative technological solutions to save human life [9]. Advances in computing, networking, sensing and medical technology have led to the dramatic increase in diagnostic and therapeutic devices in healthcare [9]. However, the lack of proper integration and operation of these systems presented systematic inefficiencies in healthcare delivery [9]. Consequently, we have witnessed the rise in development and use of software that integrated these different healthcare systems and enabled them to interoperate. Most importantly, many medical devices are software-driven which has enabled them to perform sophisticated functions. Moreover, software used in healthcare can be recognized as a medical device on its own [10].

There are two types of MDS used in the medical domain: Software as a Medical Device (SaMD) also called standalone software, and Software in a Medical Device (SiMD) also known as embedded medical device software [11]. SaMD is "software intended to be used for medical functions that performs its objectives without being part of a hardware medical device" [1, 2]. On the other hand, SiMD describes a "traditional medical device that uses software to support its functionality" [11]. Moreover, the definition of SaMD by the FDA clearly specifies that "software running on a hardware medical device qualifies as SaMD only if it does not drive or control the medical device" [12].

2.2 Software-Related Medical Device Failures

Despite the availability of numerous standards related to MDS, there have been many recalls of medical devices and medical device failures due to software defects. In 2021, in the US, software issues remained the top cause of medical device failures accounting for 162 (19.4%) medical device recalls [13]. In the EU, software was the top cause of medical device recalls in quarter three and quarter four of 2021 and was the second top reason for all medical device recalls in 2021, accounting for 408 (19.8%) medical device recalls [14]. In 2017 software was the primary cause of medical device failures with "one in every three medical devices being recalled because of software faults" [15]. Analysis of FDA recall data from 1999 to 2010 identified that four out of every ten medical devices comprising software failed due to software defects [15] and from 2014 to 2016 there were 100 software-related recalls [16].

Similar studies [3, 5] also present types of software defects that occurred in medical devices such as control flow faults and omission faults. These and many other software defects could be traced back to the software development lifecycle. Finding and fixing defects quickly in the early stages of software development is less expensive than finding and fixing defects when the software is delivered [17].

2.3 Standards

MDS must be developed in accordance to national and international regulations [18]. Regulatory bodies ensure that medical products do not pose any harm to patients and healthcare personnel. Accordingly, MDS manufacturers must adhere to numerous regulatory standards to ensure their MDS is safe. Standards are set and enforced by government agencies such as the FDA in the US and the European Commission in the EU. In [19] a detailed background to numerous standards relevant to MDS development is provided. The authors provide valuable information about how different standards came into play and how they relate to ensure that MDS is safe. Among the many standards that are relevant to the MDS domain, IEC 62304:2006+A1:2015 Medical Device – Software Life Cycle Processes is of utmost significance to manufacturers as it provides an internationally recognized standard [20]. ISO 14971 Application of Risk Management to Medical Devices and ISO 13485 Medical Devices – Quality Management Systems – Requirements for Regulatory Purposes are also vital to the development of regulatory compliant MDS [19].

2.4 State-of-the-art for Software Defect Identification

Different techniques such as taxonomy-based testing exist to help manufacturers detect software defects at earlier phases of MDS development. However, many software manufacturers avoid using defect-based testing as it requires a detailed defect taxonomy that is costly to build and difficult to validate [21]. The Association for the Advancement of

Medical Instrumentation (AAMI) developed and published AAMI SW91-2018- Classification of Defects in Health Software in 2018 [21]. SW91 is a taxonomy that provides a common language for the classification of software defects that occur in health software [22].

While defect taxonomies such as SW91 help software manufacturers to know the type of defects that occur in software, they do not assist in removing the defects. Techniques are required to identify and remove the defects. We investigate which agile practices can help to detect and remove software defects in the early stages of the software development lifecycle as defects that slip through these phases are costly to find and fix after product delivery [17].

2.5 Agile Software Development

Agile Software Development (ASD) reduces the risk of developing low quality software by minimizing defects through lightweight methods that emphasise customer collaboration and responsiveness to change [23–27]. ASD shortens delivery time while meeting changing customer needs through fast feedback and flexibility to accommodate rapid changes to requirements [27]. There are many agile methodologies such as Scrum and eXtreme Programming (XP) [28, 29]. Each agile methodology has several practices. For example, Scrum includes sprint and sprint retrospective, while XP involves pair programming and refactoring [29]. Agile practices are used to ensure principles and values of an agile method are implemented [30].

Despite the quality benefit advocated when using agile methodologies, research reveals that using them on their own they are unable to satisfy the regulatory requirements for the development of MDS [27, 31, 32]. To meet regulatory requirements, MDS is typically developed in accordance with the V-Model [18, 33, 34]. However, the V-Model is based upon Royce's Waterfall model which is very rigid in terms of requirements [35]. To overcome this issue, MDS developers have integrated specific agile practices into the V-Model [36, 37]. Despite the integration of agile practices in MDS development projects, it is still unclear as to which agile practice(s) is effective and how they can be applied to address MDS defects.

3 Agile Practices for MDS Development

3.1 Identifying all Potentially Suitable Agile Practices

We reviewed several studies to gather agile practices from the commonly used agile methodologies as indicated in a recent report by Digital.ai Agility, (formerly VersionOne) [38]. A study by [29] provides an extensive review of several agile methodologies that are outlined in the report by digital.ai and discuss their practices. In [39] the authors discuss various agile methodologies and practices they use. These studies formed the foundation for our initial list of agile practices. We also reviewed papers such as [40] which identified 50 agile practices that are used in safety-critical software development and [41] which identified 18 agile practices which they called 'universal practices'. These and other studies such as [42] and [43] were some of the sources of an initial list of the agile practices which were further reviewed to obtain our final list of agile practices. We considered the impact that the agile practice may have on the requirements, modelling, coding, testing and release stages as defects most often arise during these stages [44]. Our final consolidated list of agile practices is presented in Table 1. It is important to note that while some of these practices precede the invention of agile methodologies, they are still incorporated as agile practices in guidance documents such as AAMI TIR45 [45].

3.2 Identifying Which Practices Have Been Used in the Development of MDS

We reviewed 53 papers from the MDS domain that reported using agile practices in MDS development. Of the 53 papers, 34 were relevant to our study as they clearly indicated the agile practices used. The number of studies that utilised the agile practices in the MDS domain are shown in Column 3 of Table 1. Due to size limitation, the data showing a list of all studies and all the agile practices a study utilised cannot be included in this paper. Nevertheless, the data can be provided upon request.

Our review of articles from the MDS domain showed that Scrum and XP were the primary sources of the adopted agile practices. We also observed that agile practices were generally adopted to reduce delivery time, development costs, and to flexibly accommodate changing customer requirements [36, 37, 46–50]. Although quality improvement is mentioned in some studies, it is not clearly related to defects. Moreover, any quality improvement is attributed to the general adoption of the agile practices utilised. One study reported a 78% reduction in field defects across businesses using the SAFe® framework [48]. However, it is unclear which specific agile practice reduced the defects, because not all projects may need to adopt all the agile practices of the SAFe® framework. It is crucial that developers select the appropriate agile practice(s) to address defects in MDS development. In this regard, we reviewed each of the agile practices in our consolidated list to uncover evidence of their use to address software defects in the GSD. The number of studies that discussed the practice in relation to defects are shown in Table 1 column 2.

As shown in Table 1, despite the high number of studies that used agile practices such as sprint, sprint planning meeting, sprint backlog, sprint review meeting, and retrospective in MDS development, to date there is no study that discusses using any of these practices to address software defects. The same appears for planning game and use case. This may mean that research into these practices in relation to software defects has not been conducted or published. It may also mean that these practices have no direct impact on coding and testing during software development. On the other hand, several studies used TDD, PP, unit testing, refactoring, and continuous integration for MDS development. A high number of studies also used these practices in the GSD to address defects. However, to date there is no study that discusses using any of these practices to specifically address defects in MDS development. The high number of studies that used these practices in the GSD may indicate that they have direct impact on design, coding, and testing in the software development process. Few studies discussed using daily stan-up meeting, user story, coding standards, onsite customer, collective ownership, integration testing, simple design, user acceptance testing (UAT), and small releases in relation to addressing defects. Our review did not find any study that discussed using model storming in relation to defects despite the literature indicating its potential to resolve requirements defects collaboratively and quickly through creation of models [51, 52]. Although few studies used code review in the MDS domain, it was used in several studies for defects in GSD.

Table 1. Number of articles where agile practices have been reported.

Agile practice	Defects in GSD	MDS	Defects in MDS
Test-Driven Development	38	14	0
Unit Testing	25	15	0
Refactoring	23	10	0
Code Review	19	2	0
Pair Programming	17	12	0
Continuous Integration	10	17	0
Collective Ownership	5	3	0
Coding Standards	5	5	0
Small Releases	4	2	0
Onsite Customer	3	6	0
User Acceptance Testing	3	5	0
Daily Stand-up Meeting	3	15	0
Behaviour Driven Development	3	0	0
Integration Testing	2	4	0
Product Backlog	2	17	0
User Story	2	17	0
Simple Design	1	4	0
Planning Game	0	2	0
Use Case	0	6	0
Sprint/Iteration	0	20	0
Sprint Planning Meeting	0	15	0
Sprint Backlog	0	11	0
Sprint Review Meeting	0	8	0
Retrospective	0	13	0
Model Storming	0	0	0

3.3 Agile Practices that Could be Used to Identify Defects

We conducted a review of each agile practice shown in Table 1 to identify evidence of their use to address defects. We used several search statements to find relevant studies in sources such as SpringerLink, IEEE Explore, ACM Library, IEEE Computer Society, ScienceDirect, and Google Scholar. The statements included interchangeable terms defect, fault, bug, error, flaw, failure, and anomaly. For example, for PP the following search statements with different alterations were used:

1. Pair programming and software defects/errors/faults/bugs/failures/flaws/anomalies
2. Using pair programming to detect/identify/reduce/remove software defects/errors/faults/bugs/failures/flaws/anomalies
3. Case study of using pair programming to detect/identify/reduce/remove software defects/errors/faults/bugs/failures/flaws/anomalies
4. Using pair programming to prevent software defects/errors/faults/bugs/failures/flaws/anomalies
5. Detecting/identifying software defects/errors/faults/bugs/failures/flaws/anomalies using pair programming

Abstract and conclusion sections of studies that contained any of these terms were read and those that discussed addressing them using agile practices were read thoroughly. Studies that did not discuss addressing any of the terms using agile practices were discounted. Column 2 in Table 1 shows number of studies on the effect of agile practices to reduce defects. Overall, the reviewed articles suggest that agile practices can reduce software defects when applied correctly. We present findings on PP as an example of our review process on the agile practices.

Pair Programming for Addressing Defects. PP involves two programmers (driver and navigator) working closely together on one computer, with the driver writing code and the navigator examining it to detect defects [53–56]. The navigator also thinks of alternatives, intervenes to supply necessary information, and considers strategic design implications to prevent or remove defects early, reducing costs [57–59].

We examined 105 papers and found 17 that discussed PP and software defects. The rest (88 studies) discussed a range of other perspectives regarding PP such as system complexity and programmer expertise [60], development effort [61, 62], knowledge transfer [59], productivity [63] etc. Table 2 summarises the 17 studies. The acronyms '*IND*', '*AC*', and '*IND & AC*' denote that the study used professional developers, students, or both as subjects, respectively.

Table 2. Overview of PP usage for defects.

Study type	Domain			Improvement	No improvement
	IND	*AC*	*IND & AC*		
case study	3	0	2	4	1
experiment	0	5	1	5	1
experience report	1	4	0	5	0
survey	1	0	0	1	0
Total	5	9	3	15	2

As shown in Table 2, 29% of the studies report results from industry, 53% from the academic domain, and 18% from both industry and academic domains. Fifteen of the 17 studies report improvement in using PP to reduce software defects. These include 29% studies from the industry domain of which 3 are case studies [64–66], one is an experience report [67], and one is a survey [68]. A study by [69] found that PP prevents defects and lowers the number of defects in software. They further state that the combination of TDD and designing in pairs effectively lowered the defects. In [65] the authors report lower defect rates for the parts of code where PP was used in comparison to other parts. They concluded that PP helps to reduce the introduction of new defects when existing code is modified. A study by [66] found that an increased amount of PP within tasks lowered the number of defects and reduced the introduction of new defects. In [67] a reduction in error rate that was "three orders of magnitude" than normal for the organisation was achieved after PP was used. A study by [68] found that the number of defects for PP teams was lower than for solo groups.

Four of the 17 studies are academic experiments. A study by [70] found that PP yielded 40% fewer defects than Fagan inspection. Fagan Inspection is a group review method that involves six steps: planning, overview, preparation, inspection, rework, and follow up to detect defects in development documents like specifications, designs, source code, etc., during the various stages of software development process [71]. In [72] a lower defect count for PP teams than solo programmers is reported. A study by [73] found that the defect densities of the PP groups were much lower than those of the traditional programming groups. A study by [74] found higher defect reduction rates during integration for PP team than during inspection for TSP team. Four other studies of the 17 are experience reports from academic domain. A study by [75] report fewer defects for PP groups as compared to second-best solo programmers. A study by [76] found that the defect densities of PP groups were much lower than those of the traditional programming groups. In [77] the defect density for PP group was much lower than for solo group. The authors concluded that PP was much effective in reducing defects than solo programming. A study by [58] reported that programs written by PP groups passed more automated tests, resulting in less defects as compared to solo groups. Two of the 17 studies report results from both industry and academic. One of these is an experiment by [78] who found that PP yielded 40% fewer defects than Fagan inspection. The other study was a case study by [79] who found that PP was beneficial in reducing defects.

Two of the 17 studies did not find significant difference in defect reduction between PP groups and solo groups. One of the two studies is an *IND & AC* case study that examined whether PP improves software quality in four projects [54]. The authors calculated relative defect density in two of the four projects where defects were properly recorded. Their results showed that in one of the projects the relative defect density between pair and solo programming were almost equal, 7.0 defects/KLOC and 6.9 defects/KLOC, respectively. However, a significant difference of 1.3 defects/KLOC for PP and 8.4 defects/KLOC for solo programming was noted in the other project. Thus, the authors could not conclude whether PP lowers the defect density as the results were conflicting. The other study examined PP in relation to thoroughness and defect finding effectiveness of test suites [80]. The result showed that PP did not have significant impact on thoroughness and defect detection effectiveness. However, the author attributed the result to the small size of the project in which branch coverage and mutation score indicator tend to be insignificant as development skill alone may be enough without requiring a second pair of eyes. Overall, the findings from the reviewed papers on PP appear to suggest that PP can help to address defects in software development if applied correctly. The findings also suggest that when a developer works with a partner, there is higher chance that defects can be detected early as there is always someone examining the code as it is being developed. In general, the positive effects of using PP for reducing defects far outweigh the few negative effects reported.

3.4 Agile Practices that Could Potentially Help to Address Defects in MDS Development

Our review of agile practices has revealed that certain agile practices have the potential to reduce defects in software development. Based on review findings, the impact on various development stages, and the fact that some of the reviewed practices have been adopted and used in MDS development, we recommend agile practices such as TDD, PP, unit testing, refactoring, code review, continuous integration, integration testing, UAT, user story and onsite customer, to help address defects in MDS development. Our recommendation for certain agile practices is also based on their ability to enhance quality as detailed in the literature [81]. Despite limited studies on certain agile practices, the information strongly indicates potential to reduce defects and ensure the right product is developed. For example, UAT was commonly used in studies investigating other agile practices such as PP and TDD because it assures customers that the developed system has the expected components and that they are fit for purpose [82, 83]. Similarly, user story helps define and understand software requirements correctly [84], enabling developers to build the right software product, avoiding costly defects later in the development life cycle [85]. We recommend applying UAT early in the development process rather than waiting until the final release. This provides early feedback to the development team, reducing time and rework costs by resolving the problems early before they become bigger [86]. Coding standards and code ownership reinforce other practices such as refactoring and PP, making maintenance easier and allowing all developers to modify the code. TDD, PP, continuous integration, unit testing, code review, onsite customer, and user story help identify and remove defects early in software development [87].

4 Future Work

As part of our future work, we plan to conduct extensive research through surveys, interviews, and focus groups with industry professionals to identify agile practices that are most effective in addressing defects. Based on the findings from this research and the work presented in this paper, we will develop a comprehensive framework. This framework will incorporate the most effective agile practices for addressing defects and will be aligned with the mapping of two industry standards: SW91 and IEC62304 MDS software development life cycle processes. Our goal is to help MDS developers detect and remove defects early in the development life cycle, thereby preventing costly rework when defects are discovered later during use. By implementing this framework, MDS manufacturers can reduce the risk of defects, avoiding reputation damage and economic loss.

5 Conclusion

In this study we investigated agile practices collected from the commonly used agile methods with the aim of identifying those that could help to address defects in MDS development. We reviewed articles from the MDS domain to identify practices used to develop MDS and if any were used to address defects. We found that agile practices are generally used in MDS development to reduce delivery time, development costs, and to flexibly accommodate changing customer requirements. We reviewed each agile practice individually and found that TDD, PP, refactoring, unit testing, integration testing, continuous integration, code review, onsite customer, user acceptance testing, coding standards, collective ownership, and BDD help to identify and remove defects in the GSD. However, no study has specifically discussed using any agile practice to address defects in MDS development.

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SPI and Standards and Safety and Security Norms

Challenges in Certification of ISO/IEC 15504 Level 2 for Software for Railway Control and Protection Systems

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Abstract. ASELSAN-UGES (Transportation, Security, Energy Automation and Healthcare Business Sector) design, develop and manufacture the systems and critical components necessary for creative custom solutions for railways and highways. As a leading company in power electronics, communication, control and information technologies, we enable our customer to reach their goals safely, quickly and economically. As a result; ASELSAN-UGES conducts process improvement project which referenced to ISO/IEC 15504 framework. As a pilot project; metro management systems with signalling and control technologies based on Communication Based Train Control (CBTC) was selected and a gap analysis was performed. Besides, lessons learned and further works to do was mentioned in order to define the roadmap to ISO/IEC 15504certification and earned values.

Keywords: Software Process Improvement · SPI · EN 50128

1 Introduction

Addressing software-related safety issues is an ever-growing need in the industry for several reasons; the most important of them is the increasing importance of software in safety-related systems. [1] Addressing the software process quality as a way to increase the confidence in the quality of the resulting software product has been a key issue for three decades. EN 50128 Standard specifies the process and technical requirements for the development of software for programmable electronic systems for use in railway control and protection applications. It is aimed at use in any area where there are safety implications. These systems can be implemented using dedicated microprocessors, programmable logic controllers, multiprocessor distributed systems, larger scale central processor systems or other architectures. EN 50128 Standard is applicable exclusively to software and the interaction between software and the system of which it is part. ASELSAN -UGES (Transportation, Security, Energy Automation and Healthcare Business Sector) provides innovative software intensive system solutions, software and services which was founded in 2015 under ASELSAN Inc. ASELSAN-UGES has certifications on different Quality Management Systems such as; ISO 9001:2015, ISO TS

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22163:2017, EN ISO 13485:2016. Company had started to make investment in development of fully automatic unmanned metro management systems with signalling and control technologies based on Communication Based Train Control (CBTC) Systems as an emerging market for local needs of the country. In order to give high reliable and safe products, company is needed to define prosses that are compliant to EN 50128: Railway applications - Communication, signalling and processing systems – Software for railway control and protection systems. [2] The CBTC System will have to be demonstrated as SIL4 according to CENELEC Standards (EN50128). An approach to solve this problem is based on the main assumption that security is a process-oriented activity. According to this approach, product quality can be achieved by means of process quality – process capability. Introduced in the paper, SPICE conformant information security process capability model is based on process capability modeling elaborated by world-wide software engineering community during the last 25 years, namely ISO/IEC 15504 that defines the capability dimension and the requirements for process definition and domain independent integrated model for enterprise-wide assessment and Enterprise SPICE improvement. [3] Our goal was to have ISO/IEC 15504 SPICE Level-2 certification. Our challenge was having this certification during ongoing safety critic (EN50128 SIL4) project with minimum extra effort. In order to achieve that challenge, a pilot project was selected and a gap analysis was performed with respect to ISO/IEC 15504–5 *An exemplar software life cycle process assessment model* [4].

The requirement is that the CBTC System will have SIL4 certification according to CENELEC Standards (EN50128). For this certification we have created safety related documents to achieve EN 50128 standard requirements. The documents that we have generated due to EN 50128 standard requirements is given at Table 1 EN 50128 Documents below.

Table 1. EN 50128 Documents

CENELEC Phase	Document Title
Software Planning	Software Quality Assurance Plan
	Software Quality Assurance Verification Report
	Software Configuration Management Plan
	Software Test Plan
	Software Verification Plan
	Software Validation Plan
Software Requirements	Software Requirements Specification -
	Overall Software Test Specification
	Software Requirements Verification Report
Software Architecture and Design	Software Architecture Specification

(*continued*)

Table 1. (*continued*)

CENELEC Phase	Document Title
	Software Design Specification
	Software Interface Specifications
	Software Integration Test Specification
	Software/Hardware Integration Test Specification
	Software Architecture and Design Verification Report
Software Component Design	Software Component Design Specification
	Software Component Test Specification
	Software Component Design Verification Report
Software Component Implementation and Testing	Software Source Code and Supporting Documentation
	Software Source Code Verification Report
	Software Component Test Report
Software Integration	Software Integration Test Report
	Software/Hardware Integration Test Report
	Software Integration Verification Report
Overall Software Testing/Final Validation	Overall Software Test Report
	Software Validation Report
	Tools Validation Report
	Release Note
Systems configured by application data/algorithms	Application Requirements Specification
	Application Preparation Plan
	Application Test Specification
	Application Architecture and Design
	Application Preparation Verification Report
	Application Test Report
	Source Code of Application Data/Algorithms
	Application Data/Algorithms Verification Report
Software Deployment	Software Release and Deployment Plan

(*continued*)

Table 1. (*continued*)

CENELEC Phase	Document Title
	Software Deployment Manual
	Release Notes
	Deployment Records
	Deployment Verification Report
Software Maintenance	Software Maintenance Plan
	Software Change Records
	Software Maintenance Records
	Software Maintenance Verification Report

At this point our pilot project was at certification phase by the authorization body. All the outputs were defined and completed. At that point it was a good time to find out how far we were from ISO/IEC 15504 SPICE Level-2 practices. So, we decided to

PD ISO/IEC TR 15504-7:2008
ISO/IEC TR 15504-7:2008(E)

Table A.1 - Exemplar Organizational Maturity Model

	ML	List of Processes	Minimum Set	Additional processes ID	Conditions (Required or Optional)
Basic Process Set	1	ENG.1 Requirements elicitation ENG.2 System requirements analysis ENG.3 System architectural design ENG.4 Software requirements analysis ENG.5 Software design ENG.6 Software construction ENG.7 Software integration ENG.8 Software testing ENG.9 System integration ENG.10 System testing ENG.11 Software installation ENG.12 Software and system maintenance SPL.2 Product Release	ENG.1 ENG.4 ENG.5 ENG.6 ENG.7 ENG.8 SPL.2	ENG.2 ENG.3 ENG.9 ENG.10	Required where development covers system issues and not exclusively software issues.
				ENG.11	Required where the Organization Unit is responsible for installing the software product in the customer environment.
				ENG.12	Required where the Organization Unit is responsible for ongoing maintenance and evolution of the software and/or system.
Extended Process Sets	2	SUP.1 Quality Assurance SUP.2 Verification SUP.3 Validation SUP.4 Joint Review SUP.7 Documentation SUP.8 Configuration Management SUP.9 Problem Resolution Management SUP.10 Change Request Management MAN.3 Project Management MAN.5 Risk Management ACQ.3 Contract Agreement ACQ.4 Supplier Monitoring ACQ.5 Customer Acceptance SPL.3 Product Acceptance Support	SUP.1 SUP.2 SUP.7 SUP.8 SUP.9 SUP.10 MAN.3 MAN.5	ACQ.3 ACQ.4 ACQ.5	Required where external or internal suppliers of product components, services or infrastructure are involved in the development projects.
				SUP.3	Required where confirmation of fitness for use of the work products is the responsibility of the Organization Unit.
				SUP.4	Optional where the work in the Organization Unit involves agreements with stakeholders.
				SPL.3	Optional where the work in the Organization Unit involves product acceptance support.
	3	RIN.1 Human Resource Management RIN.2 Training RIN.3 Knowledge Management RIN.4 Infrastructure PIM.1 Process Establishment PIM.2 Process Assessment PIM.3 Process Improvement MAN.2 Organization Management MAN.4 Quality Management MAN.6 Measurement SUP.5 Audit REU.1 Asset Management REU.2 Reuse Program Management REU.3 Domain Engineering	RIN.1 RIN.2 RIN.3 RIN.4 PIM.1 PIM.2 PIM.3 MAN.2 MAN.4 MAN.6 SUP.5	REU.1 REU.2 REU.3	Optional if the Organization Unit has a structured reuse program in force - the three processes are mutually reinforcing.
	4	QNT.1 Quantitative Performance Management			
	5	QNT.2 Quantitative Process Improvement			

Fig. 1. Exemplar Organization Maturity Model

perform GAP analysis due to SO/IEC 15504 SPICE Level-2 practices. We needed to cover minimum set of processes which were colored with yellow in the Fig. 1 Exemplar Organization Maturity Model shown below. We held this as a process improvement project to close these gaps.

2 SPI Case Description

In this section, SPI [5] case is described.

2.1 Case Overview

The purpose of process improvement is to continually improve our organization's effectiveness and efficiency through the processes that are used and maintained as aligned with the business needs.

As a result of successful implementation of the process improvement:

- commitment is established to provide resources to sustain improvement actions;
- issues arising from the organization's internal/external environment are identified as improvement
- opportunities are justified as reasons for change;
- analysis of the current status of the existing processes are performed by focusing on those processes from which improvement stimuli arise;
- improvement goals are identified and prioritized, and consequent changes to the process are defined and implemented;
- the effects of process implementation are monitored and confirmed against the defined improvement goals;
- knowledge gained from the improvements that are communicated within the organization; and considerations are given for using solutions elsewhere within the organization.

At this stage we were aware that: Process improvement should be strongly supported by leadership, communication and motivation throughout the whole organization. Improvement actions can only be carried out efficiently if the appropriate organizational culture – i.e. priorities, values and expectations – is acknowledged and addressed at all levels. Moreover, major problems found in processes often arise from organizational culture. Consequently, cultural issues should be one of the factors considered in prioritizing improvement actions.

2.2 Important Strategic Features

In this SPI case, the initiator in the quality department has been aware that the following three features are important:

- Feature A People/Training: ISO/IEC 15504 processes should be understood before implementation.
- Feature B Business: ISO/IEC 15504 level 2 is first step to evolve ISO/IEC 15504 level 3 implementation.

- Feature C: Focus on the implementation of ISO/IEC 15504 with EN 50128 project.

The following sections explain each feature.

Feature A: ISO/IEC 15504 processes should be understood before implementation.

Instead of making improvements at the organizational level in the transition to the ISO/IEC 15504 level 2 perspective, first we made an assessment with EN 50128 compliant Railway Project. Due to this assessment, we discover that largely part of practices fulfilled with EN 50128 standard requirements.

o Conducting training courses about EN 50128 and ISO/IEC 15504
o Performing assessment audits of EN 50128 compliant Railway Project
o Issues not met in ISO/IEC 15504 are discussed with Gap Analysis results

On-going education and training are essential for everyone. Education and training programmes are important in creating and maintaining an environment where process improvement can flourish. Training in process improvement concepts, specifically, will increase the organization's readiness for process improvement. Important concepts that should be covered include process and quality concepts, process improvement concepts, process management skills, tools and techniques for process improvement, cultural change skills and supporting skills.

Feature B: ISO/IEC 15504 level 2 is the first step to evolve ISO/IEC 15504 level 3 implementation.

When the initial awareness event was conducted through training courses, we also try to have knowledge about implementation of ISO/IEC 15504 level 3 practices to Transportation, Security, Energy Automation and Healthcare projects.

Feature C: Focus on to the implementation of ISO/IEC 15504 with EN 50128 compliant Railway Project.

Where alternative implementation strategies are feasible, they are evaluated and the most suitable one is selected. For instance, it may be possible to implement a given action either in small steps through piloting in a selected project, or throughout the whole organization at the same time, or somewhere between these two extremes. Among the factors to consider are costs, time scales, and risks. So, our first aim was to show the success story with EN 50128 compliant Railway Project.

3 SPI Manifesto Example Experience Story

3.1 Mapping from Strategic Feature to SPI Manifesto Principle

The three Strategic Features explained in the previous section aligned with the SPI Manifesto based on their relevance to the explanation section of the Principle. SPI Team identified the following three Principles with higher level of relevance (see Table 2) [3].

o Principle 1: Know the culture and focus on needs
o Principle 2: Motivate all people involved
o Principle 3: Do not lose focus

Table 2. Mapping between Strategic Feature and Manifesto

Manifesto Value	People		
Feature	Know the culture and focus on needs	Motivate all people involved	Do not lose focus
A. ISO/IEC 15504 processes should be understood before implementation	High	Medium	Low
B. ISO/IEC 15504 level 2 is first step to evolve ISO/IEC 15504 level 3 implementation	High	High	Low
C. Focus on to implement ISO/IEC 15504 with EN 50128 project	High	High	High

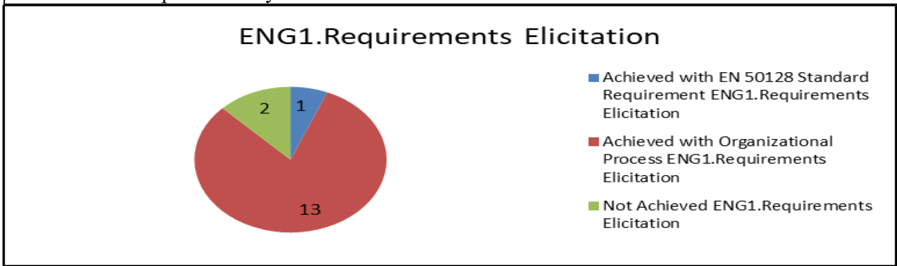
3.2 Manifesto Principle Example

Principle 1: Know the Culture and Focus on Needs

It is very important to ensure the alignment of processes and organization culture. The first step was to analyze its processes in order to learn about the project better. Then the team had to reveal the needs and focus on them. Therefore, it would be beneficial to us for analyzing processes and find gaps with ISO/IEC TS 15504–8:2012 practices.

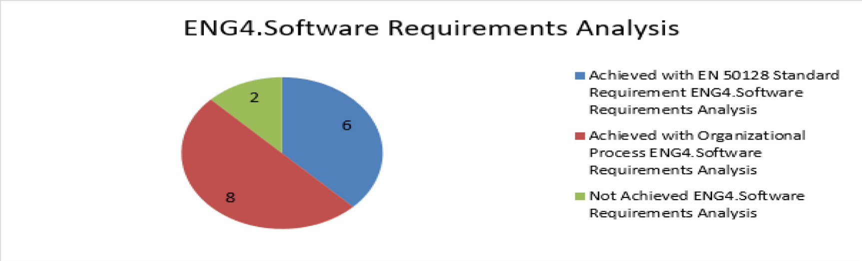
SPI Team and Pilot Project Team analyze each process in ISO/IEC TS 15504–5 Level 2 and define the needs as follows;

ENG1.Requirements Elicitation: The purpose of the Requirements elicitation process is to gather, process, and track evolving customer needs and requirements throughout the life of the product and/or service so as to establish a requirement baseline that serves as the basis for defining the needed work products. Requirements elicitation may be performed by the acquirer or the developer of the system.



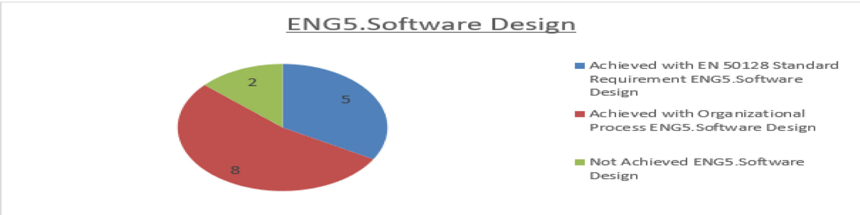
1. Objectives for the performance of the process was not identified.
2. Change control was not established for work products

ENG4.Software Requirements Analysis: The purpose of the Software requirements analysis process is to establish the requirements of the software elements of the system.



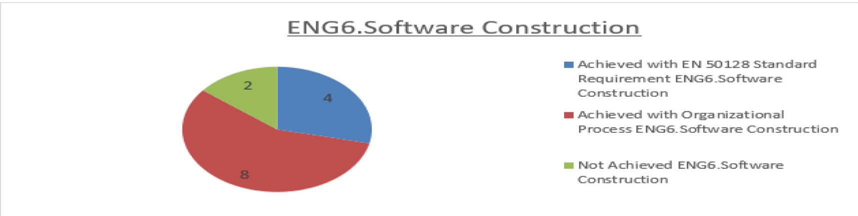
1. Objectives for the performance of the process was not identified.
2. Change control was not established for work products.

ENG5.Software Design: The purpose of the Software design process is to provide a design for the software that implement and can be verified against the requirements.



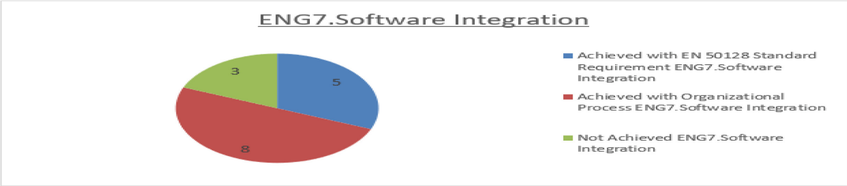
1. Objectives for the performance of the process was not identified.
2. Change control was not established for work products.

ENG6.Software Construction: The purpose of the Software construction process is to produce executable software units that properly reflect the software design.



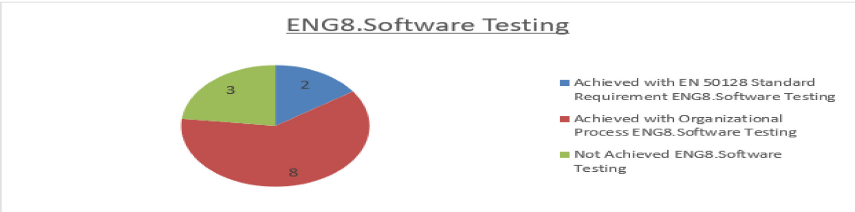
1. Objectives for the performance of the process was not identified.
2. Change control was not established for work products

ENG7.Software Integration: The purpose of the Software integration process is to combine the software units, producing integrated software items, consistent with the software design, that demonstrate that the functional and non-functional software requirements are satisfied on an equivalent or complete operational platform.



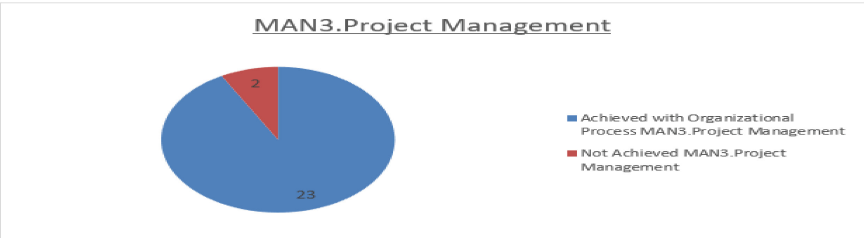
1. Regression test strategy was not defined.
2. Objectives for the performance of the process was not identified.
3. Change control was not established for work products.

ENG.8 Software Testing: The purpose of the Software testing process is to confirm that the integrated software product meets its defined requirements.



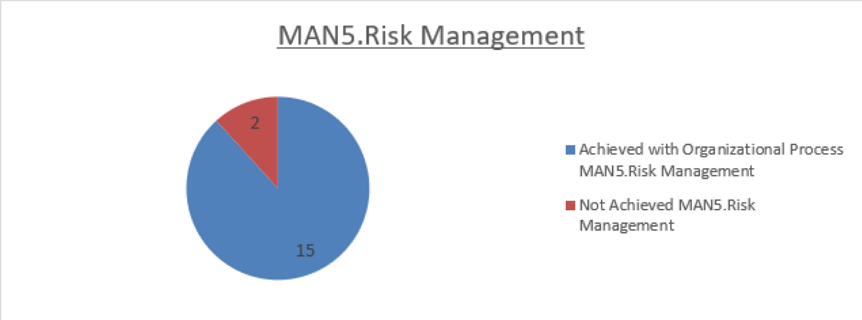
1. Regression test strategy was not defined.
2. Objectives for the performance of the process was not identified.
3. Change control was not established for work products.

MAN.3 Project management: The purpose of the Project management process is to identify, establish, co-ordinate, and monitor the activities, tasks, and resources necessary for a project to produce a product and/or service, in the context of the project's requirements and constraints.



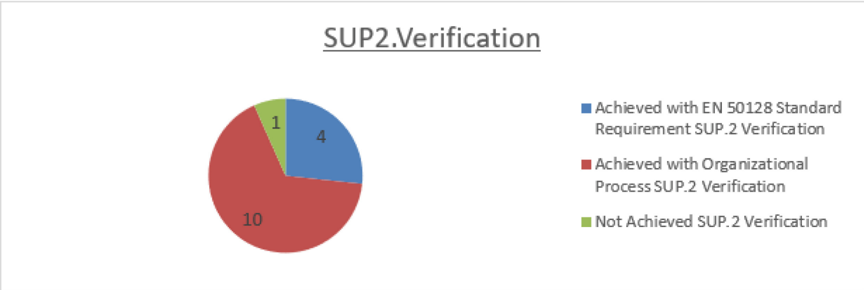
1. There was not any correction item for the deviations from the plan.
2. Project close-out review was not performed.

MAN.5 Risk management: The purpose of the Risk management process is to identify, analyse, treat and monitor the risks continuously.



1. Preventive or correction action was not taken when expected progress in risk mitigation is not achieved.
2. Objectives for the performance of the process was not identified.

SUP.2 Verification: The purpose of the Verification process is to confirm that each software work product and/or service of a process or project properly reflects the specified requirements

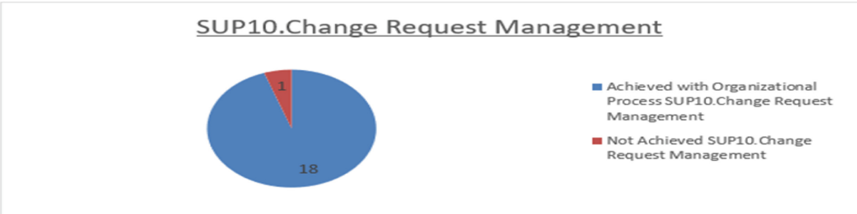


1. Objectives for the performance of the process was not identified.

SUP.7 Documentation: The purpose of the Documentation process is to develop and maintain the recorded information produced by a process.

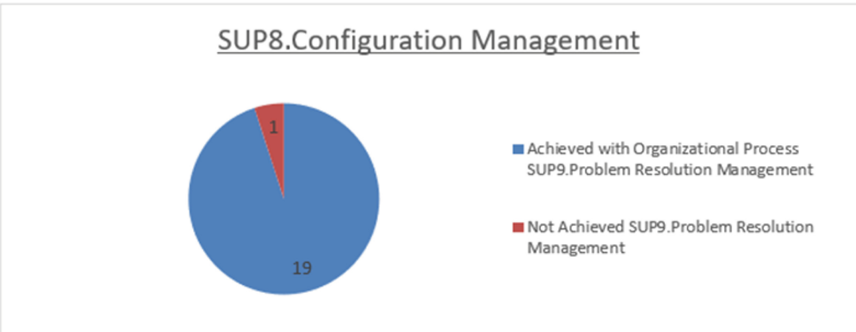
SUP1.Quality Assurance: The purpose of the Quality assurance process is to provide assurance that work products and processes comply with predefined provisions and plans.

SUP10.Change Request Management: The purpose of the Change request management process is to ensure that change requests are managed, tracked and controlled.

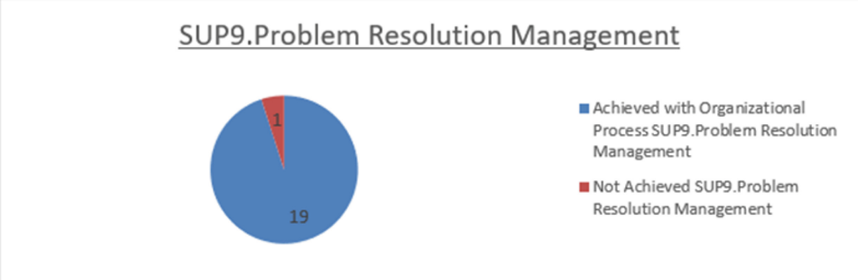


1. Objectives for the performance of the process was not identified.

SUP8.Configuration Management: The purpose of the Configuration management process is to establish and maintain the integrity of the work products/items of a process or project and make them available to concerned parties.



1. Objectives for the performance of the process was not identified.

SUP9.Problem Resolution Management: The purpose of the Problem resolution management process is to ensure that all discovered problems are identified, analyzed, managed and controlled to resolution.

1. Objectives for the performance of the process was not identified.

You can see ISO 15504 level 2 processes and EN 50128 document outputs mapping in Table 3 ISO 15504 level 2 processes and EN 50128 document outputs mapping.

Table 3. ISO 15504 level 2 processes and EN 50128 document outputs mapping

Process Name	Base Practice/Generic Practice	Artifact
ENG1.Requirements Elicitation	ENG1.BP5	Software Change Records Software Configuration Management Plan
ENG4.Software Requirements Analysis	ENG4.BP1	Software Requirements Specification Software Requirements Verification Report
ENG4.Software Requirements Analysis	ENG4.BP2	Software Requirements Specification
ENG4.Software Requirements Analysis	ENG4.BP3	Software Verification Plan Software Validation Plan Overall Software Test Specification
ENG4.Software Requirements Analysis	ENG4.BP4	Traceability between Software Requirements Specification and System Design Document
ENG4.Software Requirements Analysis	ENG4.BP5	Software Configuration Management Plan Software Change Records
ENG4.Software Requirements Analysis	ENG4.BP6	Software Quality Assurance Plan Software Verification Plan

(*continued*)

Table 3. (*continued*)

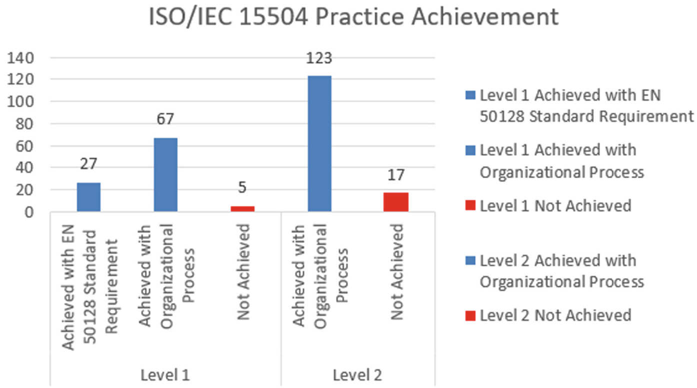
Process Name	Base Practice/Generic Practice	Artifact
ENG5.Software Design	ENG5.BP1	Software Architecture Specification
ENG5.Software Design	ENG5.BP2	Software Interface Specifications
ENG5.Software Design	ENG5.BP3	Software Design Specification Software Architecture and Design Verification Report
ENG5.Software Design	ENG5.BP4	Software Component Design Specification Software Component Test Specification traceability from requirement to code at Doors and SCADE Platform
ENG5.Software Design	ENG5.BP5	Software Design Specification Software Component Design Specification
ENG6.Software Construction	ENG6.BP1	Software Source Code and Supporting Documentation Software Component Design Specification Software Source Code Verification Report Software Component Test Report
ENG6.Software Construction	ENG6.BP2	Software Component Design Specification Software Source Code and Supporting Documentation
ENG6.Software Construction	ENG6.BP3	Software Requirements Specification and SCADE traceability
ENG6.Software Construction	ENG6.BP4	Software Component Test Report Software Integration Test Report Overall Software Test Report
ENG7.Software Integration	ENG7.BP1	Software Architecture Specification

(*continued*)

Table 3. (*continued*)

Process Name	Base Practice/Generic Practice	Artifact
ENG7.Software Integration	ENG7.BP2	Software Test Plan Sect. 3 Overall Software Test Specification Component Test Specification Software Integration Test Specification
ENG7.Software Integration	ENG7.BP3	Software Integration Test Specification Software Integration Test Report
ENG7.Software Integration	ENG7.BP4	Software Integration Test Report
ENG7.Software Integration	ENG7.BP5	Traceability between Software Requirements Specification and Software Design Document
ENG8.Software Testing	ENG8.BP1	Overall Software Test Specification
ENG8.Software Testing	ENG8.BP2	Overall Software Test Report
SUP.2 Verification	SUP2.BP2	Software Verification Plan
SUP.2 Verification	SUP2.BP3	Software Verification Plan
SUP.2 Verification	SUP2.BP4	Software Verification Plan
SUP.2 Verification	SUP2.BP5	Software Verification Plan

Due to the described analysis above, it became easier for the pilot project team to understand the current company culture. It showed us how The Team could reach the targeted ISO 15504 Level 2 with the current processes. At the beginning the team had thought that the changes and work to be done would be too much. However, after the gap analysis it was revealed by the team that only 22 practices of 239 practices had to be added to the pilot project.



This preliminary work made it easier for the team to understand the concept and understand the needs for this transition. We realized that our organizational processes and EN 50128 requirements almost covers ISO/IEC 15504 level 2 practices. We added these 22 practices in our pilot project in 3 months. At the end of 2022 we took our ISO/IEC 15504 level 2 certification for our pilot project.

In addition to process improvements, also organization needs improve about software integration, project management, risk management, measurement, regression testing and change management processes; these improvements must be held by process owners.

Principle 2: Motivate All People Involved
Since process improvement is a long and demanding work, it was very important to keep the motivation of the pilot project team high. For this reason, it was a great challenge for us to explain the importance of the pilot project, with this project UGES will be first ISO/IEC 15504 level 2 certified sector in ASELSAN.

Principle 3: Do not Lose Focus
At first, we define our targets, we prepared process improvement plan and stuck to the improvement plan. Our schedule to finish this certification was three months. After the definition of objectives, we defined appropriate measures, we followed these improvements with the same persistence as the daily business. We followed an established improvement program, even in difficult situations with respect to economics or resources, proved to the people that improvement was essential for the organization’s vision, business objectives and customer satisfaction. Our improvement measures aimed at changing human behavior. Our teams needed motivation to change and had to be aware that reluctance might lead to undesired consequences.

4 Future Directions and Discussions

In fact, this analysis has provided us a starting step for process improvement at the organizational level. As a result of the analysis, organization has revealed clearly the processes that need to be updated for ISO/IEC 15504 level 3 implementation.

The Next goal is to share the results of this new analysis with the senior management, get their support and move forward. The motivation will be evolving ISO/IEC 15504 level 3 implementation. We need to make the new GAP analysis are clearly understood for ISO/IEC 15504 Level 3 practices.

SPI is a continuous process; ASELSAN UGES is in the transition phase to use PLM tools. PLM (Product Lifecycle Management) tools will be a great opportunity to be used to support this process.

After the clear understanding of the Gap analysis, it will be more realistic to make effort estimation for this process implementation. Then the organization will make their application for ISO/IEC 15504 Level 3 certification.

5 Conclusions

When the SPI Team capture need for ISO/IEC 15504 Level 2, they acted proactively. In this study The Team started with GAP analysis. They figured out the missing ISO/IEC 15504 Level 2 practices. They injected these practices to our existing artifacts. Our organizational processes and EN 50128 practices almost cover ISO/IEC 15504 Level 2 practices. For Engineering Process Group (ENG), our gap was our measurement strategy, we measured our processes, but we did not measure our projects due to ISO/IEC 15504. We established measurement plans for each project and collected our measures due to these plans for our projects. And we did not have regression strategy, we added regression strategy to our testing plans. Change control was not established for work products, so we update our change management process due to ISO/IEC 15504 practices.

For Management Prosses Group (MAN), our gap was our measurement strategy, we measured our processes, but we did not measure our projects due to ISO/IEC 15504. We established measurement plans for each project and collected our measures due to these plans for our projects. Our second gap was taking preventive or correction actions for deviations from the plans. We initiated nonconformity records and found out the root causes of these nonconformities.

For Support Process Group (SUP), our gap was our measurement strategy, we measured our processes, but we did not measure our projects due to ISO/IEC 15504. We established measurement plans for each project and collected our measures due to these plans for our projects.

If an organization have organizational level processes and EN 50128 SIL4 project, it will take minimum three months to close these gaps.

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Automotive SPICE Draft PAM V4.0 in Action: BETA Assessment

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Abstract. After the revolution of new constraints like Cybersecurity in modern industries and high-tech fields, and the innovation of Artificial Intelligence and machine learning in the fields of Software Development in general, or the vast application of ChatGPT [1] in the automotive industry in specific, there was a urge towards the simplification of process models to cope with the change in projects nature and serve all purposes. Accordingly, VDA-QMC [2] has released a new simplified draft version of the Automotive SPICE PAM (version 4.0) [3] that encompasses many of these ideas, which is currently under review.

In this paper, we take the opportunity to demonstrate the results of a pilot assessment of this new version on a few mockup project samples, focusing on areas for improvements in hopes to enhance the final version expected June, 2023 into a more practical approach. The paper also urges the VDA to officially consider the results of this case study into the expected new version release of Automotive SPICE to ensure a more reliable and complete version.

Keywords: Automotive SPICE · Automotive SPICE PAM v3.1 · Automotive SPICE PAM v4.0 · Automotive Software · Machine Learning · ChatGPT · Cybersecurity · Improved Implementation of Process Models

1 Introduction

Automotive SPICE is a process model and reference standard that is widely used among automotive manufacturers all over the world. Many suppliers also use it as the means for process improvement or get it as a requirement from clients.

Expected in year 2023, the German Association for Automotive Industry "VDA" which holds the top car manufacturers worldwide as members to release a new version of the Automotive SPICE Process Assessment Model: PAM V4.0 to replace the current used one PAM V3.1 [4], which has been going through an expert review phase since year 2022 to complete the transition phase from the previous to the new version by year 2024.

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https://doi.org/10.1007/978-3-031-42310-9_7

Despite major acceptance and recognition in the automotive worldwide community, the A-SPICE (Automotive Software Process Improvement Capability Determination) model still faces some challenges and misconceptions that need to be addressed, and with the new emerging challenges every day in the industry, this need is further increasing. In this paper, a case study of the new A-SPICE PAM V4.0 of the standard is demonstrated, addressing some drawbacks that must be taken into consideration along with those challenges, to ensure coherence.

Key challenge is the growing interest and the involvement of Cybersecurity Constraints, Artificial Intelligence (AI) and Machine Learning in all aspects of modern industries. Last year, the VDA has already released an appendix to the Automotive SPICE PAM V3.1 to include Cybersecurity Requirements [5] as per the ISO21434 [6] specifically.

However, there was still no explicit reference to ISO26262 for Functional Safety [7], or to machine learning or deep learning models, not to mention many exclamations on how the Cybersecurity appendix would fit into an assessment schedule.

Lately the involvement of AI has been increasingly affecting the Automotive software development which caught the eye of the industry and the VDA to release the new Process Group in A-SPICE PAM v4.0 for Machine Learning Engineering Process Group (MLE). Not only using those technologies for developing innovative features in modern cars but also the use of such emerging tools like ChatGPT and Google BardAI [8] has gone unnoticed. ChatGPT was trained on vast amounts of code data and information from the Internet to help ChatGPT learn dialogue and achieve a human-like response style. ChatGPT was also trained with human feedback so that the AI learned what people expected when they asked a question that would actually play as a cornerstone in supporting Automotive software engineers with design and coding aspects. A question of how assessment process models - like Automotive SPICE - will handle this new development approach and whether the practices suggested by the MLE process group will be sufficient for this still needs to be further investigated that will be covered in the future recommendation section.

In the course of this paper, we will demonstrate the results of a case study on the version of A-SPICE PAM V4.0 while showing the key drawbacks we faced during a pilot assessment, along with a few proposals for potential improvements and lessons learnt that can be introduced to the new version PAM V4.0 to mitigate those risks.

1.1 Scope

This paper addresses the new draft version of the Automotive SPICE Process Assessment Model: PAM V4.0 to replace the current used one PAM V3.1.

The experimental assessment which was performed focused on the previously called "VDA Scope" process areas as implemented in a non-complex project with no Functional Safety, Cybersecurity, or Machine Learning scope constraints.

The assessment was performed on a selected sample of traditional development projects with distributed teams, specifically designed for the purpose of this experiment, considering the similarities and dependencies between the engineering process areas.

from different process groups, as well as the rating rules and recommendations currently available by the VDA guideline for A-SPICE.

The scope of the process capability assessment, and the process profile of it as agreed with the sponsors on the selected sample of projects is described in Table 1:

Table 1. Assessment scope - Targeted process areas

Assessment Inputs	In Scope Aspects	Out-of-Scope Aspects
Number of assessment projects	4	Machine Learning, AI, Cybersecurity, Functional Safety, Hardware, Agile Development, & Model-Based Development
Target Capability Level of SPICE	CL1	CL2/3
Assessed Process Attribute	PA1.1	PA2.1,PA2.2,PA3.1,PA3.2 & Above
Process Group	Management, Engineering (System, Software), & Support	Acquisition, Organizational, Process Improvement, Reuse, and Supply
Process Areas	VDA Scope: MAN.3, SYS.2–5, SWE.1–6, SUP.1, SUP.8–10	ACQ.2, ACQ.4, SEC.xx, MLE.xx, HW.xx
Characteristics	Class 3, Type C	–

1.2 Background and Approaches

As a result of the previously described challenges that were newly introduced in the Automotive Industry described in the introduction section, the German Association for Automotive Industry “VDA” QMC had become aware of such challenges, and started to introduce a new version of the Automotive SPICE Process Assessment Model: PAM V4.0 in a draft version that was introduced to the public during the “VDA Automotive SYS Conference” [9] of mid-2022, as a replacement for the current used PAM V3.1.

Furthermore, a new factor was introduced to the equation which is the “Automotive SPICE® [2] for Cybersecurity”, giving not only guidelines for technical implementation of such systems, but also a guide for The Process Model implementers and assessors to evaluate the development process of the Cybersecurity components (System or Software) versus the expectations of relevant standards (e.g.: ISO/SAE 21434).

The need to propose improvements to existing and newly launched versions of the Standard Process Model of A-SPICE (PAM, PRM, & Guideline) had been increased since then, as experts from various domains started to provide comparisons of the new model base practices and new terminology to other existing standard clauses provided from.

other technical references like the ISO/SAE 21434 as well as trials to tighten the gap between the standard process models and how it is practically implemented in the running projects. Moreover, not only that many experienced practitioners didn't have the chance to participate in the new PAM evolution, or even a chance for an introductory awareness session, but also couldn't submit their valid review comments and proposals into an official channel to be considered by the VDA Process Working Group no.13 [10].

Earlier this year, on Mar, 2023, A paper titled "Standardization of Cybersecurity Concepts in Automotive Process Models: An Assessment Tool Proposal" was published by Springer in the "Advances in Information and Communication Proceedings of the 2023 Future of Information and Communication Conference (FICC), Volume 2" [11] by Noha Moselhy, and Ahmed Adel Mahmoud to discuss in depth the adaptations that needed to be done to assessment approaches in order to cater for the release of A-SPICE for Cybersecurity appendix. The paper focused on the SEC process group in specific and didn't tackle the other updates on different process groups from the PAM V4.0 draft version.

As for efforts that have been made to keep up with emerging technologies, in August 2022 the paper titled "A-SPICE Applicability on New Automotive Technologies (AI)" was written by Erin Edwar, Samer Sameh and Ibrahim Sobh published in "Communications in Computer and Information Science book series (CCIS,volume 1646)" [12] to research how to apply mapping between AI Models and the A-SPICE Process Model.

On August 2021, and right after the VDA has released the official version of the Automotive SPICE appendix for Cybersecurity, Christian Schlager from Graz University published a paper titled: "The Cybersecurity Extension for A-SPICE - A View from A-SPICE Assessors" [13], which studied the relationship between the Cybersecurity process areas, and base practices from other process areas of the primary and management process groups in the A-SPICE standard. Back then, it was too tight for Mr. Schlager or anybody else to study or present any insights from applying the new model itself to come up with some challenges to reflect upon or some lessons learned to share.

On the same month, another paper was published by Springer in the EuroSPI conference titled "Impact of the New A-SPICE Appendix for Cybersecurity on the Implementation of ISO26262 for Functional Safety" [14] presented by Noha Moselhy and Yasser Aly which addressed the possible integration strategies of different standards and work products required by the A-SPICE for Cybersecurity and the ISO 26262 for Functional Safety to save time and effort of development projects.

All the aforementioned papers, however, did not address the improvements to be proposed on the new A-SPICE PAM V4.0 version expected yet to be released in 2023.

1.3 Motive

A major motive behind this paper [15], is that after the German Automotive Association "VDA" started to introduce a new version of the Automotive SPICE Process Assessment Model: PAM V4.0 in mid-2022, it included many changes that didn't only take place in the defined process model practices but in key concepts, terminology, the output work products, and most importantly, it was obvious that the deployment of these new changes will massively impact the assessment procedure itself, in terms of dependencies, and rating criteria of process attributes.

The culture and understanding that has been developed through years of implementing A-SPICE PAM V3.1 and all the used assessment tools and organizations' internal processes will need to be adapted as well – which will not happen automatically without trials, and pilots that will certainly result in incremental improvement and evolvement of this new PAM – refer to Fig. 1.

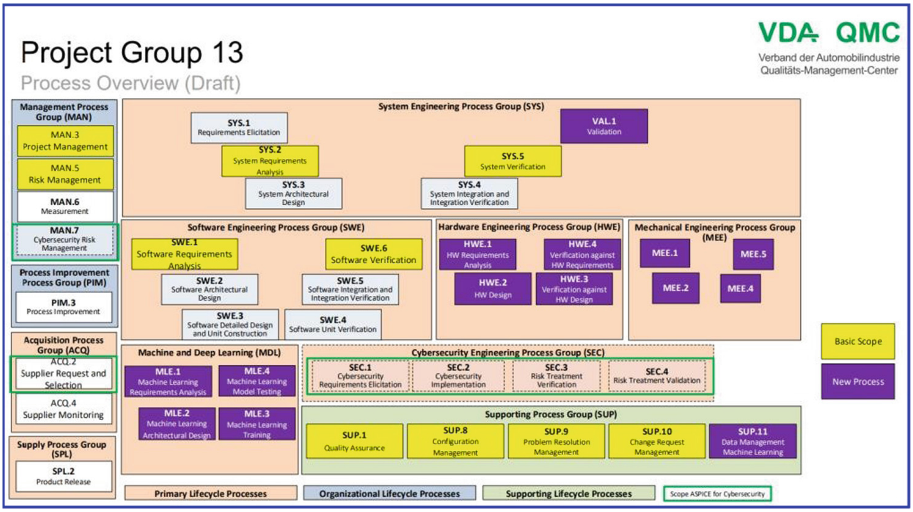

Fig. 1. Automotive SPICE PAM V4.0 Draft Process Reference Model – Overview

1.4 Relationship with the EUROSPI Manifesto

Based on the principle "Use dynamic and adaptable models as needed" from the European Software Process improvement (EURO SPI) Manifesto [16], which aims to drive organizations improvements for software development processes through applying a combination of process models. Also, based on the principal "Apply risk management" that enforces the organizations to consider and follow the risk-based thinking methodology which is aligned with the global direction of the IATF 16949–2016 requirements that were derived in line with ISO 9001–2015 requirements.

Accordingly, the following solution was suggested to improve the organization's ability to develop work products that are compliant with the new process assessment model draft version of A-SPICE for system and software development processes in the projects.

2 Case Study Methodology

A process capability assessment has been applied using the new draft PAM of A-SPICE V4.0 on a selected set of 4 traditional non-complex distributed development software projects with no Cybersecurity, functional safety, or machine learning constraints, followed by a case study to determine the impact of the new PAM concepts on the assessment methodology in terms of challenges.

The case study has been followed by a generated list of recommendations as a result of applying the new PAM concepts in the assessment of the traditional "VDA scope" as known previously until PAM V3.1, these recommendations aim to guide the model practitioners as well as the assessors on best practices during assessments, as well as potential improvements for the final version of the A-SPICE PAM V4.0 or further editions (Fig. 2).

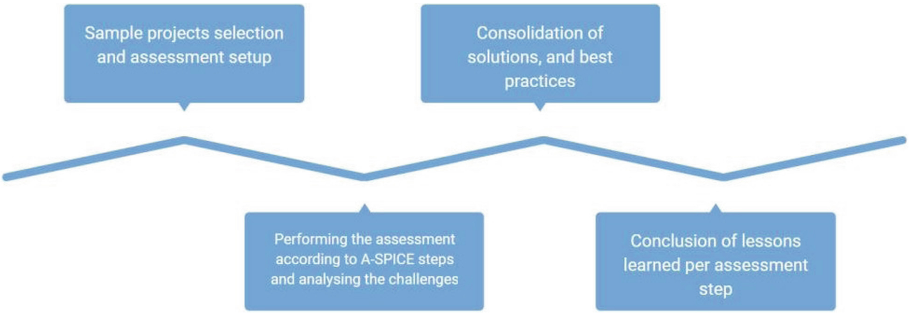

Fig. 2. The steps of this Case Study methodology followed in this paper.

Sample Selection: A specific set of sample projects were selected especially for the sake of performing a BETA trial assessment of the new draft A-SPICE process model PAM V4.0.

1) **The project set** consists of 4 projects from various platforms, and different product requirements. All of the selected projects have traditional system, & software development with limited technical complexity and potential target level of A-SPICE compliance, and no specific constraints on Cybersecurity, Functional Safety, Agile, or Machine Learning needs.
2) **The teams** working on these projects are familiar with Automotive SPICE process reference model requirements and have participated in earlier assessments with PAM3.1.
3) **The assessment team** is all of certified A-SPICE assessors and consists of 3 team members: 1 lead assessor, and 2 co-assessors.
4) **The assessment tool** has already been used in traditional assessment, and
5) **The assessment scope** has been defined as per Sect. 1.1.

Performing the Assessment and Analyzing the Challenges: In this step, the list of project work products (now called information items) are inspected and evaluated against Automotive SPICE PAM V4.0, via direct interviews with the project teams, objective evaluation of the evidence they demonstrated, and in accordance with the ISO/IEC15504 & ISO/IEC33002 requirements, and following the Automotive SPICE guidelines and steps for Assessments.

Recording the Observations, and Consolidating the Solutions: In this step, results and obtained data of the inspection from the previous step are consolidated. An investigation was carried out to determine the effective recommendations that were suggested during each of the assessment steps to tackle the challenges that were faced by the assessment team.

Conclusion: In this step a final recommendation is given via a list of lessons learned that were reached in each of the assessment steps based on application of the new proposed PAM V4.0 practices on the selected projects as suggested by the assessment team.

3 Case Study Observations and Results Consolidation:

A case study was conducted on a sample of 4 projects from different product lines selected specifically for the experiment of this research, where the new A- SPICE draft version of the PAM has been used for assessment.

The selected projects have a target to reach a specific capability level of Automotive SPICE – but for confidentiality reasons, these projects will only be referred anonymously within the course of this paper.

The case study aimed at recording the observations from 4 assessments of the 4 projects, focusing only on the common challenges, and recommendations that were encountered during the new process model application on the real operational environment of the 4 projects, and not on the rating results of the assessments. The case study cared to write the investigation of these challenges and recommendations in a simple and readable format for researchers.

3.1 Project A Observations, Findings, and Recommendations

ID	A.1	A.2
PAM4.0 update/ Observation	SYS.4, SWE.5 BP1 integration approach is not explicitly requested anymore	SWE.4: BP4 traceability is only required against verification measures not against the Detailed Design
Process Area	SYS.4 / SWE.5	SWE.4
Pros	1. Reduced Documentation 2. More flexibility for the integrator and software developers	Traceability between SW code and SW unit/ static test cases and results was ensured

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ID	A.1	A.2
Drawbacks	1. A non-predefined integration can lead to undesired integration approaches like big bang 2. Developing a simultaneous integration test strategy and test cases selection can also be impacted by the absence of an integration plan that explains the used approach 3. A mention of integration approaches exist in the IIC (Information Item Characteristic) section of the PAM, but was not considered by the team and could not be used as a rating indicator for any BP during the assessment without a guiding rule from the VDA	No guarantee of sufficient development verification in case of black box testing
Affected Indicator/ BPs	SYS.4 BP1, BP2, BP4 SWE.5 BP1,BP2, BP4	Could merely downrate BP.4 Consistency & Traceability, as the team argued that both the PAM practice description & the VDA guideline do not refer to Detailed Design

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ID	A.1	A.2
Assessment Finding	1. Following a big bang approach in the project lead to undefined root cause for detected integration issues, and extended debugging effort that was not planned 2. Unable to integrate some components due to a dependency between this component and another missed component (not developed yet & not clarified in the strategy) - referring to the need for an integration sequence in BP2 & BP4 of SYS.4/SWE.5 made the solution come in late phases of the project 3. Integration test strategy was not aligned with the followed integration approach	Skipped design updates were only discovered in the A-SPICE assessment due to focusing on the traceability of white box test cases to code only during development and not the traceability of black box test cases to detailed design
Recommendations	At least a clear note, rule, or recommendation to a have systematic integration approach predefined specially for the mentioned cases in the examples section	Rework SWE.4 BP4 to include explicit description/ note that mandate tracking of some verification measures (e.g.: in case of black box testing) to the detailed design to ensure coverage via Traceability

3.2 Project B Observations, Findings, and Recommendations.

ID	B.1	B.2
PAM4.0 update/ Observation	SYS3: BP2 SW characteristics are no longer mandated	Discrepancy between SUP.1 vs. SYS.4/5, SWE.4/5/6: SUP.1 still has targets and objectives, while none is required for testing with no rationale!
Process Area	SYS.3	SYS.4/ SYS.5 SWE.4/ SWE.5/ SWE.6

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ID	B.1	B.2
Pros	Divide the responsibilities of defining the architecture elements characteristics between departments	1. Time consumed in the assessment in the sessions of the rising edge process areas of the V-Cycle was minimized 2. Simplified the effort needed from testing teams
Drawbacks	1. SYS.3 BP2 Many High-Level characteristics of the overall software need to be defined at System level first (e.g.: response time) 2. Many High-Level characteristics of the overall software were left to be defined at SWE.2 Level only according to the Software architect experience and proposal with no direct consideration or traceability to the overall system behavior or Customer expectations	1. No expected targets from testing activities at CL1 2. High risk in managing the interface with outsourced testing teams for CL1 3. VAL.1 process area does not mitigate for these risks
Affected Indicator/ BPs	None! In case of missing SW characteristics essential inputs at system level, the SYS3: BP2 cannot be downrated as it has no direct link to the SW topic!	None! Can't be SYS.4/5, SWE.4/5/6 > > BP1! Because it no longer refers to the testing strategy As VDA PWG.13 and PAM4.0 terminology section,
		defines the term "measure" to be "used for an activity to achieve a certain intent" - so it can't be a target objective

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ID	B.1	B.2
Assessment Finding	1. The interoperability of the Software for the Application Layer with external interfaces of other ECU's at vehicle level was not considered neither at SYS.3 nor at SWE.2 levels, but rather only interfaces of the overall Software architecture of the project ECU were taken into consideration 2. Lack of allocation of requirements to Software elements didn't help the situation as well, to be discovered at assessment phase only (refer to point #h)	1. A variant with 0 passing test cases in SWE.6 could still qualify for delivery 2. 2 Features with Blocking test cases could still make it to SOP candidate release 3. Outsourced testing team for SWE.4 did not commit on requirements coverage by Unit Test at CL1
Recommendations	Update SYS.3 BP2 notes to include the need to define Special high level Software characteristics at system level just like Hardware and Mechanical are mentioned	Add a SYS.4/5, SWE.4/5/6 RL.xx in the VDA guideline to "elaborate" that each verification measure should have a target that matches the project objectives

3.3 Project C Observations, Findings, AND Recommendations

ID	C.1c	C.2f	~~g~~C.3
PAM4.0 update/ Observation	Impact of lack of strategies on the problem resolution and change management process areas (SUP.9 & SUP.10)	SUP.8: BP1 where to define Naming conventions, Versioning mechanism, Baseline Criteria, and how tools exchange info…	SWE.1 refers to SYS.3 for HSI responsibility definition, which in turn mentions nothing about HSI!
Process Area	SUP.9/ SUP.10	SUP.8	SYS.2/ SWE.1

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ID	C.1c	C.2f	gC.3
Pros	Reduce documentation in order to achieve CL1	1. Time for A-SPICE assessment	Theoretically, HSI is no longer the responsibility of Software team, and should be defined ahead by system architect
		SUP.8 session was reduced by 1/3	
		2. Configuration Manager of Project B could dedicate his time to release and baseline audits	
Drawbacks	1. Identification of problems priorities and severity criteria will not be clear for project team	1. Risk of mixed versions and duplicate file names arises	The responsibility of creating HSI will be lost, and shall lead to creating this document late which will impact software architecture, writing constraints for SWE.1 and integration testing
	2. Identification of urgent resolution strategy is not clear	2. Aspects like criteria of development baselines vs. criteria of deployment baselines or how to make a baseline set for the delivery between all artifacts from different tools couldn't be guaranteed	
	3. RACI and CCB or Fast tracking for a change request is not defined		
	4. 08–27 Problem management plan is not mentioned anywhere in the PAM		

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ID	C.1c	C.2f	~~g~~C.3
Affected Indicator/ BPs	None!	None at CL1	Confusion between assessment team members whether to
			downrate SWE.1 BP1 or SYS.3 BP3 as SWE.1 NOTES refer to SYS.3, but SYS.3 BP's say nothing about HSI
Assessment Finding	1. 2 Blocking issues from system and software verification testing were not given a high priority for resolution before delivery!	1. 2 sub-teams used different versioning mechanisms/ steps which have caused confusion to the SW integrator at merging sub-development branches for Release X	1. Missing constraints at software requirements level due to lateness of HSI
	2. In some cases the problem severities and priorities were misleading for the development team, or not agreed by all	2. One customer baseline was marked as internal development with difficulty distinguishing the Customer delivery package	2. Interfaces between hardware and software are not well defined
	3. Urgent resolution path was not clear for the team members	3. Retrospective manual effort by the project manager to map delivery artifacts from different tools with different baseline types & version increments	/tested at system level, each team though it was the others' responsibility
Recommendations	Refer to 08–27 problem management plan as process output for CL1 with all the needed characteristics	1. Add new NOTES to BP.1 & BP.3 of SUP.8 to clarify the aforementioned aspects	1. Refer clearly to the responsibility of creating HSI in System architecture SYS.3 BP1 NOTES

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ID	C.1c	C.2f	~~g~~C.3
	Have a rule to at least identify the RACI and CCB fo SUP.10	2. Update the IIC for Configuration Items to include the need to define naming conventions and versioning mechanisms for each item	2. Add a recommendation the time/ phase at which HIS shall be ready (before starting with software requirements elicitation)

3.4 Project D Observations, Findings, and Recommendations

ID	D.1~~h~~
PAM4.0 update/Observations	Allocation of requirements to architecture elements has been eliminated
Process Area	SYS.3 SWE.2
Pros	Allocation is mentioned in the ML Process areas' BPs and process outcomes as well as the IIC 04–04 Information characteristics for software architecture
Drawbacks	1. The implicit referral to the Allocation of system and software requirements to system/software architecture elements does not ensure that system/software architecture elements are satisfying the allocated requirements
	2. During the practice of determining the needed system/software elements allocation will act as the base for ensuring no missing/extra elements or components are derived without a proper justification since traceability is most probably done at the end in practice
	3. Allocation of system/software constraints in the level of system/software requirements will ensure that those constraints are adhered to by all of the required elements
	4. In case there are more granular requirements that can be considered as detailed design requirements that can be allocated directly to the proper component, the allocation will support in identifying the breakdown level of those requirements on design levels, therefore supporting the traceability and consistency checks between requirements and proper design levels
	5. The allocation concept and practice still exists in the ML Process areas' outcomes and BPs and information
	item 04–04 Software Architecture

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ID	D.1ħ
Affected Indicator/ BPs	None!
Assessment Finding	1. 386 requirements from Variant X System Requirements were not allocated to system architecture elements
	2. 5 Software design constraints were not allocated to any components and hence were missed from consideration in implementation at SWE.3 level
Recommendations	1. Addition of a separate BP for allocation in SYS.3/SWE.2 for allocating system/Software requirements to System/Software architecture elements or Components
	2. Adding the allocation as a note in SYS.3/SYS2 BP1 (Specify architecture design)
	3. Add a VDA guideline rule that BP rating depends on the completion of relevant IIC's

4 Study Results and Final Conclusion

From the case study of the conducted assessment there are some examples mentioned which show that when considering the new updates from A-SPICE PAM V4.0, results of the assessment rating, as well as the project compliance overall capability level were impacted by these updates.

The project assessment team was able to detect some gaps in the draft A-SPICE PAM V4.0 which impacted directly and indirectly the rating of the base practices of multiple process areas, in some cases there was a severe finding however we were not able to downgrade any base practice accordingly. In some other cases there was a missing work product which wasn't referenced at any process.

The gaps collected were mapped to actual examples from the conducted assessment, aiming at drawing attention to potential risks from releasing this PAM version without further reviews.

These examples are listed in detail and there are some recommendations and lessons learned for both A-SPICE PAM V4.0 and the new V2.0 of VDA guideline, which were shared as draft versions by the VDA-QMC only in Jun-23.

The enhancements in the A-SPICE PAM V4.0 in terms of simplification and consideration of new market technologies are obvious especially in the assessment efficiency and that was also detected in the sampled assessment, however it also caused some inconsistency and confusion for the assessors when it came to benchmarking generic conceptions in the PAM, and could not found them compatible across all process groups.

These gaps mentioned can be easily fixed in the new final versions of the PAM.

4.0 & the VDA guideline 2.0 to be released Q2–2024, or by adding some notes to the base practices to reference a mandated work product (information item) or to mandate a referral to another work product that was not previously in the scope of that process area. Sometimes the solution would be easier if we added the necessary rules and dependencies in the VDA guideline between different process indicators, or if we referred to the correct IIC's from the relevant BP's.

Updating A-SPICE standard is always the way to keep the standard alive and effective in the fast growing automotive industry, but putting these updates into practice and putting it under test is very important as well to make sure that both the projects and the assessors have less challenges applying it, and move it from just the theory to real-life application.

5 Recommendations for Future Work

In this paper, we share our experience of applying the new Automotive SPICE® PAM V4.0 inside simulation of real assessments.

The case study introduces improvement ideas and extra guidance of lessons learned, and proposals on how to enhance the implementation of the new PAM V4.0 and also the VDA guideline V2.0.

This leads to the following conclusion:

1. Automotive SPICE process assessments rating/ efficiency, and the achieved capability levels, are impacted by the new Automotive SPICE® PAM V4.0.
2. It is also recommended to do the same practice with the new version of VDA Guideline V2.0 and also for the processes which were not covered by this assessment "for example machine learning and hardware".
3. As a future expansion of this research, we strongly believe that AI should take a place in Automotive SPICE® and be introduced as a new process group, or at least enhance the MLE practices to include ideas that fit for deep learning concepts.

We believe these experiences and suggestions need to be shared with the VDA- QMC WG.13 and Automotive SPICE® community to push forward on having a more robust and consistent PAM and guideline editions before the final release.

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Automotive Functional Safety Standardization Status and Outlook in China

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Abstract. The automotive industry is facing rapid changes with regards to the electrification, intelligence and connectivity. These changes are transforming to more and more complex hardware and software of the electronic system in the vehicle. In China, the autonomous driving cars are even starting to move towards to the state of open road testing and commercial demonstration operation, therefore, it is crucial to include functional safety into all stages of the lifecycle of modern cars to provide an appropriate protection level. This paper provides an overview about the functional safety related national standards and regulations in China. It shows the connections and dependencies and the actual status of the publications.

Keywords: ISO 26262 · GB/T 34590 · GB/Z 42285 · GB/T 39086 · GB/T 39901 · GB/T 39232 · GB 21670 · GB 17675

1 Introduction

Since the release of the automotive functional safety standard ISO 26262 [9] in 2011, China's automotive electronics has experienced rapid development for more than 10 years, on the one hand, from combustion vehicles to hybrid and electric vehicles, on the other hand, from functional vehicles to intelligent vehicles, and finally these two lines intersected together, namely today's intelligent electric vehicles. According to the data released by China Association of Automobile Manufacturers (CAAM) on January 12, 2023, China's auto production and sales figures in 2022 were 27.021 million and 26.864 million respectively, and China's total auto production and sales have ranked NO.1 in the world for 14 consecutive years, new energy vehicle production and sales have ranked NO.1 in the world for eight consecutive years, and the passenger car market has exceeded 20 million units for eight consecutive years. China has become the world's largest automobile consumer market.

At the same time, the quality problems exposed in automotive electronics are receiving increasing attention from OEMs and regulators. Data released through the State Administration of Market Supervision and Administration shows that by the end of 2021, a total of 2,423 domestic recalls of automotive products have been implemented in China, involving 91.3 million defective products. From the distribution of recalled

M. Yilmaz et al. (Eds.): EuroSPI 2023, CCIS 1891, pp. 113–124, 2023.
https://doi.org/10.1007/978-3-031-42310-9_8

components, recalls due to defective engines and electronic and electrical components accounted for 84% of the total number.

With the transformation of the automotive industry from traditional combustion vehicles to electric vehicles and smart vehicles, and the growing of China's automotive consumer market, research on functional safety standard and other safety-related standards have risen to the national strategic level in China. Since 2016 to 2022, National Development and Reform Commission of China, Ministry of Industry and Information Technology and other national administrations have released a series of quality improvement and development plans for the automotive industry[5–8]. Furthermore, the importance of functional safety, SOTIF, and cyber security has been highlighted in the consultation drafts focusing on intelligent connected vehicle production enterprises and product homologation management guidelines at 2021. The history of strategic planning for functional safety related standards and technologies in China can be found in Fig. 1.

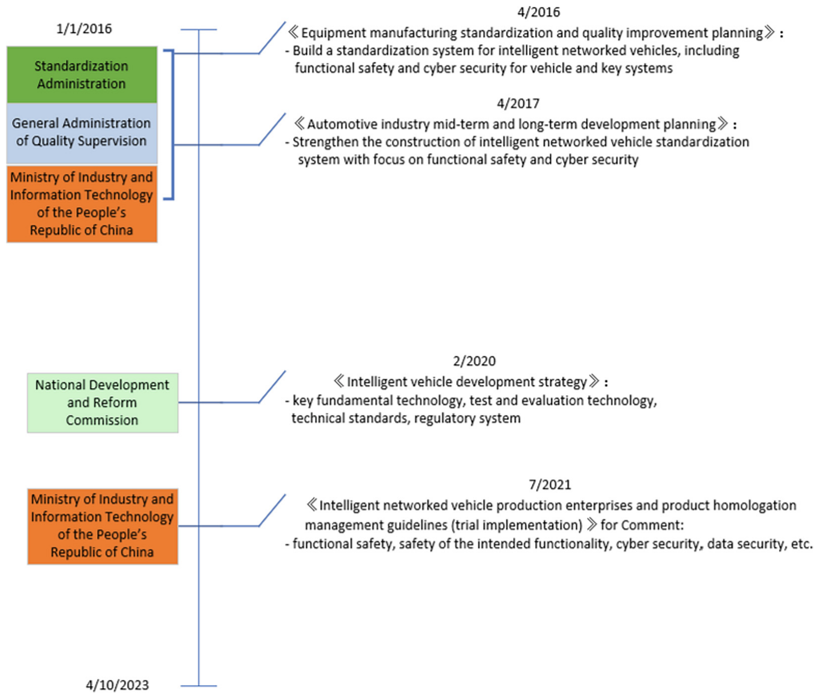


Fig. 1. History of strategic planning for functional safety related standards and technologies in China

This increasing demand for the functional safety and other safety technologies was acknowledged by the regulation authorities and standardization organizations. Therefore, new regulations and standards were released recently, or are currently under development. The following sections provide an overview about the actual status and gives an outlook about already planned follow-up activities.

2 Overview

The standards which are referenced in this document can be classified into three categories. The first one is general methods applied for E/E systems functional safety development, the second one is specific functional safety requirements of key control systems, the third one is technical requirements of other systems integrated functional safety.

The standards collected in this document are defined by National Technical Committee of Automotive Standardization (NTCAS), with the following three types:

- GB, Mandatory National Standard
- GB/T, Recommended National Standard
- GB/Z, Guidance National Standard, not legally binding, for users' reference

The following table provides an overview about the standards which are handled in this document [1, 10, 11] (Table 1):

Table 1. China Functional Safety Standards Overview

Category	Name	Main Content	Status
General methods/ guidelines	GB/T 34590–2022	Modified in relation to ISO 26262: 2018	Released
	GB/T XXXXX (Functional Safety Audit and Assessment Method)	This standard provides general requirements for functional safety audit and assessment, and functional safety audit and assessment methods applied on concept phase and system level, software level, and hardware level	Submitted for Approval
	GB/Z 42285–2022	Refer to SAE J2980, the standard defines applicable methods for Hazard identification and risk assessment of S/E/C estimation. In addition, this standard provides reference examples of risk assessment for the main systems including steering system, propulsion system, suspension system and braking system	Released
Key Control Systems	GB/T 39086–2020	Functional safety requirement and test methods for battery management system in electric vehicle	Released

(*continued*)

Table 1. (*continued*)

Category	Name	Main Content	Status
	GB/T XXXXX (Functional safety requirement and testing methods for drive motor system of electric vehicles)	Functional safety requirement and testing methods for propulsion motor in electric vehicle	Submitted for Approval
	GB/T XXXXX (Functional safety requirement and test methods for steering system in passenger vehicle)	No disclosure of the main content till now	Under Drafting
Other systems integrated with functional safety requirement	GB 17675–2021	The standard provides the basic requirement for steering system referring to UN R79 Revision 4, functional safety requirement is addressed in Annex B in the latest version, where a list of safety activities is requested, including: - Steering control system description - Hazard analysis and risk assessment - Functional safety concept - Safety analysis - Verification and Validation - Assessment	Released
	GB 21670	The standard is modified in relation to UN R13-H Revision 3, and released in 2008, it is now under revising, the functional safety requirement is addressed in Annex B of the revising version, where a list of safety activities is requested, including: - Braking control system description - Hazard analysis and risk assessment - Functional safety concept (safety measure, SW architecture) - Safety analysis - Vehicle and System level Verification and Validation plan and results	Committee Draft

(*continued*)

Table 1. (*continued*)

Category	Name	Main Content	Status
	GB/T 39901–2021	The standard provides the performance requirement and test methods for passenger vehicle AEBS (advanced emergency braking system), functional safety requirement is addressed in Annex A in the latest version, where a list of safety activities is requested, including: - Item definition - Hazard analysis and risk assessment - Functional safety concept - Safety analysis - Validation testing	Released
	GB/T 38186–2019	The standard provides the performance requirement and test methods for commercial vehicle AEBS (advanced emergency braking system), functional safety requirement is addressed in Annex A in the latest version, where a list of safety activities is requested, including: - Item definition - Hazard analysis and risk assessment - Functional safety concept - Safety analysis - Validation testing	Released
	GB/T 39323–2020	The standard provides the performance requirement and test methods for passenger vehicle LKA (lane keeping assist) system, functional safety requirement is addressed in Annex B, where a list of safety activities is requested, including: - Item definition - Hazard analysis and risk assessment - Functional safety concept - Safety analysis - Validation testing	Released

(*continued*)

Table 1. (*continued*)

Category	Name	Main Content	Status
	GB/T 41796 -2022	The standard provides the performance requirement and test methods for Commercial vehicle LKA (lane keeping assist) system, functional safety requirement is addressed in Annex A, where a list of safety activities is requested, including: - Item definition - Hazard analysis and risk assessment - Functional safety concept - Safety analysis - Validation testing	Released
	GB/T XXXXX1	This standard provides the technical requirement and test methods for single-lane combined driver assistance system in intelligent and connected vehicles, functional safety requirement is addressed in Annex A, where a list of safety activities is requested, including: - System description - System architecture - Hazard analysis and risk assessment - Functional safety concept - Safety analysis - Verification and validation	Submitted for Approval
	GB/T XXXXX1	This standard provides the technical requirement and test methods for multi-lane combined driver assistance system in intelligent and connected vehicles, functional safety requirement is addressed in Annex A, where a list of safety activities is requested, including: - System description - System architecture - Hazard analysis and risk assessment - Functional safety concept - Safety analysis - Verification and validation	Submitted for Approval

(*continued*)

Table 1. (*continued*)

Category	Name	Main Content	Status
	GB/T XXXXX1	This standard provides general technical requirements for automated driving system in intelligent and connected vehicles, functional safety requirement is addressed in Annex A, where a list of safety activities is requested, including: - System functional description - System architecture - Hazard analysis and risk assessment - Functional safety concept - Functional safety verification and validation - Safety assessment	Final Draft

1: National Standards which are under working without standard ID.

GB type standard is mandatory to apply, regarding GB/T type standard, event if this is only recommended to apply, but for the GB/T standards which are listed in the homologation requirements, will serve as a mandatory standard. In Fig. 2, an overview of the homologation regulations for road vehicle, new energy vehicle and intelligent and connected vehicle have been presented, in each homologation regulation, a list of national standards are provided, e.g., GB/T 34590 has to be applied for intelligent and connected vehicle homologation.

For combustion vehicle homologation, an exhausted list of national standards is listed in the regulation specification [4]. For New energy vehicle homologation, only the additional requirements for new energy vehicle comparing with combustion vehicle are specified in the regulation [3]. Similarly for intelligent and connected vehicle homologation, only the additional requirements for automated systems comparing with traditional vehicle are specified [2].

3 Functional Safety Standards in China

The following section provides an overview about the different categories of functional safety related standards in China.

3.1 General Methods and Guidelines for Functional Safety

GB/T 34590 is the foundation standard for functional safety in Chinese automotive industry. The framework and content of this standard refer to the ISO 26262 standard, with the first edition released in 2017 (referencing ISO 26262:2011) and the second edition released in 2022 (referencing ISO 26262–2018).

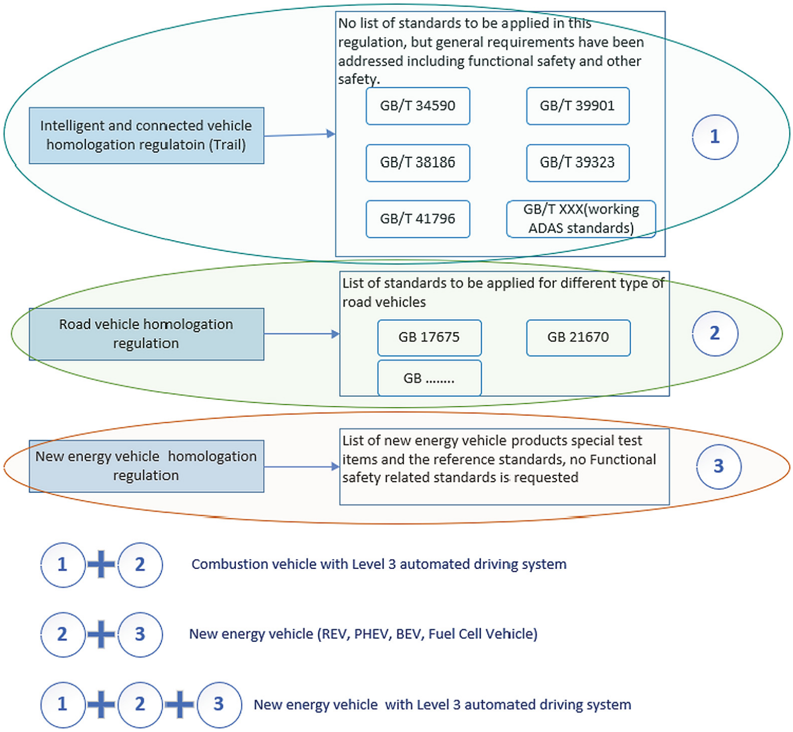


Fig. 2. Homologation Requirement Overview for Road Vehicles with Different Configurations

GB/Z 42285–2022 is an ASIL determination guidelines, it provides HAZOP-based guideline for hazard identification, and provides practical guidance on how to use the S, E, C evaluation criteria of GB/T 34590. Additionally, this standard provides hazard analysis and risk assessment examples of steering system, propulsion system, suspension system and brake system. The steering system malfunction behavior, vehicle level hazard and the critical hazardous event and the resulting ASIL are shown in Table 2. GB/Z42285–2022 provides technical guidance on the hazard analysis and risk assessment for vehicle motion related functions.

GB/T XXXXX (Functional Safety Audit and Assessment Method) has 4 parts:

– Part1: General requirement, this part provides the process to perform functional safety audit and assessment and provides the inputs and checklists for functional safety audit and assessment on functional safety management, production phase, supporting process, ASIL-oriented and safety-oriented analysis.
– Part 2: Concept phase and system level, this part provides the inputs and checklist for each concept phase and system level safety activities.
– Part 3: Software level, this part provides the inputs and checklists for each software level safety activities.
– Part 4: Hardware level, this part provides the inputs and checklists for each hardware level safety activities.

Table 2. Example of Steering System Hazard and ASIL ratings

Malfunction behavior	Vehicle level hazard	Critical hazardous event	ASIL
unintended steering assist	Unintended lateral motion / unintended yaw moment	Vehicle might leave track and crash into oncoming vehicle	D
reverse steering assist	Unintended lateral motion / unintended yaw moment	Vehicle might leave track and crash into oncoming vehicle	D
too high steering assist	Unintended lateral motion / unintended yaw moment	This might lead to oversteering when vehicle is executing lane change at high-speed driving	B
steering stuck in specific position	loss of vehicle lateral control	Vehicle might leave track and crash into oncoming vehicle	D
loss of steering assist	too heavy steering (request higher steering torque)	It will be challenging for some drivers to apply sufficient steering torque in time during low-speed driving	vehicle-dependent

This standard provides an executable checklist for functional safety audit and assessment for vehicle E/E systems.

3.2 Functional Safety for Key Control Systems in the Vehicle

GB/T 39086–2020 provides the following safety goals related to battery thermal runaway, for each safety goal, the functional safety requirements, safety verification specification and safety validation specification are proposed:

- Prevent thermal runaway caused by cell overcharging ASIL C
- Prevent thermal runaway caused by cell charging after over discharging ASIL C
- Prevent thermal runaway caused by cell over temperature ASIL C
- Prevent thermal runaway caused by battery system over current ASIL C

GB/T XXXXX (Functional safety requirements and testing methods for drive motor system in electric vehicles) provides the following safety goals related to torque, for each safety goal, the functional safety requirements, safety verification specification and safety validation specification are proposed:

- Prevent loss of propulsion torque from drive motor ASIL A
- Prevent too high torque provided by drive motor ASIL C
- Prevent reverse torque provided by drive motor ASIL C

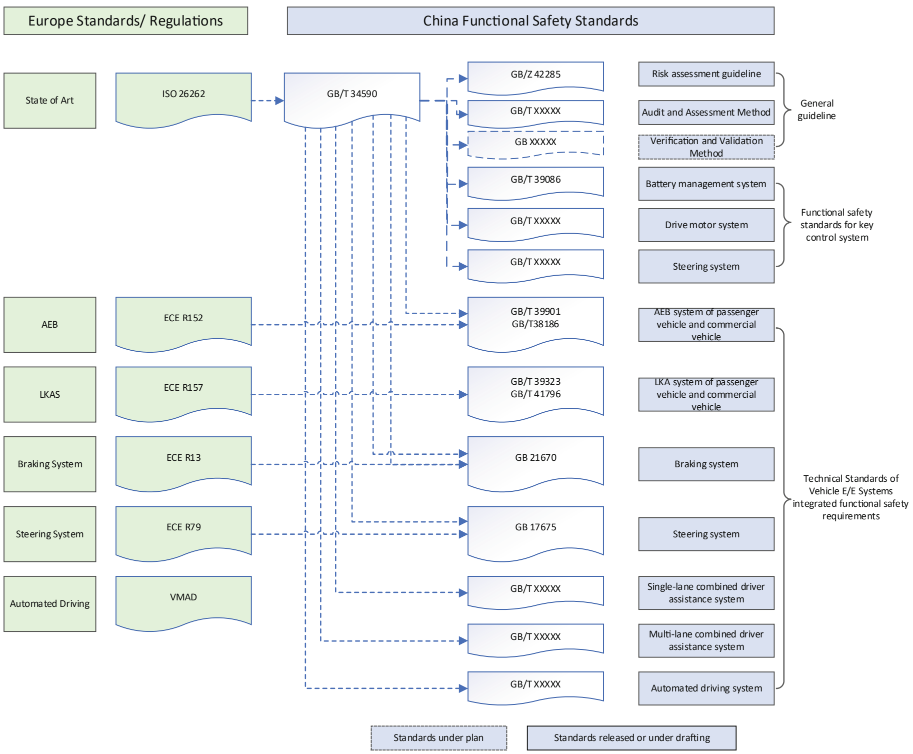
– Prevent unintended propulsion torque provided by drive motor ASIL C
– Prevent loss of brake torque from drive torque ASIL A
– Prevent too high brake torque provided by drive motor ASIL C
– Prevent unintended brake torque provided by drive motor ASIL C

3.3 Standards of Other Vehicle E/E Systems

In addition to the functional safety standards mentioned in Sects. 3.1 and 3.2, the functional safety requirements as per request of GB/T 34590 have been referred in the process of revising existing national standards and developing new standards for automated driving systems specifically. Following systems are:

– Steering system (GB 17675-2021)
– Braking system (GB 21670)
– AEBS (GB/T 39901-2021, GB/T 38186-2019)
– LKA (GB/T 39323-2020, GB/T 41796 -2022)
– Single-lane combined driver assistance system (GB/T XXXXX)
– Multi-lane combined driver assistance system (GB/T XXXXX)
– Automated driving system (GB/T XXXXX)

3.4 Comparison of China and Europe Functional Safety Related Regulation and Standards



Above diagram has summarized the dependency of the China functional safety related standards with Europe regulations and standards. It can be seen that in addition to general standard of GB/T 34590, a series of guidelines have been drafting to assure the car makers or suppliers can easily understand and apply the safety process in the product development process. Furthermore, for the key control systems like battery management system, technical specifications have been provided in the format of national standards to provide safety goals and their ASIL ratings, serving as a baseline for the product design. Other vehicle E/E systems, the main functional safety activities have been integrated in the technical standards to enhance the importance and necessary of functional safety.

4 Conclusion and Outlook

Since 2017, China has started to release functional safety-related standards one after another. The framework of China's functional safety standards is to build a series of general functional safety methods to support the functional safety development, testing, audit and assessment, on the other hand, functional safety standards for specific E/E systems are developed with detailed safety concept and verification and validation criteria. Most of the standards are GB/T (recommended standard), the implementation of specific standards is bound by the homologation regulations of various vehicle products.

For long-term research, the functional safety standardization working group has planned research activities on the following topics [1]:

– Functional safety and AI
– Functional safety requirement and verification and validation methods (GB)

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Digitalizing Process Assessment Approach: An Illustration with GDPR Compliance Self-assessment for SMEs

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Abstract. While many regulations are highly prescriptive in informing regulated entities of what to do and how to do it, this is not the case with the General Data Protection Regulation (GDPR), which simply requires data protection principles (Art. 5) to be respected to ensure compliance. This compliance regime implies a liability shift between the regulator and regulated entities, with the latter becoming "responsible for, and […] able to demonstrate compliance with data protection principles ('accountability')" (GDPR, Art. 5.2). It is then up to the regulated entities to demonstrate they have implemented the "*appropriate technical and organisational measures to ensure […] that processing is performed in accordance with*" this regulation (GDPR, Art. 24.1). In addition, regulated entities must demonstrate that these measures are "*reviewed and updated where necessary*". Due to a lack of resources, small and medium-sized enterprises (SMEs) struggle to identify both privacy requirements and the technical and organizational measures needed to meet them. To support the compliance of SMEs with GDPR, a regulatory technology has been developed based on the digitalization of a GDPR capability assessment approach. The proposed regulatory technology goes beyond the previous process assessment automation by considering the digitalization of identification and collection of objective evidence. After introducing the main features of this regulatory technology, the paper presents the results of its assessment process, measurement framework and assessment model conformity assessment. The paper also discusses the challenges and opportunities offered by the automation of the ISO/IEC 330xx series assessment framework.

Keywords: GDPR · Compliance self-assessment · SMEs · organizational and technical measures · ISO/IEC 330xx

1 Introduction

Over 25 million European SMEs face multiple challenges related to personal data protection; ranging from awareness and access to both affordable and professional legal advice/consulting to related tools and approaches. Compared to larger enterprises, SMEs

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are less likely to adopt digital technologies [1] and are more impacted by GDPR [2]. Furthermore, as stated in [3], the vulnerability of SMEs to cybersecurity attacks is growing, whereas the risk perceived is generally low [4].

Combined with the perceived complexity introduced by data privacy, security, portability and governance requirements, the need for robust SME-specific support measures is obvious and warranted. In line with the quality assurance approach, the SENTINEL H2020 project [5] aims to provide SMEs with a cost-efficient and simple-to-use platform to support them in their effort to address data-related challenges. One of the services provided by the platform is an end-to-end digital GDPR compliance self-assessment tool (GDPR CSA). This tool aims to provide support for SMEs in order for them to comply with GPDR through the demonstration of their accountability.

GDPR CSA has been adapted from the data protection process assessment approach presented in [6]. However, the tool cannot be considered a pure digitalization of the former approach due to the differences in the assessment method, model and measurement framework. This paper presents this self-assessment tool in detail. Thus, the following section will summarize how compliance with GDPR affects companies handling personal data. It will also give an overview of existing self-assessment approaches used to this end. The third section will present the compliance self-assessment solution (and its components) offered to SMEs in the context of the SENTINEL platform. In the fourth section, the results of a conformity assessment (with regards to ISO/IEC 330xx family standard) will be presented. The last sections will open up the discussion on the conformity of the digitalized self-assessment approach with process assessment standards and present conclusions.

2 Demonstrating GDPR Compliance

Since May 2018, companies that process the personal data of EU citizens must comply with the General Data Protection Regulation (GDPR) [7]. Regardless of whether they are based in the EU or not, these companies must take the appropriate technical and organizational measures and be able to demonstrate their effective implementation. The biggest change brought by the European data protection regulation is the introduction of accountability as a compliance principle. Enshrined in article 5, paragraph 2, it illustrates the liability shift between the regulator and the regulated entities: the latter "shall be responsible for, and be able to demonstrate compliance with, data protection principles ('accountability')" (GDPR, article 5(2)). More precisely, "[…] *the controller should be obliged to implement appropriate and effective measures and be able to demonstrate the compliance of processing activities with this Regulation, including the effectiveness of the measures.*" (GDPR, recital 74).

The principle of accountability, a cornerstone of the General Data Protection Regulation (GDPR), implies that companies must demonstrate compliance with data protection principles. While adhesion to a code of conduct (such as the EU Cloud Code of Conduct[1]), a certification mechanism (such as CARPA[2] or EuroPrivacy[3]), or a privacy seal

[1] https://eucoc.cloud/en/home/.

[2] https://cnpd.public.lu/fr/professionnels/outils-conformite/certification/gdpr-carpa.html.

[3] https://www.europrivacy.org/.

(such as EuroPrise[4]) are optional instruments that can help a company demonstrate compliance, these are not always appropriate for SMEs (due to the high cost of certification and limited number of recognized codes of conduct and seals). However, other means, such as compliance checklists and maturity models, could be used by small and medium-sized companies to support their compliance with the GDPR accountability principle.

GDPR compliance checklists (such as [8–10]) seek to provide a high-level overview of the key requirements of the GDPR. They usually display a flat list of requirements, grouped by category, for which the company itself has to verify whether an appropriate set of technical and/or organizational measures has been implemented to address each requirement.

Maturity models (such as Fort PMM [11], Mitre PMM [12], and SPCMM [13]) are frameworks that organizations can use to assess and improve their level of capability or maturity in a particular area. They are typically presented as a series of stages or levels that an organization can progress through, with each level representing a higher degree of maturity. In [14], Laposa and Frivaldszky reviewed the methodology of maturity models and compared twelve models in the privacy domain based on their main methodological elements. They concluded that "*it is advisable to elaborate a GDPR-specific model that addresses the relevant requirements to achieve compliance and its levels should be defined according to the risks taken.*"

Amongst the existing data protection maturity models, the GDPR Process Assessment Model presented by Cortina & Al in [15] targets the requirements of the European regulation (GDPR) exclusively. This process assessment model is compliant with ISO/IEC 33004 requirements and has been used by competent assessors to determine the capability levels of data protection processes implemented within a company [6]. This capability assessment model was the starting point of the development of a digital GDPR compliance assessment for SMEs embedded within the SENTINEL platform, as explained in the following section.

3 Digital GDPR Compliance Self-Assessment (GDPR CSA)

The GDPR compliance self-assessment was developed within the framework of the SENTINEL H2020 project. The project aims include the development of a platform to offer digital support to SMEs in cybersecurity and personal data protection [16].

3.1 GDPR CSA in a SENTINEL Platform Environment

The SENTINEL platform (see Fig. 1), is composed of a set of core modules and plugins orchestrated together via restful application programming interfaces (APIs). Examples of core modules are modules for companies to describe themselves and the personal data processing activities they perform and to store these descriptive data in a so-called "company profile". The digital GDPR compliance assessment is a plugin of the platform, and, within the platform, it is referred to as the GDPR compliance self-assessment

4 https://www.euprivacyseal.com/.

plugin, or GDPR CSA in short. GDPR CSA works in isolation through containerization technologies and exposes its interfaces through APIs. As a restful thus stateless application, the plugin is triggered by requests received from a message broker and outputs its results back to the message broker. Messages are in JSON format and the plugin itself is developed in R.

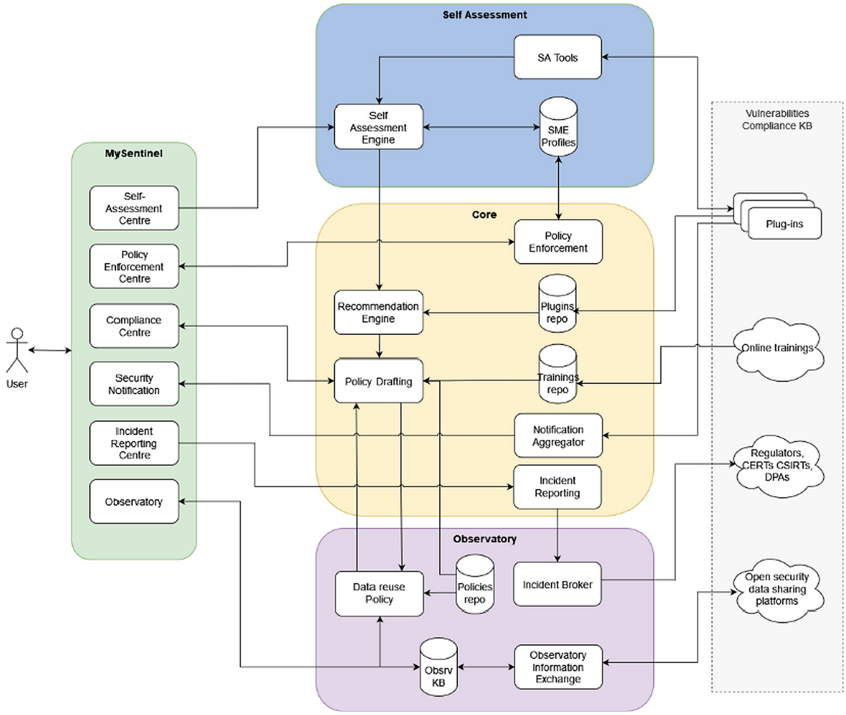

Fig. 1. The SENTINEL framework architecture.

GDPR CSA was built from a process-based approach compliant with the ISO/IEC 330xx family standard, but is not considered the result of a simple digitalization of this. Obviously, automation can lead to an adaption of the process assessment method, especially when automation means that assessors are no longer involved in process assessment. However, discrepancies between GDPR CSA and previous process-based approaches are also due to the fact they are intended to support different assessment participants and achieve different assessment purposes. Taking the nature of the assessment (automated), assessment participants (responsible for data protection) and purpose (support accountability) into consideration, the assessment model and method of GDPR CSA have been adapted accordingly.

3.2 GDPR CSA Assessment Model

One major difference between the previous GDPR process assessment approach and GDPR CSA is the assessment purpose. In the former, the purpose of the assessment is to determine the capability level of a set of processes that are required to ensure personal data is handled in accordance with the GDPR. The assessment purpose of GDPR CSA is different: while process assessment aims to understand the state of GDPR processes for process improvement, GDPR CSA aims to determine the appropriateness, effectiveness and demonstrability of the Organizational and Technical Measures (OTMs) put in place to preserve privacy. The consequence of such a purpose shift is both the adaptation of the process assessment model and the creation of a specific measurement framework.

Process Reference Model

The GDPR CSA Process Reference Model is depicted in Fig. 2. It is a subset of the ISO-compliant process model used as an input [15], and focuses on the four processes that should be assessed for each processing activity (Personal Data Lifecycle Management (PDLM), Record of Process Activity Management (RECORD), Data Subjects Rights Management (RIGHTS) and Consent Management (CONSENT)) and the two organizational processes (Data Protection Management (DPMAN) and Personal Data Breach Notification (BREACH)).

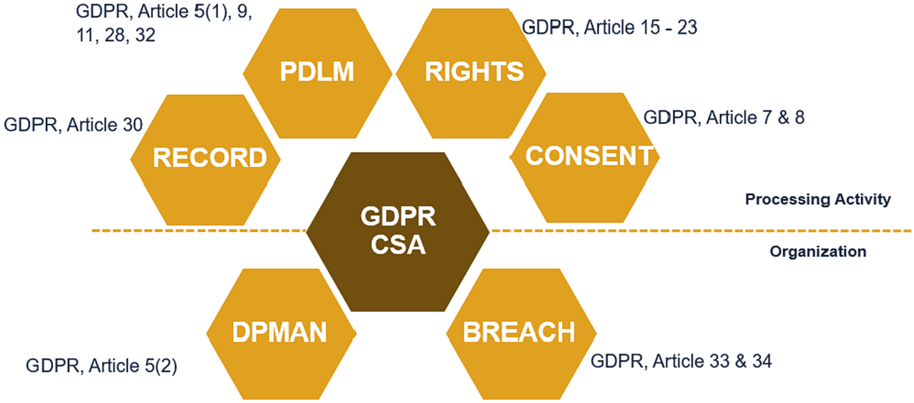

Fig. 2. The GDPR CSA process assessment model.

Measurement Framework

The GDPR CSA measurement framework has also been adapted for the purpose of the SENTINEL project. Whereas classical measurement frameworks aim to measure a process capability level, the objective of the GDPR CSA measurement framework is to determine the level of accountability. As stated in Sect. 2, the GDPR integrates accountability as a principle which requires that "*organisations put in place appropriate technical and organisational measures and be able to demonstrate what they did and its effectiveness when requested*". To be able to measure accountability, the authors created a new scale that enabled the evaluation not only of the appropriateness and the effectiveness of the measures implemented by an SME, but also of its capacity to demonstrate, upon request, that appropriate and effective measures have been taken. The components of the GDPR CSA measurement framework are the following:

Level 1: Process suitability

PA 1.1: Process Performance attribute

PA 1.2: Process Appropriateness attribute

Level 2: Process assurance

PA 2.1: Process Effectiveness attribute

PA 2.2: Process Demonstrability attribute

Where PA1.1 is the classical Process Performance attribute, required (by ISO/IEC 33003) in any measurement framework, and representing the capacity of a process to reach its purpose, and where Appropriateness (PA 2.1) is defined as *"the quality of being suitable or right for a particular situation or occasion"*, Effectiveness (PA 2.1) is defined as *"the ability to be successful and produce the intended results"*, and Demonstrability (PA 2.2) as *"the fact of being able to be proved"*, according to the Cambridge Dictionary[5].

As an example, when self-assessing how employees access personal data, a GDPR CSA respondent will select, in a closed list, the technical measure implemented in his/her company (such as a Role-Based Access Control Mechanism). The appropriateness of this measure will depend on how it aligns with the risk level associated with the processing activity. The effectiveness of this measure will be evaluated through the frequency of the review of the rules and roles, whereas the demonstrability will be estimated through the capacity to produce some tangible proofs (such as an access log).

3.3 GDPR CSA Assessment Process

The GDPR CSA assessment process relies on two main features that are in interaction with the rest of the platform. The first feature is the inspection of the record of processing activities stored in the Register Of Processing Activities (ROPA) and the second is a question-based assessment. From a logical perspective, the first feature corresponds to the inspection of an information item, based on the description given by the user. The second feature is an assessment of testimony, based on the answers provided by the user to questions that were asked prior to launching the automatic assessment. The questions are contextualized, i.e. they depend on the description of the company profile, risk level of processing activity assessed and existing measures already identified. These questions target data protection measures implemented at the level of the processing activities (management of consent, data subjects' rights, ...) and at the organizational level (organization-wide management of personal data and personal data breaches). This second feature corresponds to the assessment of the remaining five processes of the GDPR CSA assessment model (see Fig. 2).

Processing Activity Record Inspection

Instead of considering the assessment of processes dedicated to the management of the Record Of Processing Activities (ROPA), the plugin inspects the record of the processing activity itself. It first assesses the completeness of the processing activity description. A common set of descriptive data is systematically checked (name and country of the company, name of the processing activity, type of personal data recipient ...), then,

5 https://dictionary.cambridge.org/.

depending on the role of the organization and whether data are transferred outside Europe, the presence of additional description data is also checked. The absence of these data is assessed with regards to the risk level of the processing activity and its record is rated accordingly. Recommendations are issued to users recommending or requiring them to fill in missing data depending on the record management process score. It is worth noting that such an assessment is closer to an information item inspection than a process assessment.

Question-Based Assessment

For the five remaining processes, the assessment is based on a set of questions that the user must answer prior to launching the assessment. These questions are asked to determine which organizational and technical measures have been implemented at the organizational and processing activity levels. These questions are part of the core modules of the platform and thus answers are shared with other modules and plugins, like the plugin for performing the Data Protection Impact Assessment (DPIA). All questions are closed, meaning that the user must select one or more answers.

When the GDPR compliance assessment is triggered, answers to the questions are passed on to the plugin's API. Answers are grouped by process. Contextual conditions are applied based on the organization and or the processing activity descriptions. This is done firstly to filter out the questions and answers that are not relevant to the assessment due to the context and secondly, to select the applicable scoring scale.

The scoring scale is applied to determine the score (a numeric value) corresponding to each answer. The answer scores are aggregated for multiple choice questions (which can have multiple answers). This aggregation is question-specific and can be either a simple arithmetic mean or a weighted arithmetic mean, where weights are context-dependant. Then, a rating scale is applied to convert the aggregated score of the questions into a process assessment rating. For this, GDPR CSA relies on the Process Attribute Rating Scale defined in [17], which is an NPLF ordinal scale where N is "Not Achieved" (0–15%), P is "Partially Achieved (16–50%), L is "Largely Achieved (51–855%) and F is "Fully Achieved" (86–100%)).

Finally, a set of recommendations is issued for each process based on the rating and the organizations and processing activity contexts.

Assessment Result Compilation

The results of the two features of the plugin are consolidated and the results are provided back from the plugin to the platform through the API response. Assessment results concern the compliance level of each relevant data protection process of a processing activity, and processes that take place at the organizational level (i.e. Data Protection Management and Personal data breach notification). Assessment results are expressed as follows:

- Compliance label: "Not compliant","Partially compliant","Largely compliant","Compliant";
- Compliance score on an integer scale (0 for Not compliant and 3 for Compliant);
- The set of recommendations issued by the assessment.

For the current version of the plugin, the recommendations are text-based suggestions on what shall be done to comply with the law (for example: “Please consider implementing a mechanism to control access to personal data”). In a future version of the plugin, we expect to provide compliance recommendations by suggesting organizational and technical measures (OTMs) exposed by another plugin of the SENTINEL platform (for example: “Please consider implementing a 2FA mechanism”). These OTMs will be selected on the basis of the assessment results, as well as other criteria, such as the company profile and the risk level from the DPIA plugin and the OTMs already implemented.

4 Verifying the Conformity of GDPR CSA with Regards to ISO/IEC 3300x

The digital GDPR CSA is composed of an assessment method combined with an assessment model and a measurement framework. In the following sections, the authors will verify the conformity of these components with regards to the requirements of the ISO/IEC 3300x series of standards.

4.1 Conformity of the GDPR CSA Assessment Process

The ISO/IEC 33002 standard [18] defines the requirements for performing a process assessment. Clause 4.1 states the following set of general requirements:

- *the documented assessment process shall identify as a minimum, the assessment activities;* [Req1.1]
- *the documented assessment process shall identify as a minimum the roles, responsibilities and competencies;* [Req1.2]
- *the documented assessment process shall identify the classes of assessment for which the documented assessment process can be applied, and the nature and extent of tailoring associated with each class addressed by the documented process;* [Req1.3]
- *the documented assessment process shall define the criteria for ensuring coverage for both the defined organizational scope and the defined process scope for the assessment, in terms of the strategy for collecting and analysing data;* [Req1.4]
- *the documented assessment process shall identify the rating method(s) to be used in rating process attributes;* [Req1.5]
- *the documented assessment process shall identify or define the aggregation method(s) to be used in determining ratings.* [Req1.6]

As explained in Sect. 3.1, GDPR CSA is one of the components of the SENTINEL platform. Although GDPR CSA is partially automated, its usage requires following a series of steps on the SENTINEL platform. First, a user needs to describe the company profile and processing activities he/she is responsible for. Subsequently, he/she completes the description by answering closed questions related to the measures eventually implemented. Once the description is done, GDPR CSA automatically computes the information gathered and determines a compliance level that is displayed on a dashboard. All of these steps (Plan the assessment, Collect the data, Validate the data, Determine the results, Report the assessment) constitute the GDPR CSA assessment activities

(Req1.1). In this context, the roles and responsibilities (Req1.2) are the following: the SME using the SENTINEL platform is considered as the assessment sponsor and GDPR CSA is seen as a lead assessor. GDPR CSA relies on both an automatic inspection of a work product (the Register or Processing Activity) and a self-assessment based on closed questions. As a self-assessment, it is, according to [18] a Class 3 assessment based on category D of independence (Req1.3). Class 3 assessments are suitable for monitoring the ongoing progress of an improvement programme, identifying key issues and generating results that may indicate critical opportunities for improvement. Moreover, a self-assessment implies that "the body performing the assessment is part of the organization being assessed", which is how [18] defined category D of independence. The organizational and process scope of the assessment is chosen by the SENTINEL user by defining the company profile and the description of the processing activities of the SME. The target level is automatically determined by GDPR CSA based on a risk level computed by the SENTINEL platform and associated with the processing activities (Req1.4). The rating method and the aggregation method used by GDPR CSA are defined and coded within the "Assessment rule engine" (Req1.5) & (Req1.6). However, when looking at the content of the ISO/IEC 33002 standard in detail, we can see that a documented assessment process should also ensure a certain degree of documentation of the assessment inputs and outputs. Regarding this, GDPR CSA lacks the ability to formally record the inputs of each assessment and should provide more information in the output produced. Consequently, we can state that the conformity assessment process of GDPR CSA only partially conforms to the requirements of ISO/IEC 33002.

4.2 Conformity of the GDPR CSA Measurement Framework

As presented in Sect. 3.2 of this paper, the GDPR CSA assessment model relies on a customized measurement framework. The ISO/IEC 33003 standard [19] defines the requirements for process measurement frameworks. Clause 4 of this document contains a set of requirements for developing new measurement frameworks whereas clause 5 defines the requirements for their validation. These requirements can be grouped into the following categories:

– *Conceptualization (§4.1);* [Req2.1]
– *Construct definition (§4.2);* [Req2.2]
– *Operationalization (§4.3);* [Req2.3]
– *Construct specification examination (§4.4);* [Req2.4]
– *Rating process attributes (§4.5);* [Req2.5]
– *Aggregation (§4.6);* [Req2.6]
– *Sensitivity analysis (§4.7);* [Req2.7]
– *Validation (§5);* [Req2.8]

The GDPR CSA measurement framework is defined for the single quality characteristic of Accountability. It is a construct made up of four process attributes that define different properties of accountability. The process attributes of this measurement framework are formative and not directly measurable. Process attributes are required in order to construct the accountability. Process attributes are demonstrated by the achievement of the process attribute outcomes, which are reflective measures (Req2.1).

The meaning and specifications of the process quality characteristic and its process attributes are defined within the SENTINEL model. One of the process attributes comprises the achievement of the defined process purpose (process performance attribute – PA 1.1). The others process attributes are Process Appropriateness (to what extent the measures implemented are the right ones, with regard to risk level), Process Effectiveness (to what extent the measures implemented produce the intended results over time), and Process Demonstrability (to what extent the user can prove what he/she declared). (Req2.2).

The process attributes are defined within the GDPR CSA assessment model, and their achievement is demonstrable on the basis of objective evidence, employing the process attribute outcomes as base measures (Req2.3). Each process attribute is operationalized through a set of base or derived measures (Req2.4).

The GDPR CSA measurement framework relies on an ordinal scale (Not achieved – Partially achieved – Largely achieved – Fully achieved) for the rating of the Process attributes. A matrix for assigning a value to the measure of accountability (by combining the rating of the two process attributes of level 1 with the one assigned to the two process attributes of level 2) is defined for each process (Req2.5).

To obtain a process attribute rating, we converted the ordinal ratings (assigned to each assessment indicator) to interval values. Then, (one dimension) aggregation is performed by computing the arithmetic mean (average) of the ratings of the interval values and converting the result back to the corresponding ordinal rating (Req2.6).

The SENTINEL project is now entering a pilot phase, in which SMEs will test the platform and provide feedback on the GDPR self-assessment, amongst other things. Therefore, at the time of writing this paper, the authors have not started sensitivity analysis or obtained validation of the measurement framework from the early adopters of SENTINEL. Consequently, we can only confirm partial conformity of the GDPR CSA measurement framework with the requirements of ISO/IEC 33003.

4.3 Conformity of the GDPR CSA Assessment Model

The GDPR CSA assessment model presented in Sect. 3.2 is derived from an ISO/IEC 33004 compliant Process Assessment Model. The ISO/IEC 33004 standard [20] defines the requirements for process reference, process assessment and maturity models. It contains the requirements for developing new process assessment models. These requirements can be grouped into the following categories:

- *Process assessment model purpose (§4);* [Req3.1]
- *Process assessment model scope (§6.2);* [Req3.2]
- *Requirements for process assessment models. (§6.3);* [Req3.3]
- *Assessment indicators (§6.3.8);* [Req3.4]
- *Mapping process assessment models to process reference models (§6.3.9);* [Req3.5]
- *Expression of assessment results (§6.3.10);* [Req3.6]

The purpose of this GDPR CSA assessment model is to support the assessment of accountability using the GDPR CSA measurement framework defined in the framework of the SENTINEL project (Req3.1). Processes in the GDPR CSA model are based on the process description provided in the process reference model of the GDPR PM [15].

The accountability levels and attributes are described in the measurement framework defined specifically for this purpose. However, as stated in Sect. 4.2, this measurement framework only partially conforms to ISO/IEC 33003 (Req3.2). The GDPR CSA model incorporates six of the eight processes defined in the GDPR Process reference model. It addresses all the process attributes and accountability levels defined in the GDPR CSA measurement framework (Req3.3).

The GDPR CSA assessment model provides a two-dimensional view of accountability for the processes in the process reference model, through the inclusion of assessment indicators. The assessment indicators used are the following: base practices, work products and Organizational and Technical Measures (OTMs) supporting data protection.

These indicators support the automatic assessment of the accountability level (appropriateness, effectiveness and demonstrability of the implemented measures) performed by GDPR CSA (Req3.4).

Each of the processes in the GDPR CSA model is identical in scope to the process defined in the process reference model. Each base practice and work product is cross-referenced to the process outcomes it addresses. Each of the process attributes in this process assessment model is identical to the process attribute defined in the process measurement framework (Req3.5).

The process attributes and the process attribute ratings in this process assessment model are identical to those defined in the measurement framework. Consequently, the results of assessments based upon this process assessment model are expressed directly as a set of process attribute ratings for each process within the scope of the assessment. However, for the purpose of the SENTINEL project, the results of the assessments are displayed to SMEs after a conversion step; whereas attribute ratings are converted into an accountability score (Req3.6).

Finally, as the GDPR CSA assessment model relies on a partially conformant measurement framework, it only partially conforms to ISO/IEC 33004.

5 Discussion

5.1 On Conformity of GDPR CSA Components

The SENTINEL platform delivers an innovative personal data protection compliance self-assessment module, which aims to help SMEs adhere to the accountability principle.

Assessments completed with this framework effectively establish accountability by recording: (a) the completeness of the OTMs put in place by SMEs to comply with GDPR or other custom-defined personal data protection requirements; (b) the assurance level regarding the effectiveness of the organizational and technical measures in place; and (c) the SME's capabilities to demonstrate the appropriateness and effectiveness of measures in place to comply with the requirements. It is also critical to underline the role of automation in the above process as a necessary requirement to overcome the barriers SMEs face when becoming aware of the need for compliance, such as cost-of-entry and complexity.

However, this automation comes at a cost. Transforming a human-based assessment process into a self-assessment implies having a set of assessment-related activities (such as selecting a target level) being automatically performed in the back-end, without any participation by the assessment sponsor. Moreover, since GDPR CSA was designed for non-expert users, its assessment process has been simplified in such a way that some minor non-conformities (record of the assessment input, presentation of the assessment results by attributes) were introduced, as stated in Sect. 4.1. Additionally, the SENTINEL project is now entering in a trial phase, where SMEs are testing the whole platform, and in particular, the GDPR CSA module. We expect these early adopters to provide feedback on the usage of the self-assessment module as well as a validation of the suitability of the assessment model and its associated measurement framework, in order to base our future improvement on experience and measurements, as suggested by the SPI Manifesto [21].

5.2 Making Objective Evidence Explicit to Ensure Self-assessment

Self-assessment approaches such as GDPR CSA are consistent with the requirements of ISO/IEC 33002. However, because assessment is not performed by an independent assessor, confidence in the assessment results is more limited (i.e. category D of independence, described in clause 4.1). In comparison with previous digital solutions supporting process assessment as proposed by [22], GDPR CSA sets itself apart. While the module takes advantage of the automation of both aggregation principles and assessment result compilation, it also goes beyond this by removing the need for external assessors. This means that knowledge of the latter must be captured and encoded in the system. The knowledge in question concerns both privacy requirements and the way to meet them, since this requires the implementation of "organisational and technical measures" (OTMs), which constitute "objective evidence" that supports the process attributes rating.

The privacy requirements were identified from base practices and attributes defined in the GDPR assessment model presented in [6]. However, the identification of objective evidence or OTMs that are expected to consider the fulfilment of privacy requirements was a greater challenge. It consisted of the capture and formalization of the tacit knowledge of experienced GDPR compliance assessors. To overcome the "it depends" syndrome, knowledge capitalization was based on the existing OTM taxonomy as proposed by [23] and [24]. The result is a list of OTMs and privacy controls that could be implemented to meet each privacy requirement.

Pre-defined objective evidence does not allow us to include all specific practices, tools and other measures that a company can implement to meet data protection requirements. However, by making privacy requirements and the way to meet them explicit, GDPR CSA should help SMEs to close the knowledge gap around GDPR.

6 Conclusion

The SENTINEL platform aims to enhance the GDPR compliance-preparedness level of SMEs by offering an end-to-end digital data protection compliance framework based on the established process assessment principles that were defined in the ISO/IEC 3300x standards. To this end, SENTINEL digitalized every related process and prepared a complete framework to be offered in a Software-as-a-Service offering, emphasizing simplicity and automation, and minimizing the need for costly training and external consulting. Although it is based on the ISO/IEC 3300x series of standards, the GDPR CSA components are partially conformant with expected process assessment requirements. The authors plan to review these components at the end of the pilot phase when early adopters of the platform will have shared their feedback.

Moreover, amongst the various potential improvement paths, the authors will consider the possibility of extending the scope of the SENTINEL platform to address Artificial Intelligence challenges. This could be done by expanding the scope of the assessment model to include new requirements coming from the upcoming IA regulation (i.e. "AI Act") on the one hand, and by incorporating an AI-powered document analysis module able to perform work product inspection (and, as an example, verify the content of the "privacy notice"), on the other hand.

Finally, as mentioned above, the GDPR CSA assessment model does not cover all the GDPR requirements. For instance, it addresses neither the lawfulness of the processing activity nor the duration of the retention period. Evaluating such aspects would require additional legal expertise that is not included in the SENTINEL platform today. Thus, the assessment results provided by GDPR CSA shall not be considered as a comprehensive and objective evaluation of compliance with GDPR but as an evaluation of the accountability level of the data controller.

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Acceptance Criteria, Validation Targets and Performance Targets in an ISO 21448 Conform Development Process

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Abstract. This thematic paper presents an approach of handling Acceptance Criteria and Validation Targets within an ISO21448 conform development process for highly automated driving functions. This includes an approach for breaking down Acceptance Criteria from global level to scenario class level. Furthermore, the application of Validation Targets for the respective Acceptance Criteria is addressed while the underlying methods for definition are briefly described. In order to support efficient development on component level and to avoid premature testing, quantitative Performance Targets are introduced functioning as quality goals for integration and testing on higher engineering levels.

Keywords: SOTIF · ISO21448 · Acceptance Criteria · Validation Targets · Performance Targets

1 Introduction

Ensuring Vehicle safety for autonomous driving technologies is a critical up-to-date topic as technology evolution strives towards the development of higher automation levels. The ISO21448 "Road vehicles—Safety of the intended Functionality" (SOTIF) provides a framework for ensuring the safety of automated driving systems (ADS) by identifying and mitigating hazards the system can be confronted with during the whole operational lifecycle [1].

Acceptance criteria are a crucial artefact of this framework as they are setting the target values for the accepted residual risk and behavior of the system. The directly linked validation targets provide the testing target to ensure the system compliance with the acceptance criteria. Unfortunately, the ISO21448 [1] does not provide more information how to actually apply acceptance criteria and validation targets to the development or how to use these artefacts within the SOTIF Argument. It is on the user of the standard to develop appropriate methods for the definition, application, and argumentation. Considering that the residual risk must not be concentrated to a specific group of involved individuals [2], a generally applied system level value for tolerated fatalities is certainly not sufficient as acceptance criteria [3]. A structured approach for acceptance criteria

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definition, breakdown and fulfilment is required to reach the necessary confidence to operate the system on public roads.

AVL Software and Functions GmbH is a German automotive supplier with the focus on power train engineering and software development. In the field of Advanced Driver Assistance Systems (ADAS) and Automated Driving (AD) Safety, the company is conducting both research and customer projects with the focus on Functional Safety and SOTIF in the context of both SAE Level 2 and 4 Automated Driving Systems (ADS) [4]. The current focus of the ADAS/AD Safety Team lies on process and method development for the ISO21448 "SOTIF" conform development process. In the sense of the SPI Manifesto [5], AVL Software and Functions GmbH strives to publish considerations and results in order share knowledge and enable constructive discussions.

In this paper AVL Software and Functions GmbH presents an approach of defining and applying Acceptance Criteria, Validation Targets, and underlying Performance Targets to reach structured scenario focused evidence for the overall SOTIF Argument. This work is in line with the ISO21448 and contributes to the discourse on enhancing the safety of autonomous vehicles and promoting best practices in the automotive industry.

2 Acceptance Criteria Definition and Breakdown

This chapter provides an informal definition of Acceptance Criteria (ACCR) and presents the AVL Software and Functions GmbH breakdown approach to reach a structured distribution of the accepted residual risk within the scenario space. The scenario-based testing principles and the scenario classification approach (functional, logical, and concrete scenarios) of the Pegasus Project are used [6].

2.1 General Definition

The ISO21448 defines an acceptance criterion as criterion representing the absence of an unreasonable level of risk [1]. Since this definition is quite generic, the following informal definition of Acceptance Criteria is proposed.

Acceptance Criteria provide target values and requirements that represent the criteria under which the ADS is considered free of unreasonable residual risk caused by failure of the intended functionality. Acceptance Criteria address both statistical target values and behavioural requirements on system level for the specific absolute scenario space of both known and unknown scenarios. Statistical target values are based on quantitative data derived of e.g., accident databases, traffic analysis, surveys or simulations and are linked to the fundamental principles PRB (positive risk balance), MEM (minimal endogenous mortality) or GAMAB (Globalement au moins aussi bon) [7–9]. The behavioural requirements are based on qualitative expectations, e.g., by legislation, social/society expectation, or ethical standards and can be related to the ALARP (as low as reasonably practicable) principle [8, 9]. Since the accepted values and behaviours might change over operational lifetime of the ADS, the Acceptance Criteria must be reviewed, updated, and reassured cyclically as aspect of the continuous system care. An argument and respective evidence for continuous compliance of the system to the Acceptance Criteria must be provided as part of the continuous SOTIF Argument.

2.2 Breakdown Approach

Defining a single Acceptance Criteria for the ADS may lead to the concentration of residual risk to scenarios related to specific parameter combinations and makes it hard to formulate a structured argument for achieving the SOTIF within the full scenario space. Hence, AVL Software and Functions GmbH developed an approach for breaking down the acceptance criteria in a structured way to ensure a more controlled and scenario class specific testing approach. Figure 1 provides an overview of the Acceptance Criteria breakdown. The Validation Target (VT) related links are further described in Sect. 3

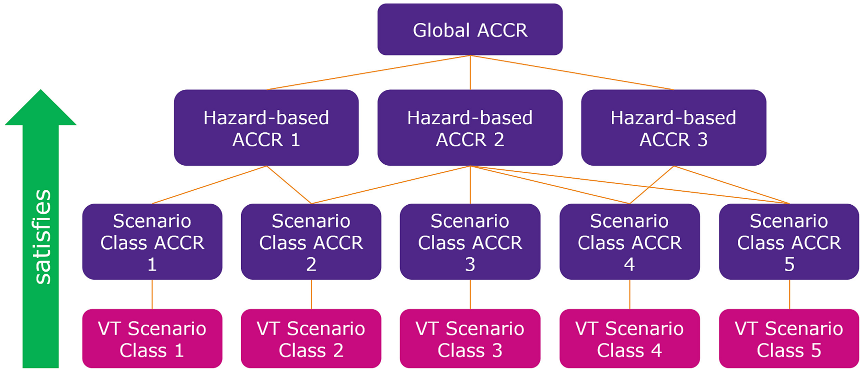

Fig. 1. Breakdown of Acceptance Criteria (ACCR) from top level (global) to scenario class specific level and relation to Validation Targets (VT).

The following statements describe the relations of the Acceptance Criteria:

- The Global ACCR, generally valid for the ADS, is broken down into Hazard-based ACCR.
- The Hazard-based ACCR are broken down into Scenario Class ACCR.
- One Scenario Class ACCR can be defined by multiple Hazard-based ACCR.
- The sum of linked Scenario Class ACCR satisfies the Hazard-based ACCR.
- The sum of Hazard-based ACCR satisfies the global ACCR.

The detailed dependencies and breakdown are further described in the following sections.

Global Acceptance Criteria. The global acceptance criteria describes the conditions under which an ADS is considered "free of unreasonable risk due to failure of the intended functionality" to be used on public roads.

The Global Acceptance Criteria is valid for the ADS in context of the System Specification, the Feature Definition Document (FDD) and the Operational Design Domain (ODD). The Global Acceptance Criteria includes statistical and behavioral aspects. The statistical aspect of the acceptance criteria is based on statistical values for the overall acceptable residual risk (due to failure of the intended functionality) within the context of the function (ODD, FDD). This threshold is valid for the complete scenario space, so all known and unknown scenarios, the system can be confronted with during operation.

This statistical value must be derived of quantitative data sources specifically analysed in context of the ODD and FDD [10]. Sources can be accident statistics like GENESIS, GIDAS, CARE, BASt [11–14] supported by traffic analysis data, simulations, etc.

Behavioural aspects of the Global Acceptance Criteria give mandatory high level system behavioural requirements for all scenarios. These criteria are based on fundamental requirements given by general safety considerations, legislation, society, and ethics. An example for the behavioural aspects of Global Acceptance Criteria can be found in Table 1.

Table 1. Examples for behavioral aspects of the Global ACCR for the exemplary ADS Feature "Inner City Autopilot".

Fundamental Requirements	Example Global ACCR	Remark
Legislation	A minimum distance to cyclists must be 1.5 m at all times [15]. The system shall not plan or execute any movement violating this distance	
Social/Society	The AD Vehicle shall renounce the right of way and yield to a cyclist if it creates a safer trajectory for the cyclist	Strongly dependent of the national, regional, and even local social/society behaviour
Ethics	The ADS shall not differentiate between individuals in a way that one individual is exposed to a higher risk than the other [2]	

Hazard-Based Acceptance Criteria. The Hazard-Based Acceptance Criteria describe the conditions under which an ADS is considered "free of unreasonable risk due to failure of the intended functionality" in context of a specific hazard.

For this, the Global Acceptance Criteria are broken down to the acceptable values and behaviors related to the individual hazards the system can be confronted with. As base for this, the hazards identified within the SOTIF Hazard and Risk Assessment on system level are used. The Hazard-based Acceptance Criteria are valid for all scenarios in system context (ODD, FDD) within which the respective hazard can occur. The Hazard-based Acceptance Criteria follow the same structure, so both statistical and behavioral aspects, as the Global Acceptance Criteria.

The statistical aspects of the Hazard-based Acceptance Criteria provide the acceptable residual risk for a specific hazard and must be constructed by further analysis of the available statistical data and additional quantitative methods, e.g., statistical ODD evaluation, traffic simulations or additional data acquisition. As a next step, the acceptable residual risk can be transformed to acceptable occurrence rates of the hazard and hazardous behavior (in context of the hazard) using the respective probabilistic relations between hazardous behavior, hazard, and harm [3]. The relations are illustrated in Fig. 2.

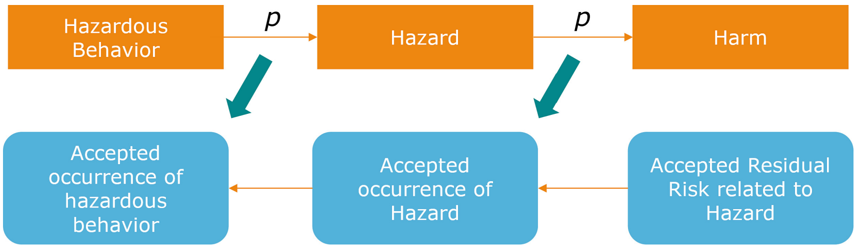

Fig. 2. Relation between Harm, Hazard, and Hazardous behavior.

Formulating the accepted residual risk as accepted hazard/hazardous behavior occurrence rate enables the derivation of Validation Targets and underlying Performance Targets. It is likely that the available data is not sufficient to directly derive the statistical values. In this case structured assumptions for an accepted risk distribution must be made. At this point it is highly important to construct the Hazard-based Acceptance Criteria in a transparent and logical way, documenting the argument and assumptions for further confirmation.

The behavioral aspects of the Hazard-based Acceptance Criteria require a detailed elaboration based on the Global Acceptance Criteria to be valid in context of the specific hazard. These aspects can focus on behavior related to the specific hazard and hazardous event. Additional information, e.g., stakeholder interviews, surveys, etc., might be necessary. Examples for the behavioral aspects of Hazard-based Acceptance Criteria can be found in Table 2.

Scenario Class Acceptance Criteria. To avoid an unreasonable concentration of residual risk within specific ODD areas/scenarios, the Hazard-based Acceptance Criteria are further broken down into scenario class acceptance criteria.

A scenario class is a sum of logical scenarios and is defined by common attributes e.g., parameters, parameter ranges, common object types or constellations or by a common expected severity class in context of a hazard. This brake down allows a structured testing approach ensuring the coverage of the whole scenario space in context of the ODD and FDD. The scenario classes must be chosen in a way that the assignment of reasonable common acceptance criteria, both statistical and behavioral aspects, is still feasible. Choosing a high number of scenario classes, each containing only a low number of logical scenarios, will lead to the problem that the accepted residual risk value (statistical aspect) for the scenario class gets extremely small. Proving the compliance to such a low residual risk/occurrence rate by testing requires immense test efforts, making this practically infeasible. Hence, the scenario classes must be chosen in a way that a reasonably granular assignment of residual risk is possible while covering as many logical scenarios as possible.

The Scenario Class Acceptance Criteria follow the same structure (statistical and behavioral aspects) as the Hazard-based Acceptance Criteria. The statistical aspect

Table 2. Examples for behavioral aspects of the Hazard-based ACCR for the exemplary hazard "Side collision with cyclist" of the exemplary ADS Feature. "Inner City Autopilot". Here the example for Legislation from Table 1 is continued.

Feature	*Inner City Autopilot, Bavarian City, SAE Level 4* [4]	
Hazard	*Side collision with cyclist*	
Fundamental Requirements	Example Global ACCR	Remark
Legislation	The ADS shall avoid trajectories where driving next to a cyclist occurs. If a cyclist is next to the ego vehicle closer than 2 m for longer than 5 s, the trajectory shall be selected in a way that the cyclist is given the right of way and that the ego vehicle is placed in front or behind the cyclist	*This is a constructed example to demonstrate the breakdown approach. It is not complete and directly applicable in reality*

addresses the accepted residual risk within the scenario class while the behavioral aspects specify the detailed accepted behavior for the respective (logical) scenarios. Examples for the behavioral aspects of Scenario Class Acceptance Criteria can be found in Table 3.

3 Validation Targets

As described in the previous chapter, the Scenario Class Acceptance Criteria provide the target values and requirements for all known and unknown scenarios sharing the significant attributes of the respective scenario class. But since the number of concrete scenarios within this space goes towards infinity, a binary statement for compliance to the acceptance criteria is not possible [16]. Hence, a probability-based argumentation must be built up supported by evidence for compliance [17]. For this, the ISO21448 [1] introduces the Validation Targets as "values to argue that the acceptance criteria are met with sufficient confidence". As seen in Fig. 1 (Sect. 2), the Validation Target are allocated to the Scenario Class Acceptance Criteria as one to one relation. The following informal definition of the Validation Target is in line with the ISO 21448 [1].

The Validation Target specifies the necessary test efforts and expected test outcomes to argue that the Scenario Class Acceptance Criteria is met with a sufficient confidence. Or in other words, the Validation Target addresses the argument and evidence for the sufficient handling of functional insufficiencies due to known triggering conditions as well as the argument and evidence for sufficient coverage of unknown triggering conditions. Figure 3 shows the aspects to be considered in the Validation Target.

The test space defines all relevant known scenarios of the respective scenario class and is done based on the scenario analysis in context of ODD and FDD.

This test space can be broken down into test sub spaces describing a number of logical scenarios that can be tested in the same test environment and under similar

Table 3. Examples for behavioural aspects of the Scenario Class ACCR for the exemplary scenario class "All scenarios containing ego vehicle standing at traffic light" of the exemplary ADS Feature "Inner City Autopilot" Here the example of Table 2 is continued.

Feature:	*Inner City Autopilot, Bavarian City, SAE Level 4* [4]	
Hazards:	*Side collision with cyclist*	
Scenario Class	*All scenarios containing ego vehicle standing at traffic light*	
Fundamental Requirements	Example Global ACCR	Remark
Legislation	If a cyclist is approaching the ego vehicle in a way that it is anticipated to be next to the ego vehicle during start of movement, the ego vehicle shall not start movement If a cyclist is present next to ego vehicle in the same lane, the ego vehicle shall not start movement until the road users have cleared the space next to the ego vehicle in the same lane	*This is a constructed example to demonstrate the breakdown approach. It is not complete and directly applicable in reality*

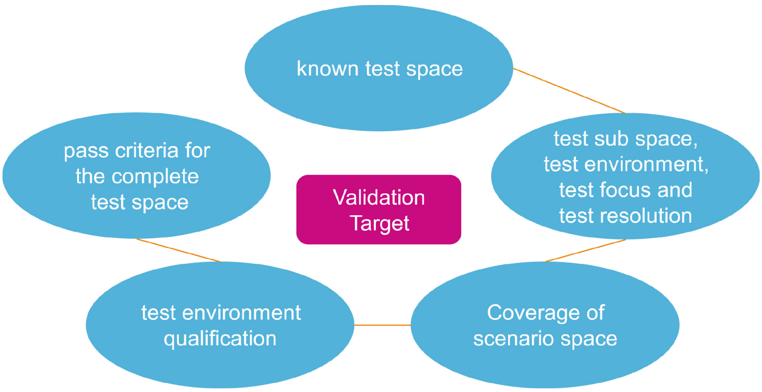

Fig. 3. Aspects of the Validation Target

test conditions (e.g., weather, objects, dynamic aspects). Criteria for test environment assignment are test environment characteristics and capabilities. For example, a certain portion of the scenario class can be sufficiently tested virtually using simulations. For another portion the simulations might not be sufficient, but it can be tested using recorded data. A third portion must be tested doing proving ground tests or open loop drives. The test resolution definition and test focus distribution within the test sub space must be done applying quantitative and qualitative methods like hazard modelling, analysis of minimum detectable parameter resolutions or exploration of critical unknown parameter combinations [18]. Dedicated methods like full factorial approach, combinatorial testing, random search, or active DOE can be applied [19]. The expected test outcomes for each test case are defined considering the behavioural aspects of the acceptance criteria and scenario specific expectations.

The coverage of the scenario space, hence, the probability-based absence of unknown triggering conditions, must be shown ensuring a significant representation of the scenario class within endurance test data in the real world. To ensure test environment capabilities, qualification requirements must be formulated for each test environment to ensure the validity of the generated test results. The pass criteria for the complete test space are specified by the Scenario Class Acceptance Criteria.

Finally, an argument for probabilistic validity of the Validation Target must be provided as part of the SOTIF Argument. This probabilistic validity, so the quantification of the certainty of the SOTIF Argument, is defined as Confidence Level (CL). It considers uncertainties in scenario analysis (probability-based quantification of unknowns), test bench qualification, test results, statistical data as well as argumentative assumptions.

4 Context to Automotive Engineering Levels and Introduction of Performance Targets

After the informal definition and breakdown to scenario level, this chapter provides a mapping of the respective Acceptance Criteria and Validation Target to the generic engineering levels of the ISO21448 conform development process and the application of the supportive Performance Targets. As seen in Fig. 4 (left part), the Global Acceptance Criteria is defined on Vehicle level while the Hazard-based Acceptance Criteria, the Scenario Class Acceptance Criteria and the Validation Target are allocated on AD Feature level. Since the Acceptance Criteria and Validation Target are based on residual risk and scenarios a breakdown to lower architectural levels results in increasing effort due the complex cause and effect relations within the software. This means, at a certain point it gets impractical to breakdown the accepted residual risk on AD Feature level to accepted residual risk portions for individual software (SW) components like object detection, fusion, or trajectory planning.

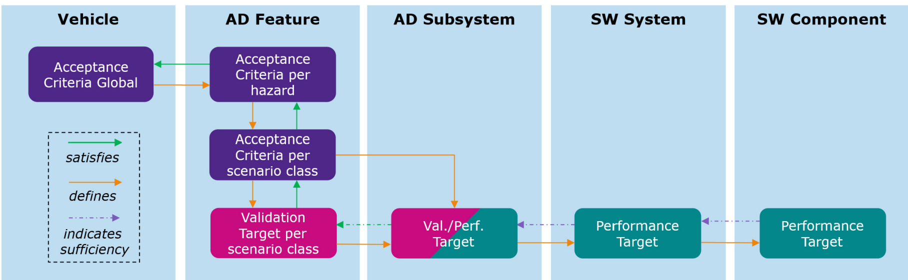

Fig. 4. Allocation of ACCR, VT, and PT to the engineering levels. The application of VT or PT on AD Subsystem and eventually lower levels. is dependent of the respective complexity.

To support efficient development and to avoid test efforts on premature software, Performance Targets are introduced in order to provide dedicated quality goals for development on AD Subsystem, SW System and SW Component level. The Performance Targets on the respective level indicate the maturity for integration and testing on the next higher level up to the validation activities on AD Feature and Vehicle level.

Performance Targets are Key Performance Indicators (KPI) indicating the maturity of the respective AD Subsystem, SW System or SW Component for further integration and testing on higher level. Performance Targets can be e.g., bounding box accuracy (Object Detection), drop-out rates (tracking, positioning), false positive/false negative rates, uncertainty values (aleatoric and epistemic), precision-recall values, etc. The types and values of the Performance Targets are strongly dependent on the AD Subsystem/SW System/SW Component specification and context and have to be defined individually based on qualitative and quantitative methods.

5 Summary and Outlook

Within this paper we presented the AVL Software and Functions GmbH approach of defining and breaking down Acceptance Criteria from global to scenario class level. The Validation Target for the Acceptance Criteria per scenario class is defined and underlying methods are briefly described. Performance Targets are introduced to support efficient development and to avoid premature testing by setting quantitative values as quality goals for integration and testing on higher engineering levels. Next to the definition of the Acceptance Criteria, the definition and argument for the Validation Target is one of the key challenges of ensuring the SOTIF. We must prove confidence that our argumentation for test sufficiency is valid and actually can be seen as evidence for the Acceptance Criteria compliance. In this course we come across many open questions like.

- which logical scenarios within the test space do we need to test?
- with which granularity of parameter variations do we need to test this sub spaces?
- how do we find the critical parameter combinations?
- which test environment is suitable and sufficient to test the individual scenarios?
- are this test entities sufficient? What is the uncertainty of the results?
- what is the uncertainty of the scenario analysis? How much is still unknown?
- and finally, what is the uncertainty of my argumentation?

To summarize, defining the Acceptance Criteria and Validation Target is one of the key challenges of SOTIF. We are aware that this paper just scratches the surface of this topic and leaves many open questions when it comes to the actual “how to”. AVL Software and Functions GmbH intends to continue the theoretical and practical elaboration of underlying methods and strives to publish the results in order share knowledge and enable constructive discussions.

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Sustainability and Life Cycle Challenges

Sustainable IT Products and Services Facilitated by "Whole Team Sustainability" – A Post-mortem Analysis

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Abstract. IT Sustainability becomes more and more important within the growing digitalization. To lever as much as possible it is more than green coding or the usage of power-efficient hardware. The overall value stream from Business over Development to Operations (BizDevOps) is subject of sustainability alignment. This holistic alignment enables a life-cycle view about sustainable IT product and service delivery. An approach and its key aspects is presented how a whole team sustainability – based on the interdisciplinary cooperation of the BizDevOps-team around the sustainability topic- could be established within large enterprise IT settings. The approach is analyzed on a case study of a cloud service team within the Volkswagen Group IT.

Keywords: sustainable software engineering · green coding · agile transformation · green IT · ISO 14001 · DevOps · BizDevOps

1 Motivation, Context and Methodology

Many enterprises in different countries and regions are working to become more sustainable. Examples within the IT domain are with, e.g., carbon neutral or negative targets Google [1] or Microsoft [2]. To establish a whole sustainability different dimension are on scope. At least these four dimensions are relevant according to [3]:

- "Social sustainability. Social sustainability focuses on ensuring current and future generations have the same or greater access to social resources by pursuing generational equity. For software-intensive systems…;
- Environmental sustainability. Environmental sustainability aims to improve human welfare while protecting natural resources; for software-intensive systems, this means addressing ecological requirements, including energy efficiency and creation of ecological awareness; and
- Technical sustainability. Technical sustainability addresses the long-term use of software-intensive systems and their appropriate evolution in a constantly changing execution environment; and
- Economic sustainability. Economic sustainability focuses on preserving capital and financial value."

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To address these four dimension a holistic approach is needed which simultaneously focus the dimensions contininously. The work suggests that to deliver continuously sustainable IT products releases and services the whole BizDevOps team has to be aligned with a sustainable mindset and has to establish practices to ensure a life-cycle sustainability. In agile setups the Biz – business – is typically represented by the Product Owner, the Dev is the development team (including topic experts like for security or testing) and Ops is the team running the service. For the case that it is established as a DevOps team both is combined in one team. The term *whole team sustainability* is defined in this context by a BizDevOps team handling systematically sustainability aspects with the focus on the long-run respectively with a life-cycle view of the IT product or service they build and run.

The research questions around whole team sustainability within an enterprise IT are:

RQ1: Why the 3 parties – BizDevOps - have to work together respectively be aligned about sustainability to form the base for whole team sustainability?
RQ2: What is needed to establish a setup fostering whole team sustainability organizations?
RQ3: How to manage and perform whole team sustainability approaches in Agile organizations respectively organizational units?

Section 2 elaborates the relevant literature. Section 3 presents the applied methodology and Sect. 4 presents the gathered data from the Volkswagen Group IT cloud service. Section 5 analyzes the data and generalize were possible. Section 6 discuss the analysis and reflects its limitations. Finally, Sect. 7 concludes by summarizing the article's key contributions to research and practice and giving an outlook to the authors' ongoing research activities.

2 Literature

The literature sections elaborates the state of literature about "whole team", key-aspects for IT sustainability, life-cycle views and evaluation approaches.

The term "whole team" comes from the eXtrem Programming (XP) community and characterize that customers and developers work respectfully side-by-side together [4]. XP is based on a set of practices which are more or less intuitive or have to be learned [5]. This origin can be a base to extend the existing XP approach with sustainability aspects and operate them with additional practices as proposed for security in [6].

Wirth's Law which claims "software is getting slower more rapidly than hardware becomes faster" [7] is a significant issue for the IT. The issue makes it difficult to become more sustainable from the "footprint" perspective in the long-run. Because the software demands more and more hardware by making old non-performant hardware obsolete. Existing other "IT law's" [8] with similar effects about a short hardware usage period. At least this topic as the main outcome respectively value has to be addressed by a whole team sustainability within the IT domain.

From a sustainability view the value stream is an important lever for improvement. Existing approaches to identify improvement potentials like Value Stream Mapping (VSM) which can be combined with a life-cycle view and Life-Cycle Assessment (LCA)

[9]. Sustainable VSM is an refined approach to emphasize the sustainable aspect in manufacturing [10]. The issue with these approaches is that they are not designed to address IT or software with its specific aspects.

Sustainability is a multi-dimensional topic in [3] are four dimensions defined. However, others define more like [11] with five dimensions. At least a basic set of dimensions should be addressed by a whole team sustainability approach.

A IT product or service has a life-cycle [12]. However, the product or service is based on the software life-cycle [13] and hardware respective data center life-cycle [14]. Additionally, the team responsible for these life-cycles has also a life-cycle respectively stages [15]. A whole sustainability approach should handle these different life-cycles to address the cradle to cradle mindset [16]. The approach should identify dependencies of the life-cycles and manage them for an overall sustainability were possible. Furthermore, cradle to cradle is seen from turnover-view e.g. of a software release to the next release or team constellation to a next constellation with other team members. Because in most cases the turnover is not a complete new thing – it has to be compatible to its “history” to avoid too much “waste”.

3 Methodology and Evaluation Context

For a systematic elaboration of a whole team sustainability approach a post mortem analysis [17] of an enterprise IT service is conducted. A post mortem analysis is useful to evaluate projects in a retrospective view. Also running projects can be evaluated to get an interims state and can be realized by documentation analysis and interviews of project members [18]. The evaluation and analysis of its results is used to identify practices which are performing in agile teams within large enterprises.

Whole team sustainability has to address within a sufficiency approach at least the four sustainability dimensions of [3]. These four dimensions are used to structure the gather information of the post mortem analysis. This structure is used to avoid to separate the whole team into its three parties – this shows that success comes from the interdisciplinary working of BizDevOps. Furthermore, the mapping to the United Nation Sustainable Development Goal (UN SDG) [19] is made with a reference (SDG number) to show that different goals can supported with a whole team sustainability approach.

The context of the analyzed cloud service Test-Runtime execution (T-Rex) [20] is an over three year systematically established sustainability engineering. T-Rex offers on demand test-runtime execution – the on demand approach avoids by design unnecessary resource allocations. As testing service for IT systems the BizDevOps-Teams of T-Rex is completely located in the Group IT. Over the years more and more sustainability aspects were identified and addressed by the agile team. The sustainability journey started with the Volkswagen goTOzero initiative instantiation in the T-Rex service setup. The analyzed cloud service supports the Volkswagen Group IT with its scaling testing capability. The post mortem analysis is conducted in the T-Rex service team to get an intermediate result about their sustainability journey. The agile team is responsible for the service strategy, development and delivery to the users – a typical BizDevOps-team which evolves and established its whole team sustainability capabilities.

4 Post Mortem Analysis of a Cloud Service

The over the three years applied sustainability actions and measures are structed by the four sustainability dimensions. In the following notable information is listed. The topics are assigned based on their key-contributions to the sustainability dimension (often many dimensions are supported):

Ecologic Sustainability:

- Sustainability case evaluation: helps to identify what features are helping to reduce the footprint in comparison to the "traditional" handling without a footprint view for the T-Rex service. In most cases the footprint of, e.g., an additional micro-service is small and explicit mappable to a functionality or user value unit. This action contributes to SDG 8, 12 and 13.
- Sufficiency evaluation: to avoid unnecessary implementations by rigor demand analysis,e.g., to avoid that political/money-driven features are implemented. For "non-avoidable" demands the optionality is expressed by, e.g., not activate the feature by default to reduce footprint and measure its active usage (to deprecate not anymore used features). This action contributes to SDG 12 and 13.
- Rightsizing: to address workload specific characteristics different "templates" are used to ensure a high utilization of the allocated resources for example for compute respectively vCPU. This action contributes to SDG 12 and 13.
- Offer fine-grained configuration options: to enable operating to adjust, e.g., data delete policies and redundancies to reduce the storage footprint. This action contributes to SDG 12 and 13.
- Default settings are "green": the default is set to the smallest footprint option available, e.g., real-time monitoring for test-jobs is "off" by default, because in many cases it is not needed. This action contributes to SDG 12 and 13.
- Power efficient solutions: to address the topic a cheat sheet for sustainable software engineering [24] was developed to facilitate the design and implementation of power efficient features and capabilities. This action contributes to SDG 12 and 13.
- User value unit footprint reduction: to address this topic different actions were placed to reduce, e.g. scaling respective starting-time for workloads. Measures are, e.g., container size, cache usage rate, synchronizing time-frames. The measures also initiated changes in the build process to optimize runtime footprint. Examples are the usage context specific optimized frameworks and libraries. This action contributes to SDG 12 and 13.
- Monitoring of resource allocations: to address this topic two views are established one on a low-level resource allocation level like CPU and RAM usage to optimize utilization of resource units. Second, a consumer respectively user value unit oriented monitoring view is established which is also used to feedback to consumer to motivate less consumption. Both are used for the optimization of the service delivery footprint. This action contributes to SDG 12 and 13.
- Usage of remote work option: to significantly reduce the travel footprint of the (EU-wide) distributed agile team. This action contributes to SDG 12 and 13.

Economical Sustainability:

- Rebound-Effect evaluation: Helps to identify rebound effects generated by “smart digitalization” services like significant more service consumption fostered by usage facilitation. However, it is not always easy to limit this additional consumption effects. This action contributes to SDG 8 and 12.
- Analysis of feature usage: helps to optimize highly used features footprint. Furthermore, it can be used to make currently not attractive features within a strategic area more attractive or deprecate and remove “unused” features. This action contributes to SDG 8 and 12.
- “Sweet spot” evaluation: placement keeps the service offer competitive and the sweet spot focused optimizations boots attractiveness. This action contributes to SDG 8 and 12.
- Cooperations: find partners to lever synergy effects and free resources to focus on own value propositions and future topics, e.g., around the sweet spot. This action contributes to SDG 17.

Social Sustainability:

- Trainee program: objective is to continuously host two trainees for a few months and have at least one junior developer in the team. This action contributes to SDG 4, 5, 8 and 10.
- Establish remote work respectively home-office: were possible remote-work is used for better work-life-balance and it is an entry-point for “non-local” team members. This action contributes to SDG 3, 4 and 10.
- Avoid vendor-locks: keeps independence of specific cloud providers to go to greenest cloud service offer or fairest employee management provider etc. This action contributes to SDG 8 and 12.
- Systematic team development: Team development with efiS® framework Em power pillar and the building blocks aTWQ [21] and TTM [22]. This action contributes to SDG 4.
- Awareness “program” Sustainable Software Engineering (SSE): cyclic refresh SSE skills in the team. This action contributes to SDG 4.
- Transparency and awareness for user/customers: offer consumption information on the login page and integration of the sustainability topic into the official T-Rex trainings. This action contributes to SDG 12 and 17.

Technical Sustainability:

- Technical assessment: new technologies like serverless, artificial intelligence, CPUs architectures are scouted and assessed about opportunities they offer to become a more sustainable service if they are integrated adequately. This action contributes to SDG 9, 12 and 13.

– Adopt disruptive options: do not spend more effort in “outdated” approaches as needed to keep the change efforts for migration small and easy were possible and get the benefits from new more sustainable options early. This action contributes to SDG 9, 12 and 13.
– Adapt the architecture: establish a flexible architecture and adapt it to exploit chances to improve the footprint etc. and refactor technical debts to stay nimble. This action contributes to SDG 9, 12 and 13.
– Build new technical solutions: find non-standard ways to integrate technologies like a “small” monitoring/logging approach. This action contributes to SDG 9, 12 and 13.
– Build new processes: establish a new approach to automatically evaluate Free and Open Source Software (FOSS) components [23] for better selections and long-term use. This action contributes to SDG 9, 12 and 13.

Additional notable information are:

– To establish team awareness cyclic the cheat-sheet for sustainable software engi neering [24] was “refreshed” in the team.
– To establish a continuous improvement in the long-run the ISO 14001 was instan tiated in a lean way with the efiS® framework [25] LoD layer [26].

The topic sustainability is driven without “extra budget”. The savings of the “quick-wins” were re-invested into sustainability related stories to initiate the continuous improvement. Later on, the sustainability mindset was integrated into the daily work and is part of the normal effort respectively cost estimation of features and stories.

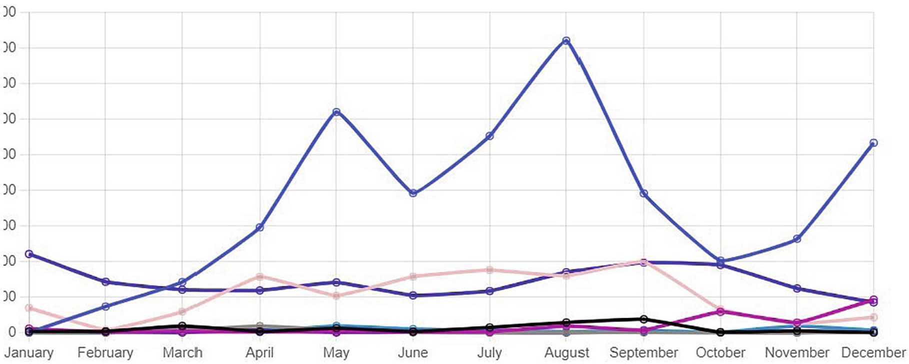

Fig. 1. Example of cyclic consumption analysis to identify “power-users”.

Furthermore, the team actively communicate, participate and contribute on the organizational level discussion about how to improve the sustainability of the Group IT. An example is the evaluation of the usage to detect rebound effects and power users respectively customers. The Fig. 1 presents an analysis on a monthly T-Rex usage based machine allocation minutes of some selected power-customers (each line represents an project/program). The positive thing is that no systematic rebound effect is visible. Identified top-customers get “special care” and consulting about improvement of their testing approach to reduce the large consumption. However, some large programs as "single" customer have still large consumptions also after optimizations. Especially, the again upcoming blue-line trend in December initiates actions in January about redesign of the workload to run less resource intensive. Additionally, the violet-line came into action scope, too. One generic learning from the first consummation evaluations was that a feature was developed which indicates for each value unit (test job) the resource efficiency based on the utilization of the user demanded and deployed resources.

5 From Value Stream Analysis to Whole Team Sustainability

This section consolidates the experience and learnings from the post-mortem analysis and arrange them to a blueprint for an enterprise IT setup. The consolidation results in a life-cycle view which derives a mindset, values, principles, practices and an indicator set to establish whole team sustainability for a value stream.

To address the four dimensions of sustainability each phase of the life-cycle has to be analyzed about its contribution to the sustainability dimensions. To ensure that all are optimizing the same sustainability goals and targets it is important to have a transparent sustainability vision and mission refined. In most case the enterprise has this established. If not, with the UN SDG a product or service team can define this by their own. Depending on the business domain and objectives which are supported by the software different UN SDG are relevant, e.g., a maritime trade software can contribute to UN SDG 14 (life below water). Important is that within the entire life-cycle existing independent sub-life-cycles. These life-cycles have to be addressed and managed from a whole sustainability perspective. On an abstract view the IT builds and ships releases of software running on hardware infrastructure. The life-cycle of the software depends on (security) patches, bug fixes and the rollout of new features and capabilities. This leads to a more or less high frequent commissioning and decommissioning of software components forming the product or service. The infrastructure respectively hardware running this software has an independent life-cycle – often defined by, e.g., an on the enterprise level defined amortization schedule or leasing contract. Also "virtual hardware" of cloud infrastructure is managed in a life-cycle by the cloud provider, too. The team building and running the service also has a life-cycle [15] which is independent of the overall product respectively service life-cycle [27].

Figure 2 shows the different life-cycles. Sometimes the team life-cycle is oriented on the different phases of the service to adjust skills to the specific service phase demands. Furthermore, the team life-cycle depends on personal respectively individual decisions of team members – the team constellation in the IT domain is volatile in the war for talent [28], but has an impact about the overall performance [29]. This make the team life-cycle a relevant parameter for whole team sustainability. A change of the teams constellation, e.g., coming or leaving team members are leading to a new "release" of the team, because relevant attributes of the team are changing like skills.

Furthermore, in the startup, scaling, running and retire of the IT product and service life-cycle phases the team needs other skills and capabilities and its size is adjusted to the demands of each phase. During the startup phase the team grows and adds skills to build and run the service. In the scaling phase skills about availability and performance

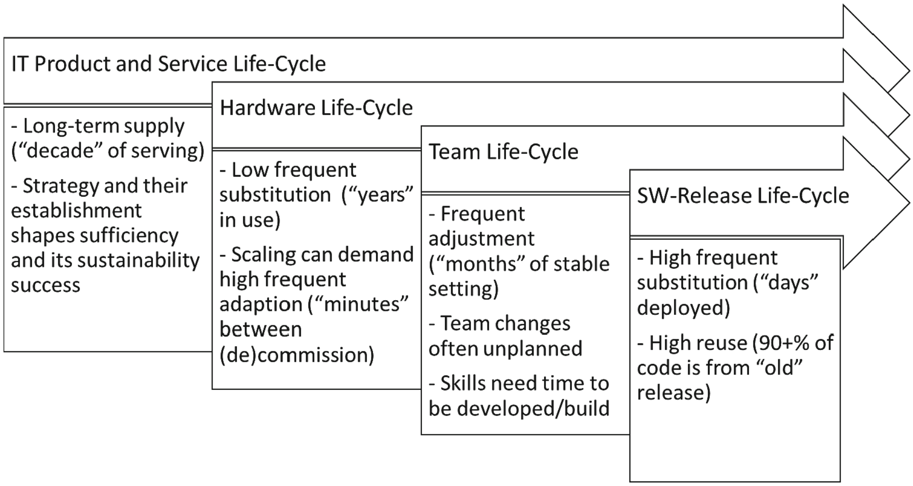

Fig. 2. Typical enterprise IT service life-cycle.

are added. During running development skills are reduces. During the retirement phase the team focus on conserve relevant data or migrate it to a successor service.

Each of the four life-cycles has its specific sustainability levers. The product and service life-cycle has to establish strategic sustainability goals like "we beat Wirth's law" to keep the topic on the long-term agenda. The hardware life-cycle is often defined by team-external parameters like enterprise procurement and amortization policies. The goal is to use the hardware with a high utilization within its life-cycle and if possible enlarge the life-cycle by trigger the substation later than the amortization plan allows. Sharing hardware is an valid option to reach high utilization, too – as cloud computing it does. The software release life-cycle has as objective to service the customer/user within minimal resource allocation from the sustainable view. This can be realized by omitting what is not needed (sufficiency) and optimized efficiency for doing what is not avoidable or positive: necessarily needed. The most important on the sustainability journey is the team who is implementing and acting. The team can be aligned with the agile approach to establish a mindset, values, principles and practices for sustainability.

Figure 3 shows what is contributed to the whole team sustainability in a value stream of an IT product or service. The sustainability levers are handled by the BizDevOps teams. To realize the levers all three parties of the team have to work interdisciplinary together. An important role has Biz which demands IT or software and uses the result. Biz initially evaluates the demands against sufficiency aspects and also influences the workload with responsible consumption. Dev is accountable for a small footprint of the running software with the build for sustainability in operating and usage. Ops is responsible for adequate workload sizing of the scalable components and adequate configuration to keep the footprint as small as possible. This value-stream view helps to answers RQ1 why all have to work together to establish whole team sustainability.

To establish a setup fostering whole team sustainability the sustainability aspect is integrated into the agile backbone of the team. It extends the agile mindset, values,

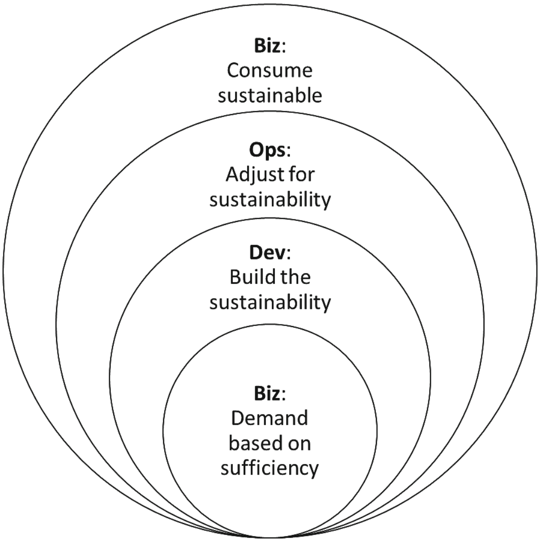

Fig. 3. Typical enterprise demand IT (BizDevOps) sustainability distribution.

principles and practices. Derived from the presented life-cycle approach the following mindset should be established:

- sustainability is a journey of releases from cradle to cradle to reduce “waste”;
- beat Wirth’s law in the long-run and reduce software growth;
- optimize customer respectively user value units footprint.

The value set should include:

- sufficiency over full-blown solutions;
- reuse over self-made components;
- adopt disrupting technologies over optimize established technologies.

The principles should include:

- evaluate the “sustainability case” for new demanded features, functionality and characteristics;
- collect, process and store only necessary data;
- build on optimized libraries and algorithms were possible;
- build fine-grained scalable software components to realize user value units;
- respond to workload changes with fast adaption of the running software.

The practices often are depending on the technology. However, some generic practices to include are:

- measure sustainability indicators to track their trends;
- reflect respectively challenge cyclic with all team members the status quo and ideate sustainability possibilities;

- define milestone targets for sustainability possibilities to address them with dedicated actions;
- handle sustainability as a first class design decision aspect in the daily software development.

These presented extended agile approach helps on team level to establish whole team sustainability. Additionally, on organization level the following aspects have to be established:

- establish an awareness program about IT sustainability;
- foster trainings of the employees about IT sustainability;
- establish a management system with cyclic reviews or audits about IT sustainability to keep the topic present in the long-run.

Together, the team and organizational facilitations are fostering whole team sustainability within an organization – this addresses with focus on adequate skill-sets and continuous focus respectively improvement RQ2.

The management of environmental and sustainability aspects of the organizational level has to be refined into the BizDevOps teams to establish a systematic measurement and improvement of sustainability and whole team sustainability. The ISO 14001 with its focus on environmental sustainability is a good base to widen the focus also to the four dimensions ecological, economical, social and technical sustainability. The proposed approach is a pragmatic approach, because many enterprises have a management system aligned with the ISO 14001 established since years. To extent the ISO 14001 management system for whole team sustainability the indicators from Table 1 are recommended. Table 1 shows the matrix of the dimensions of sustainability and the whole team sustainability parties with indicators to manage and perform whole team sustainability in Agile organizations – this addresses RQ3.

Table 1. Indicators to perform and manage whole team sustainability.

	Biz	Dev	Ops
Ecologial	Sufficiency evaluation established for demand Measure "over-consumption" and potential rebound effects to initiate actions like adjust price-model User-Consumption is optimized/minimized	Sustainability evaluaion of architecture, design and implementation – handles sustainability as first class optimization attribute Implement fine-grained adjustment options for customer/user value units Define sustainability measures and act about the measures	Fast adjustment of resource allocations to current workload Use configuration option to minimize footprint Collect and evaluate sustainability measures

(*continued*)

Table 1. (*continued*)

	Biz	Dev	Ops
Economical	Business-case evaluation established for demand Service price is aligned with resource allocation per user* value-unit Reinvest at least savings from footprint reductions into future sustainability actions	Implementation is driven by minimalism/sufficiency Implementation is simple to foster maintenance	Fast adjustment of resource allocations to current workload
Social	Ethical aspects are evaluated for demand	Train/educate trainees and junior developers	Train/educate trainees and juniors
	(dataprotection, tracking etc.) UseHome-Office were possible	Keep ethical aspects of the software in mind during development Use Home-Office were possible	Keep ethical aspects of the deployment in mind (data protection etc.). Use Home-Office were possible
Technical	Demand is independent of technical "requirements" were possible	Select power efficient programming language. Select power efficient platform/technology	Select deployment platform/environment with best configuration options to minimize footprint Select most power-effcient hardware possible

* user(s) drives the operational consumption, not the formal customer who gets the bill.

6 Discussion and Limitations

Based on the gathered data and its analysis it is visible that established LCA or VSM are not the right measures to address sustainability in IT or software driven products or services. Additionally, the established approaches do not address the life-cycle of teams itself – they only focus on outcome. The presented approach incorporate the four life-cycles (product, hardware, team and software) to have a holistic view on the value stream of the team who builds and cares about the valuable product and service. Based on this view the whole team sustainability is established.

The proposed whole team sustainability approach is effective in the four dimensions of sustainability. For example in the social sustainability dimension the presented T- Rex case is part of the Volkswagen Group IT environmental awareness training. An additional education action is that the T-Rex team offers the vocational training organization four half-year training slots per year to run as trainee a small project within the T-Rex setup.

The most important is, that the value-units a service offers as deliverables to the customer are sustainable. This is realized by a systematic interdisciplinary work of the BizDevOps team within a whole team sustainability thinking. First the Biz evaluates the “footprint” of the existing approach to see how much by design the new T-Rex approach can potentially improve (EU Taxonomy oriented) – in Fig. 4 the blue (static machine allocation) vs. the other bars with the on-demand average virtual machine allocation. Then Dev starts to improve the architecture, design and implementation about the ecological footprint – in Fig. 4 the red bar with low horizontal inclination. Ops optimize during runtime - e.g., decide to offer High-Availability (HA) deployment - and measures about potential footprint optimizations - e.g., based on utilization measures and potential rebound effects. Over time the red bar is pushed more down. Important is that the overall architecture is able to add new use-cases. This is a good position for sustainable growing, if each new customer moving from the traditional approach to T-Rex reduces its “test-runtime footprint” to less than 1/10.

Additionally, the growth into new market segments of other test-runtimes also is sustainable, because the integration – based on the whole team sustainability mindset and its cross-functional respectively interdisciplinary working - comes with an extreme small additional footprint of a micro-service. An example is that to add a new T-Rex test-runtime engine only 2 to 3 new billed customers are needed to have a break even from the implementation costs respectively efforts in approximately one year. The ecological footprint reduction to the existing usage approach is still valid. The overhead footprint of T-Rex grows only about the additional micro-service with typically a few hundred MB RAM and approximately 0,2 vCPU core allocation for the management and handling of the additional test-runtime engine.

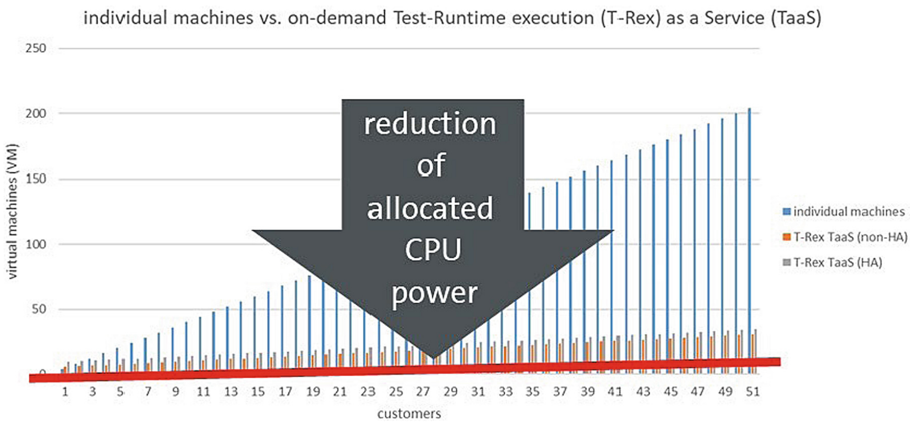

Fig. 4. Ecological sustainability effects from whole team sustainability acting.

The proposed activities can be started without an large additional sustainability budget, because in most cases the realized footprint effects come with some cost optimizations, too. This enables also teams within a Zero Budget approach to start the whole team sustainability journey if the realized savings are re-invested into the team respectively their products and services.

A limitation is that the observation is based on a typical enterprise IT setup. Not all companies have the same strategy about service development or team setup. In case in which, e.g., the team is more stable other strategies and operational approaches can be more effective. Furthermore, the post-mortem analysis focus only on one service within a 3 year sustainability journey – this does not address the entire service life-cycle. However, the focus of this work is only the establishment of whole team sustainability. In observed time the turnover-rate of the team members was high and shows that the observations are stable in many different team constellations respectively "team releases". An additional limitation is, that the Biz was also the IT domain with an IT for IT service for software testing. This made it easier to "integrate" the Product Owner as member of the IT and not from a real business department. However, the role and the job of a Product Owner is not dependent on its department allocation in the organization and should not influence the observations.

7 Conclusion and Outlook

This work shapes the term *whole team sustainability* and shows how an enterprise IT product respective service delivery team enables itself with a whole sustainable approach to establish a sustainability life-cycle for their service delivery value stream with a holistic BizDevOps view. Overall, we suggest to combine sufficiency approaches for sustainable engineering with frugal innovation approaches [30] to avoid over-engineering in combination with an agile organization to establish a sustainable value stream driven by a whole team sustainability culture. The presented approach is not limited by design to specific agile approaches like XP – it can be used as an overlay to many other approaches, too.

The key contributions *to practice* can be summarized by the following aspects:

- It is possible to establish a whole team sustainability driven value stream for IT products and services within a large enterprise IT setup.
- In established enterprises it is active work to establish and maintain a whole team sustainable setup respectively environment for the value stream over the product and service life-cycle – the turnover of team members has a significant influence.
- It is possible to run sustainability value streams aligned with the UN SDG and the ISO 14001 setup of the enterprise to ensure strategic alignment within the autonomous agile whole sustainable teams.

The key contributions *to theory* can be summarized by the following aspects:

- Identification that there is a kind of convergence of Agile and Zero Budget approaches to establish a sustainable value stream at least at the beginning of the sustainable journey.
- Presenting "facilitation parameters" (mindset, values, principles and practices) to establish a whole team sustainability environment for continuous sustainability improvement delivered by a product or service value stream within large organization.
- Presenting an indicator set to perform and mange a whole sustainable team fostering a sustainable value steam establishment.

As summary about the entire organizational context there are some open questions: Does an Agile and Zero Budget approach for projects intuitively become a business accepted approach over time – especially when sustainability becomes over time an area of investment instead of cost reduction?

Also keep in mind the question how to keep the whole team sustainability approach respectively culture established after leaving people the team and new stakeholders are coming in about the sustainability focus – the topic needs continuous attendance and prioritization?

An additional investigation aspect for the future is: existing standard patterns or KPIs to establish and maintain whole team sustainability? What is needed to extend the IT view to, e.g., an embedded system view with mechanic or systems engineering in general?

A further question derived from our observations is does it need a specialized governance or is it a topic of the autonomous teams to build and establish a whole team sustainability culture?

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Emerging Technologies Enabling the Transition Toward a Sustainable and Circular Economy: The 4R Sustainability Framework

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Abstract. A Circular Economy (CE) is an emerging economic model, restorative and regenerative by both intention and design. The CE evolves in a repetitive cycle, where waste is returned back into the of a new product by recycling and reusing materials. Thus, CE represents a sustainable and productive economy model that is financially, economically, and socially feasible. It is increasingly regarded as an acceptable and desirable solution to achieving prosperity whilst acknowledging ecological and social boundaries. Opposed to the unsustainable Linear Economy, it draws on complexity and systems thinking by imitating nature that does not produce any waste. However, the implementation of CE in industry is slow paced, mainly due to barriers caused by complex sustainability transitions and innovations needed to cover a systemic and systems thinking approach. In the last few years, the concept of a CE and the transition from a linear, take-make-waste system to a cyclic system that reuses, remanufactures, and recycles materials, have gained increased importance, and have attracted considerable attention from both scholars and practitioners. Research that examines the role of emerging technologies in supporting this transition is therefore imperative. The CE has also become a key policy objective due to increased frequency of natural disasters which have been caused by human activity and social pressure on policymakers and governments to introduce measures in order to ensure sustainability, bio-based products and sustainable processing. This study discusses the concept of the CE as well as the transition from a Linear to a closed-loop Circular Economy based on resource regeneration and ecosystem restoration. It unfolds the role and importance of emerging technologies related to Industry 4.0 and Industry 5.0 in this transition by analyzing their adoption and implementation in the context of the CE. The key benefits of transformational change include increased engagement, improved performance, and higher levels of creativity and innovation. The ultimate and implicit aim of this paper is to increase awareness of the required actions ideally from every single individual on earth. Through increasing understanding of the fact that the use of emerging technologies is not a magic wand for addressing

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the ecological challenges but a tool for supporting the transition to a cleaner environment. In order to obtain an authentic and genuine transition, a fundamental social and cultural shift needs to pave the way.

Keywords: Circular Economy · Sustainability · Blockchain · Artificial Intelligence · Internet of Things · Sustainable Development Goals

1 Introduction

The economy of today is wasteful. We are using the equivalent of 1.6 Earths to maintain our current way of life, meaning that natural resources are consumed to an extent that exceeds what the Earth can generate each year[1]. A shift in the way we use resources, materials and energy within the economy should urgently be made to come up with more sustainable solutions; hence, a social and cultural shift is required, as it has been pointed out in the 2030 Agenda for Sustainable Development[2].

No waste is produced by nature. Biodegradation breaks down dead plants, animals and the things produced from them so that invaluable nutrients are released into the environment to be reused by other organisms. The whole planet is an interconnected complex and adaptive system thanks to this principle [37]. On the contrary, since the industrial revolution, design, production, and consumption systems have predominantly been based on a linear system that extracts, uses, and then discards resources at the end of their life. This trend is also called "*take-make-dump/take-make-dispose/take-make-waste*" ref. The closed-linear system, powered by finite fossil fuels resources, such as oil and gas, depends heavily on immense consumption. It leads to resource scarcity and pollution and has a profound environmental and social impact. This outdated world-view is based on the 18th century enlightenment period, which comprehends natural systems through a mechanistic approach [51]. Unsustainable consumption, resulting in increased extraction of raw materials, manufacturing, and production, is contributing to environmental degradation and acceleration of climate change. Today we are increasingly talking about 'upcycling', a term used for recycling or reusing waste by giving it a second life and a new function [53].

The European Union (EU) binding recycling target[3], which indicates progress toward using more waste as a resource, can be mentioned as an attempt to address these challenges. However, recycling rates of packaging waste, municipal waste and electrical and electronic waste are progressing at a very slow pace in Europe. A surprising result is that the rate of progress has been slowing down lately, with packaging waste recycling even decreasing in the past 5 years. The majority of waste ends up in diverse disposal operations including incineration and landfills. This clearly indicates that a fundamental social and cultural shift is a must. CE strives to prevent waste and pollution from being created in the first place. In contrast to the Linear Economy, the CE concept derives from a systemic and system thinking approach that tries to imitate natural systems which are

[1] https://euagenda.eu/news/710876.
[2] https://sdgs.un.org/2030agendahttps://sdgs.un.org/goals.
[3] https://www.eea.europa.eu/ims/waste-recycling-in-europe.

considered as open, diverse, adaptive, complex, resilient, and optimized [9, 12, 15]. CE thinking has increasingly been encouraged in business, policy, and academic discussions to address environmental sustainability that aims to minimize waste and make the most of resources [7].

Fig. 1. Linear, Recycling and Circular Economy regarding the amount of waste created

CE can be seen as a systems solution framework that tackles global challenges, such as climate change, biodiversity loss, waste, and pollution.

It keeps materials, products, and services in circulation for as long as possible. The CE is a promising approach for addressing challenges of the Anthropocene and a key principle for accomplishing the Sustainable Development Goals (SDG)[4]

Figure 1 shows the differences in the amount of waste in the Linear, Recycling, and Circular Economy.

Studies have showcased that CE is steadily gaining ground and is leading to significant economic benefits [e.g. 8, 47]. Conceptual research has also identified diverse drivers and barriers to the transition [43]. The most noteworthy barriers are old school self-seeker lobbying activities, regulatory, market, technological, cultural, and organizational barriers. The regulatory, organizational, market and cultural barriers are likely to be reduced by increased awareness, as well as compensatory and punitive actions. Innovation is a crucial aspect of CE [21], together with changes in consumer behavior, design approaches, and material choices. In particular, awareness of acceptable consumer behavior in the light of CE needs to be cultivated.

The emphasis of this paper is on the transition from a Linear to a closed-loop Circular Economy based on resource regeneration and ecosystem restoration. More specifically, this paper unfolds the role and significance of emerging technologies in this transition. The main contribution of this study is the development of insights that contribute to the adoption and implementation of emerging technologies related to Industry 4.0 and Industry 5.0 and their integration into CE to minimize the effects of resource scarcity through innovative alternatives. This study also contributes to raise awareness of threatening ecological challenges and to increase understanding of the underlying social and cultural factors that need to be nurtured and encouraged to accomplish the transition to a CE.

[4] https://www.un.org/sustainabledevelopment/sustainable-development-goals/.

The remainder of this study is organized as follows. In the following section, we introduce prior work regarding the CE. The amplified challenges, particularly the ones relating to the urgency of transitioning to a CE are discussed as well as the role and importance of emerging technologies in achieving this transition. It continues by presenting different emerging technologies through the lens of sustainability and CE. The 4R Sustainability Framework is outlined in Sect. 4. Finally, conclusions and future research directions are provided.

2 The Circular Economy

The definition of the Circular Economy was given by the European Union in December 2022[5]: "*The Circular Economy (CE) is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible*". *The definition is followed by an explanation* "*In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible. These can be productively used again and again, thereby creating further value*". In practice, this means a sustainable development that meets present needs without compromising future generations' needs.

The EU produces more than 2.5 billion tons of waste every year[2]. By 2050, worldwide municipal solid waste generation is expected to have increased by roughly 70% to 3.4 billion metric tons[6]. The CE aims to tackle global challenges, such as climate change, waste, pollution and biodiversity loss, by implementing a design-based approach regarding three basic areas, namely: waste and pollution, circulation of products and materials, and regeneration of nature. Three main actions, called the 3R Principles, related to CE are Reduce, Reuse and Recycle[7]. The 3R initiative was launched by the G8 summit in Tokyo in 2005 with the "*aim to shift the global consumption and production patterns towards building a sound-material-cycle society*" (See Footnote 7).

The Finnish Bio-economy 2035 strategy, updated in 2022[8] as seen in Figure 2, includes three overlapping circles, namely Ecologically Functional (Biodiversity, Carbon capture, Solutions to Global Problems), Economically Rational (Double value added, Advanced technologies), and Socially Sustainable (Equity, Well-being, Jobs).

The common area of the three overlapping circles includes equivalent weightings from the three circles and is expressed as Green Transition, Circularity and Renewables. In other words, the common area articulates the transition from a linear economy to a greener, renewable, and circular future.

Both the CE and Circular Business Models (CBMs) are conceptualized and depicted in various ways leading to increasing divergence and a growing semantic dissonance which are intensively detrimental to the implementation of CE principles [7]. For example, Pieroni et al. [39] argued that the existence of different CE propositions without

5 https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits.

6 https://www.statista.com/topics/4983/waste-generation-worldwide/.

7 https://uncrd.un.org/content/3r-initiative.

8 https://www.bioeconomy.fi/facts-and-contacts/the-finnish-bioeconomy-strategy/.

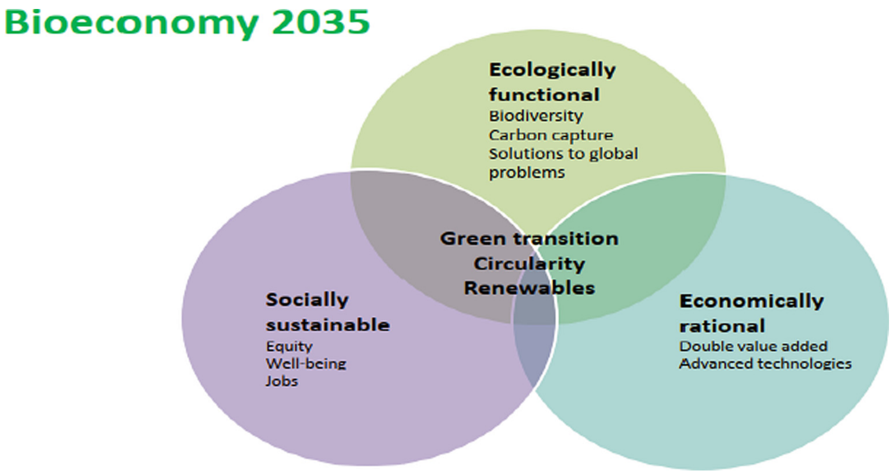

Fig. 2. Finland's Bio-economy 2035 strategy

a consensus might hinder the knowledge consolidation in the field. They claimed that it is fundamental to establish a common discourse and a common language in order to facilitate the dissemination and adoption of circular objectives collaboratively both at an interorganizational and at a societal level.

3 Transition from a Linear to a Circular Economy

Taking part in the CE is a necessary step toward sustainability and fighting climate change. Sustainability can be said to be an approach to systems level that includes economic, social/societal and environmental/ecological factors and the assessment of their interaction [33]. The Triple Bottom Line business concept (Economy, Society and Environment, also called the three Ps: Profit, People, and Planet) suggests that to create increased business value, businesses should commit to measuring their performance in a broader perspective by including social and environmental impact in addition to their financial performance [52].

Some scholars have been critical regarding the CE concept in reference to the following:

i. Contradictory definitions of CE [23];
ii. Theoretical robustness of CE concept developed by policymakers and businesses [44];
iii. Eco-efficiency may lead to more consumption, the so-called "*Jevon's paradox*" [24];
iv. Long-lasting products may not be environmentally friendly (disposal difficulty) [32];
v. Prolonged use of eco-inefficient products [3].

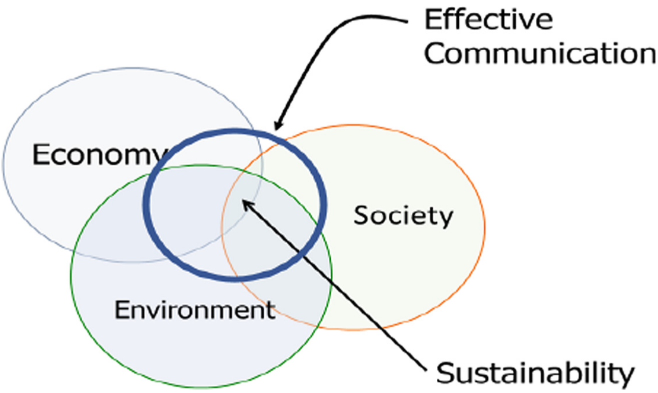

Fig. 3. Sustainability adapted from [52].

Sustainability is an umbrella term that addresses a wide range of scenarios and issues and is far more complex than simply focusing on conservation, eco-friendly options, and renewable energy. To obtain sustainability, a shift in mindsets is essential. Effective communication is imperative for increasing awareness of the need for sustainability. Figure 3 depicts effective communication as a circle covering all dimensions of the Triple Bottom Line.

Many businesses have made the decision to transit to circular and more sustainable approaches. One of the main challenges today is to harmonize and make the green actions visible. Green washing is a big threat for the CE transition because it allows the blending of fake green products with actual green products; hence confuses customers and the transition loses traction and credibility.

4 Emerging Technologies Enabling the Transition to CE

The European Commission's Circular Economy Action Plan[9] explicitly states that "*digital technologies, such as the Internet of things, big data, blockchain, and artificial intelligence will... Accelerate circularity*". Similarly, numerous businesses worldwide have built on digital technologies to further circularity. However, the progress toward CE implementation in industry has been slow paced [38]. Diverse emerging technologies, such as Internet of Things (IoT), Cyber-Physical Systems (CPS), blockchain, Artificial Intelligence (AI), and cloud computing are enablers for the transition to a CE. They are also often used in combination. Moreover, small-scale chemical transformation processes enable shifts in the production-consumption and socio-economic systems [5]. Examples of recycling solutions include "micro-recycling" (selective synthesis of materials from electronic waste) [45]; "peer-to-peer circularity" (features of the sharing/platform economy regarding access over ownership) [2]; and 3D printing-enabled production and consumption [16, 48].

[9] https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en.

4.1 Industry 4.0 and Industry 5.0

The fourth industrial revolution (Industry 4.0) aims at transforming traditional industries into intelligent ones by incorporating innovative, intelligent, and smart technologies. CPS, IoT, and digital twins are some of the contemporary technologies that are used in the context of Industry 4.0 to instill intelligence into the industrial sector by changing traditional manufacturing to smart manufacturing [1, 27, 41].

Industry 4.0 enables physical assets to be integrated into intertwined digital and physical processes creating, thus, smart factories and intelligent manufacturing environments [30]. Industry 4.0 can be described as the convergence of several emerging concepts and new technologies, including radio-frequency identification (RFID), smart sensors, robotics, additive manufacturing, big data, cloud computing, AI, machine learning (ML), and IoT [6]. The main goal of Industry 4.0 is to enhance and transform traditional industries into "intelligent" ones by using new technologies and the improved computation power and hardware of modern systems and by creating a network of interconnected machines, devices, processes, and systems that can interact with each other in real time [26]. Manufacturing industries that adhere to Industry 4.0 technologies are expecting transformational and promising solutions [11]. For example, the creation of digital twins of objects, machines, systems, processes, and assets are no longer just physical copies but virtual models [27]. Industry 4.0 capitalizes on this fact in order to perform real-time monitoring and optimization through simulation-based decision support tools utilizing digital copies of physical systems.

Industry 4.0 and the CE are two major areas in the current manufacturing industry and they are both still in the nascent stage of development. It is generally expected that Industry 4.0 technologies will contribute to the CE. Despite the differences in aims, the technologies and approaches used in the context of Industry 4.0 can also be used for achieving a CE; hence, Industry 4.0 and CE are complementary. However, it is rather unclear how Industry 4.0 technologies might contribute to CE. Industry 4.0 has been recognized as a dynamic enabler of circular approaches which, in turn, can lead toward sustainable Industry 5.0 solutions [32].

Smart manufacturing provides autonomous decision making and simulated environments and optimizes the entire operation procedure (by digitalizing the production process as well as by transmitting, collecting, and analyzing data) [46], thus, it effectively influences the whole manufacturing process by increasing productivity and reducing costs [27]. Enterprises, which capitalize on smart manufacturing, utilize data analytics and information and communication technologies (ICTs) so as to change from knowledge-based manufacturing to data-driven intelligent manufacturing [26].

Industry 5.0 leverages collaboration between creative human experts and powerful, smart, and accurate machinery. It is anticipated that Industry 5.0 will merge this machinery with cognitive thinking humans, thus creating versatility between humans and machines, improving human-machine interaction, and enabling real-time monitoring. Reddy et al. [32] argued that the quality of the production will increase by assigning repetitive and monotonous tasks to processes, robots, and machines and tasks which need critical thinking to humans. They also asserted that another important contribution of Industry 5.0 is mass personalization according to customer needs and preferences.

Di Maria et al. [1] quoted that smart manufacturing technologies have a greater impact on CE outcomes than data processing technologies. Industry 4.0 can also be linked to the aims of CE to disentangle environmental pressure from economic enhancement and bring the environment, economy, and society in harmony [18]. CE seeks cleaner production arrangements, adoption of renewable technologies and know-how, and development of appropriate policies and tools. Interweaving the issues of Industry 4.0 into the systems development life cycle (SDLC) from the perspectives of sustainability and CE will bring combined effects and important meaning to the world. Industry 4.0 is transforming operations management in industrial automation and manufacturing, supply chain management, lean production, and total quality management [6]. Rahanu et al. [41] proposed that Industry 4.0 designers and developers need to be conscious of the duty they have to incorporate ethics into the system specification and design at every stage of the SDLC. This is also true for CE designers and developers as ethics and social responsibility are key aspects of CE.

Mumbarik et al. [34] suggested that policymakers and managers should promote Industry 4.0 technologies, such as blockchain technology because they (i) enhance the integration across the streams of the supply chain (ii) improve the demand and supply planning, eliminating, thus, redundant production and enabling just-in-time production, and (iii) promote green supply chain practices by eliminating unnecessary operations. However, a major shortcoming limiting the widespread application of blockchain technology is the huge amount of power required in validating transactions.

4.2 Cyber-Physical Systems (CPS)

CPS include engineered interacting networks of effectively integrated cyber and physical processes and components enabled by a network, contemporary computing, and sensor technologies [28]. They can be considered as complex multidimensional systems or systems of systems with real-time requirements. They can exert influence on both the digital and physical worlds. These interconnected and interdependent systems can work autonomously both collaboratively and independently due to the dynamic integration of control, computing, and communication. They can also interact with the physical environment by safely and robustly manipulating, emulating, controlling, and monitoring real processes, entities, and objects in real time. Such systems play an important role in enabling innovative services, solutions, and applications, impacting various aspects in everyday life and increasing the global market competition. Hence, they can be considered as critical infrastructure. The demand for their integration and utilization in various domains is continuously rising. Examples of their application domains are smart cities, intelligent manufacturing, e-health, e-commerce, agriculture, robotics, transportation, environmental quality, and energy. For instance, a smart building can sense the needs of the inhabitants and of the building (including weather sensing and forecast system) and adjust different mechanisms, such as blinds, windows, Heating, Ventilation and Air Conditioning (HVAC), lightening etc. to minimize the energy consumption and pollution, while at the same time to create a comfortable and healthy indoor environment.

4.3 Smart Additive Manufacturing (SAM)

A cost-effective manufacturing industry approach that supports execution of development plans, pollution reduction and resource utilization throughout the development life cycle is sustainable or additive manufacturing [32]. It is a process of creating an object by building it one layer at a time, opposed to subtractive manufacturing, in which an object is created by cutting away at a solid block of material until the final product is complete. Smart additive manufacturing (SAM) applies AI algorithms for accuracy and better graphical representation (e.g., 3D printing product design). Sustainability, profitability, and productivity are the main advantages of smart manufacturing industry. Additive manufacturing in Industry 4.0 facilitates transparency, interoperability, automation, and practicable insights [19]. SAM by default reduces resource consumption; hence it positively contributes to the CE goals. SAM can reduce unnecessary mass production for scarce machinery parts and provides the possibility to create parts that are no longer produced.

To obtain the utmost benefits of Industry 5.0, SAM is merged with integrated automation capability to streamline the processes involved in supply chain management and reduce the delivery time of the products.

4.4 Blockchain Technology

Blockchain technology is becoming popular in several domains (e.g., supply chain, retail, healthcare, insurance, travel, and energy) as well as in the context of Industry 4.0 due to its ability to decentralize data and processes whilst also warranting security [28]. Particularly, Blockchain is an open-source, peer-to-peer, distributed ledger including multiple transactions and related data stored within a chain of interconnected blocks in decentralized, peer-to-peer, open-access network [28, 54, 55]. These blocks can be validated by the network using cryptographic means [36]. It is used for sharing and updating information by linking ledgers or databases in a decentralized open-access network and as a result, it improves collaboration and interaction between organizations and individuals within the network. It has the potential to create cleaner economic transactional processes and help achieve balance and harmony in the environment, economy, and society [18]. The underlying foundation of CE is sustainability, ethical cleaner production, and social responsibility. This applies to both service and manufacturing industries. Furthermore, blockchain is characterized mainly by anonymity, transparency, auditability, permanence, persistency, and decentralization which in turn leads to improved performance, efficiency, and reduced costs [28, 55]. During the transaction processes, the blockchain technology uses public and private keys, which although traceable, are not disclosed [40]. Blockchain technology as a powerful distributed ledger tool of secure interconnectivity has the ability to facilitate cleaner production of goods and services, address the ethical agenda of business development, and support the creation of a CE.

Böhmecke-Schwafert et al. [4] presented a theoretical model which included the relationships among (i) drivers and barriers of the transition to a Circular Economy; (ii) blockchain innovation for the Circular Economy; (iii) technical challenges of blockchain; and (iv) Circular Economy. Additionally, studies have shown that the blockchain technology can contribute to the Circular Economy by reducing transaction costs, enhancing performance and communication along the supply chain, ensuring human rights protection, enhancing healthcare patient confidentiality and welfare, and reducing carbon footprint [49]. On the other hand, the environmental effects of blockchain technologies are also expected to bear pressure on the environment. Running a blockchain requires a significant amount of electricity, particularly when mining cryptocurrencies. However, blockchain integration in renewable energy sources could be the key to realizing energy sustainability by acting as an enabler for the creation of a decentralized and democratized energy system. Blockchain will also help foster better climate governance due to its transparency, global decentralization and cooperation. The information stored on a blockchain is decentralized, unquestionable and inaccessible [55]. This increases trust in any kind of information, which is important in the transition to a CE.

4.5 Artificial Intelligence (AI) and Machine Learning (ML)

AI is an important enabler for CE. It is central to realizing the transition from a Linear to a Circular Economy. It can support the design, creation and maintenance of circular products and the creation of circular business models [44]. AI can be used for designing robust and sustainable products, facilitating new circular business models, and supporting the broader infrastructure needed to scale circularity [44]. Researchers [e.g., 22 have worked toward attaining SDGs by using AI and ML.

ML capitalizes on the increasing amount of data, the advancements in processing and computational power as well as the use of algorithms and statistical models. It imitates the human way of learning through examples by drawing conclusions from patterns in data without following explicit instructions [28]. By employing ML, human-like decision-making systems can be established which enhance the overall efficiency of a specific process or task without requiring any human intervention.

The use of AI and ML aims to develop an efficient mechanism to facilitate CE by taking the needs of the present generation into consideration without disconcerting the capability of future generations. AI encompasses a set of technologies that include ML and natural language processing (NLP), which enable machines to feel, understand, act, and learn [25]. AI aims at creating machines, systems, and applications that simulate human intelligence and imitate human actions to achieve increased rationality, learning, and reasoning capabilities [28]. As AI-based systems can observe their surrounding environment and autonomously carry out tasks, they have the potential to self-learn, adapt, and transform [26]. Used in conjunction with other novel technologies (e.g., ML, big data analytics, etc.), AI can assist in the creation of intelligent, autonomous, rational, and sophisticated decision-making systems [13]. When integrating AI into organizations, their overall efficiency, performance, and gains can be improved. Although there are several open issues and challenges related to privacy, security, fairness, and interoperability of AI systems, the use of AI to achieve a CE is vital as they can support the realization of CE in several domains including [31]:

- *Design of circular products, components and materials.* AI can accelerate and enhance the development of new products, components, and materials that fit the Circular Economy through iterative ML assisted design processes that allow for rapid prototyping and testing.

- *Operation of circular business models.* AI can increase the competitive strength of Circular Economy business models, such as product-as-a-service and leasing. By combining real-time and historical data from products and users, AI can help increase product circulation and asset utilization. This will have an influence on pricing, demand prediction, predictive maintenance, and smart inventory management.
- *Optimization of circular infrastructure.* AI can help build and improve the reverse logistics infrastructure required for improving the processes of sorting and disassembling products, remanufacturing components, and recycling materials.

4.6 Internet of Things (IoT)

IoT can semantically be defined as a dynamic, addressable, self-configuring, and worldwide network infrastructure of interconnected "things" that is based on standard and interoperable communication protocols [30]. Within this infrastructure, "things" possess sensing, communicating and naming processes. They are interconnected and seamlessly integrated into the information network that connects resources and collects data about the physical and virtual worlds.

IoT pervades our everyday and its objects, linking the physical to the digital world and allowing people and "things" to be connected anytime, anywhere, with anything, and anyone, ideally using any network and service [29].

For some time now, the manufacturing sector has been using sensors and devices as part of IoT projects to improve efficiency, detect and prevent issues before they occur, and maintain products remotely. Remote monitoring is becoming the norm, with manufacturers now seeking to extend this to improve customer experience (CX) and build brand loyalty. Industrial Internet of Things (IIoT) is a complex system of diverse systems and devices that function more efficiently than the sum of its parts and focuses on intelligent manufacturing and modern industries by implementing secure, autonomous, and robust connection and data exchange among "things".

IoT enables enterprises to gain a competitive advantage by providing more effective scheduling, planning, and controlling of operations and systems, ubiquitous connectivity as well as efficient decision-making systems and decentralized data analytic tools that develop insight, enable real-time responses and reactions and improve the capability of monitoring and controlling enterprise processes and assets [27]. To enhance productivity, intelligence, and efficiency, IoT combines several emerging technologies and utilizes networks of embedded sensing devices that communicate and share intelligence. For IoT to be fully integrated and its full potentials to be realized within the context of Industry 4.0, several security challenges need to be addressed.

The evolving capabilities of IoT opportunities in the CE have given rise to the creation of new technological architectures, such as IoT circular strategies and designs and enhanced systems of reusing, remanufacturing, and recycling enabled by IoT technologies [50]. Industry 4.0 and Industry 5.0 promote new perspectives in production and consumption by incorporating circularity principles. Additionally, the combination of Industry 4.0 and Industry 5.0 with CE is a key enabler for reduced costs, increased efficiency in monitoring resources, and high-quality throughout the life cycle of products and services. From a technological perspective, IoT technologies apply process algorithms developed for analysis of generated circular data and provide optimized decision-making actions for circularity [42].

5 The 4R Sustainability Framework

Dufourmont et al. [14] identified aspects that often remain blind spots in the literature and practice of CE. These areas of ignorance involve: legal systems, culture, education, quality of life, values, behavioral norms as well as governance and political considerations. Therefore, this study advocates the proposal of a fourth R, RETHINK, which can be appended to the 3R Principles (Reduce, Reuse and Recycle)[10], presented above, related to CE.

The new, proposed 4R Sustainable Framework, shown in Figure 4 embeds in the very core of the 3R Sustainability Model a need for changing mindsets and taking action that demands the areas of ignorance be consciously considered. Whatever the initial aim, it is proposed that RETHINKing involves evaluation and quantification of the results.

RETHINKing is the heart of the 4R framework (Figure 4). If the target is to achieve Reduction specifications and metrics should be agreed Reappraising and Quantifying is carried out with Rethinking/and actions taken. Before finalizing the output. The entry/exit points are the 3 satellites i.e. Reduce, Reuse, Recycle. It can be seen that there are multiple journeys/pathways e.g. {(Reduce, Rethink, Reuse), (Reduce, Rethink, Reuse, Rethink, Reduce), …}.

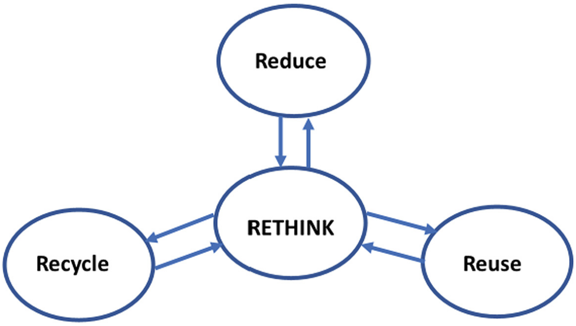

Fig. 4. The 4RSustainability Framework

An example of RETHINKing is that regulations at EU level need to be created in order to ensure that before certifying and taking a product to the market the producer needs to prove that the materials used are recyclable, eco-friendly and sustainable. This is a complex process that includes many stakeholders and interests. For example, currently wind mill blades are almost impossible to recycle[11]. Efforts to find technologies that make it economically viable to recycle them are ongoing. However, our concern is that more research and efforts should be put on finding materials and technologies to create blades with similar characteristics but made of materials that can be recycled. Hence, we need to RETHINK in order to establish the root causes of eventual problems.

For example, if the aim is to achieve reduction of using resources (physical, economic, human) by planning and following actions toward achieving reduction, the RETHINK

[10] https://uncrd.un.org/content/3r-initiative.

[11] https://www.bbc.com/news/business-51325101.

process will quantify the outputs and outcomes from different perspectives and dimensions (Sociocultural, Technical, Economic, Environmental, Political, Legal, Ethical, Demographic) [17, 41]. The impact of actions (or inactions) will be manifold. The centrality of the RETHINKing process (in the 4R Sustainability Framework) emphasizes the need to always review, analyze, measure, learn, and improve.

6 Conclusions and Future Work

The aim of this study was to describe the Circular Economy and the emerging technologies used to enable a transition from today's Linear Economy to a Circular Economy. Attempts to adopt to CE is bound to fail if we do not RETHINK our current political, and economic system, which values profit about all whilst neglecting the 17 sustainable development goals. Technologies can support the transition to CE but is not a panacea; when used correctly they can accelerate the transition toward a circular future.

The Software Process Improvement (SPI) Manifesto[12] under the People Value the principles (i) "*Know the culture and focus on needs*", *(ii)* "*Motivate all people involved*", and (iii) "*Base improvement on experience and measurements*" attain a deeper meaning that can be adapted to the transition from a Linear to a Circular Economy. CE focuses on better use of natural resources. For developing a viable re-modelling approach of deep-rooted practices, a change in mindset is required; hence, the transition should be linked to society and culture through policy debates and frameworks. Individual consumers' cultural behaviors are the key factors in this transformational change. Individual actions need to be aligned with a wider social and cultural shift. The global challenges need to trigger and foster local changes at an individual level. The key benefits of transformational change include increased engagement, improved performance, and higher levels of creativity and innovation. The use of emerging technologies is a significant tool to achieve a CE and sustainable development which, in turn, will lead to a social and cultural shift.

Future work will concentrate on qualitative interdisciplinary inquiry using STEEPLED analysis for identifying the changes needed in order to achieve social and cultural shift towards a Circular Economy, and to reduce resource input and waste, optimize renewable resources, production, and consumption.

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Methodological Transition Towards Sustainability: A Guidance for Heterogeneous Industry

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Abstract. No matter the sector, type, or philosophy of companies, there is strong evidence of sustainability awareness and environmental proactivity in industry. However, heterogeneity of firms shows that undertaking environmental actions may be a major challenge, where success is not guaranteed. This is a central issue for the ecological transition of industry and, unfortunately, it is an issue that cannot be tackled by a unique perspective. Still, for a transition occur, at least an initial and an envisaged state should be defined; and a procedure for transition between both must be formalized. In this sense, the literature provides methods to define, yet not to enhance the ecological states of firms, exposing a critical inattentiveness in the process for transformation and, in industrial diversity. To stablish the foundation for dealing with these issues, this paper first synthesizes these methods —which showed a strong alignment to Information science and strategic sustainability, and proposes a matrix for transition, composed of an informational and ecological dimension. Later, this matrix is used to propose and fuel a preliminary methodology delineated by different firms. Both are oriented to guide the ecological transition of all kind of companies.

Keywords: Sustainability · Environment · Transition · Strategy · Information Science · Data · Information · Knowledge · heterogeneity

1 Introduction

Sustainability emerges, not through fixed definitions of the concept, but through its interpretation and its continuous practice [1]. Nowadays, a sustainability mindset is being adopted progressively and is gaining momentum, as increasing organizations embark on their sustainable transitions in different ways. As a result, significant improvements in the economic, environmental and social contexts are evidenced around the world. In France, for example, the industrial sector has reduced approximately 40% of its Greenhouse Gas (GHG) emissions over the last three decades [2]. Although the credit of this notable achievement is due to several factors, there are specific sectors, such as those of the mining, chemical and metallurgical that reported significant advancements. This suggest that sectors and firms are dissimilar and embrace sustainability differently, so much, so that the orchestration of their environmental actions merits more investigation. Indeed,

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there is evidence that sustainability goals (e.g., resources efficiency or decarbonization [3]), challenges (e.g., globalization or innovation [4]), and key capabilities (e.g., in traditional or new technologies [5]) differs from one sector to another and from one company to another.

In the face of such heterogeneity (which is surely replicated worldwide [6]), environmental initiatives may not be successful [7], or strategic sustainability and initial steps may not be clear [8]. These issues are critical for the transformation of industry and must be tackled by adopting a comprehensive posture to avoid resource waste. Pragmatism (and later own research) suggest that hard beginnings and hesitation are expected, especially when a long-term vision is not clear [8], and when operative process are not synchronized [5].

Nevertheless, firms confront the challenge of embarking on their ecological transitions without a framework that prevent them from failing, or that facilitate tracing the transformation process in a holistic way. Pragmatically, for a transition to happen, current and envisaged states need to be recognized, and transition means between them need to be established at least. In this sense, measuring the ecological state of firms gets significance, and knowing the dynamics of change become fundamental for materializing environmental agendas. Accordingly, several authors abstract those key features that defines representative states, but they only arrange these states in rigid sequences, according to different domains. Thus, available models help to recognize, yet not to enhance the ecological position of firms [9]. In addition, they fall short regarding heterogeneity of firms [6, 10].

In the light of this complex reality, this work aims to give an answer to the following question: "how to guide efficiently heterogeneous firms into their successful transitions towards sustainability?".

On the other hand, previous research exposes the strong ties and paradoxes between sustainability and different facets of Information and Communication Technologies [11], especially data [12]. For example, data circulating along cloud-based IT architectures may generates environmental damage (especially when uncontrolled service propagation occurs [13]), but data may also nourish industry transformation [9] and environmental performance [14, 15]. Here, we not only advocate for the pros of data, but also hypothesize that the collection of appropriate data, its transformation into information and its further exploitation, altogether are vital for ecological evolution. Accordingly, this work synthesizes key aspects found in literature so that they (1) be related in a transition model and (2) fuel a guidance method. This is of particular interest for ensuring the success of environmental initiatives and the strategic sustainability of all kind of companies.

The rest of the article is organized as follows. Section 2 present the research methodology adopted to answer the aforementioned research question. Section 3 presents our results that generate a transition matrix, proposed in Sect. 4, and a guiding methodology, proposed in Sect. 5. Section 6 reports ongoing and future work and concludes this article.

2 Research Methodology

The research methodology followed in this work is composed of two parts. The first part consists in a systematic review of the literature and the second part consists in a qualitative research. In the first part, we are interested in methods that help to construct, assess or guide the ecological transition of firms. Because the concept of environmental transition is complex —difficult to be abstracted in single keywords and mandatory to be tackled from different perspectives, this part covers the systematic review of four bodies of literature, organized as follows:

- Assessment methods for environmental maturity
- Assessment methods for environmental awareness
- Assessment methods oriented to ecological performance
- Methods oriented to stablish environmental roadmaps

In this way, the first two cover methods focused on recognition of ecological states, and the last ones cover methods (researched in academy and advisory praxis) used in the dynamics of change (both for implementing environmental projects and for assessing the successful of such initiatives). Figure 1 describes the simplified selection process of methods based on the Preferred Reporting Instrument for Systematic Reviews and Meta-Analysis (PRISMA) (a methodology designed to report, in a transparent way, the followed steps and the obtained results in systematic reviews [16]).

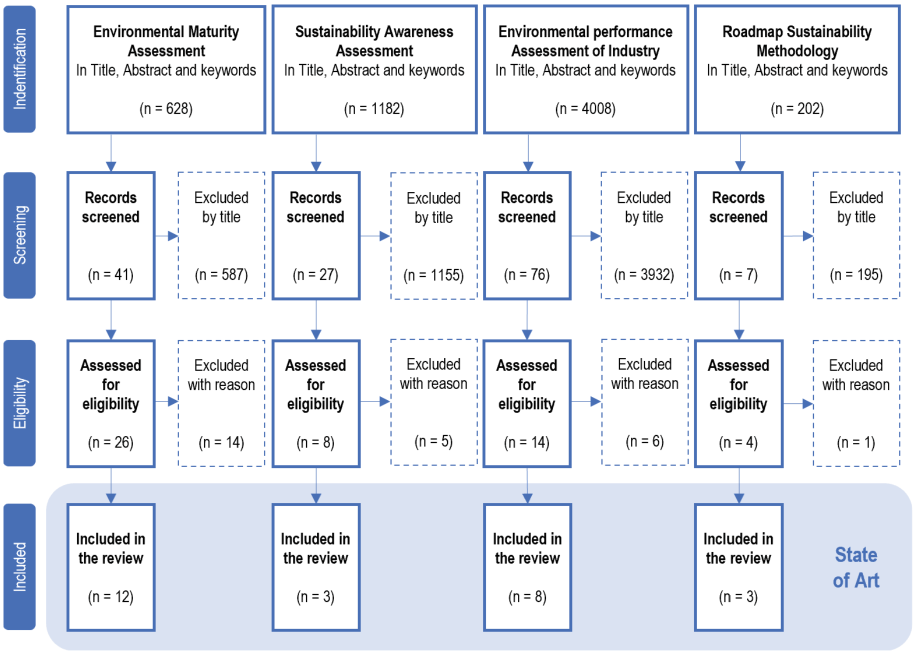

Fig. 1. Systematic Literature Review process of the four bodies of literature that define ecological transition

As observed, the Systematic Literature Review process was conducted in four steps. In the first step, each keywork group (e.g., Environmental Maturity Assessment) is searched by title, abstract and keywords in Web of Science. In the second step, the results are screened by title, keeping only instances that suggest the introduction of methodologies. In the third step (eligibility), works oriented to very specific sectors or firms are excluded, and the abstracts of remaining peer-reviewed works are read. Only those validated empirically are included for full lecture. This process allows to stablish the State-of-Art, which will be later analyzed in Sect. 3.1 to propose a transition model deductively, in Sect. 4.

In the second part, we are interested in inquiring into the heterogeneity of firms to construct a flexible methodology for ecological transition. Figure 2 shows the design of this investigation according to the research methodology proposed by Maxwell, J. [17].

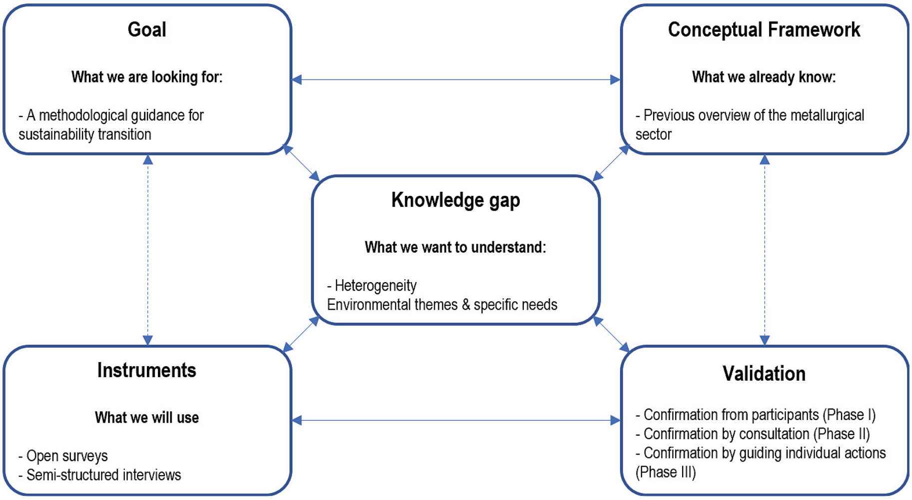

Fig. 2. Design of the qualitative research. Validation may require revisiting the conceptual framework and additional instruments may be applied, according to the goal of the study.

Starting from previous knowledge that introduces the diverse nature of ecological attempts of companies in the metallurgical sector [5], we define our goal oriented to find key concepts to construct a methodology for guiding heterogeneous companies in their ecological transition. To achieve this goal, we aim to get comprehension of two aspects. Firstly, we want to understand heterogeneity in terms of products and/or services, achievements, ongoing environmental actions and impact hotspots (which will stablish the current state of a firm); and in terms of environmental objectives. Secondly, we aim to understand the usual ecological themes and specific needs of enterprises.

The first aspect is covered by semi-structured interviews and the second aspect is covered by an open survey lunched in industrial workshops. This qualitative research is conducted within the UIMM industrial network at the French region of Ain, in the context of the ACCEL4.0 project [18]. Industrial members belonging this consortium validate this investigation in three phases: a first phase (phase I), in which synthetized results from open surveys and semi-structured interviews are reviewed; a second phase (phase II), in which preliminary versions of the envisaged methodology are discussed; and a third phase (phase III), in which application of our methodology is tested, under the context of individual projects. This work presents the results of the first phase that produce a preliminary version of the guiding methodology, presented in Sect. 5.

3 Results

3.1 Key Findings from the State-of-Art

From the State-of-Art showed in Fig. 1, Maturity- and Indicators-based models are dominant. Very few contributions under alternative approaches are found (e.g., Sustainable Business Models [19]), although not in the four bodies of literature. With the exception of Ngai, E., et al. [20], who offer the concept of "maturation levels" and Vasquez, J., et al. [21], who offer a transitional routine based on the fulfilment of "characteristics"; Maturity Models (including variants) and Indicators-based approaches (which we later considered as a vehicle for assessing maturity) only allow positioning companies in environmental levels. In other words, they show the "you are" and "you should be", but they fall short in guiding the transition from one maturity level to the other (that is, the "how to enhance"). Added to this, the "you should be" is established in function of rigid roadmaps, rather than appropriate strategy [8].

On the other hand, the literature review highlighted quite similar postures from very different authors. These similarities have to do with environmental aspects, usually interpreted in impact categories (e.g., global warming or resources depletion) and the circulating information used to estimate and reduce the environmental damage in each level of maturity. Indeed, with few exceptions, the majority of authors reveals clearly (1) the relevance of data collection, (2) the inevitable information treatment and (3) the automatization means, for dealing with impact categories. Besides, a subjacent tendency related to environmental initiatives, modification of processes and strategy is perceived in most of operational aspects (here, also, the notion of data and information flow persists, although more subtly (e.g., in the structural enablers studied by Güngör, B., et al. [22] or in the policy domain studied by Eisner, E., et al. [6])).

This tendency describing initiatives, processes and strategies aligns with the explicit evolution evidenced and promoted in the scarce literature of environmental advisory. Certainly, experience from consultors [8] and representative case studies [23] suggest that ecological initiatives evolve from a tactical sustainability (unrelated actions or isolated initiatives), to a strategic sustainability (new sustainable business models) driven by the change of transversal core processes of companies (process sustainability).

Aligned with this, Chofreh, A. G. & Goni, F. A. [24] suggest that a strategical level (top management activities), a tactical level (mid-level management activities) and an operational level (supervisory activities) form a decisional paradigm usually adopted in the design and implementation phase of sustainability roadmaps. Based on this, they later proposed a framework for the design of Sustainability Environmental Resource Planning implementation covering relevant aspects for all industrial sectors, including sustainability indicators and tactical, operational and strategic management [25].

The supplementary material that accompanies this work summarizes these key aspects and includes more works, that align to these findings in an implicit or explicit way. Together, they allow the construction of two generic Maturity Models that generate a transition Matrix, proposed in Sect. 4.

3.2 Results from the Qualitative Research

Initially, the open surveys were distributed during industrial workshops and putted online to everyone during seven months. The responses of nine companies belonging to different sectors were analyzed to identify common themes regarding ecological transition. From this, it was found that 5 of 9 enterprises require support in environmental impact estimation and environmental impact reduction (including eco innovation and eco design). Also, 4 of 9 enterprises require assistance in strategic sustainability and training (including environmental education, raising internal awareness and coaching). These results coincide with certain groups of aspects saw in literature (such as performance enablers, human factors, top management, product lifecycle or business models).

Subsequently, 5 enterprises participated in semi-structured interviews. The statements of participants were analyzed systematically to identify specific needs regarding impact estimation, eco innovation, strategic sustainability and training; all in the context of certain aspects that characterize the current state and ecological objectives of their companies. Figure 3 illustrates an instance of a specific need (dotted arrow) that must be fulfilled to achieve a specific objective from a current state, all in the context of a common theme.

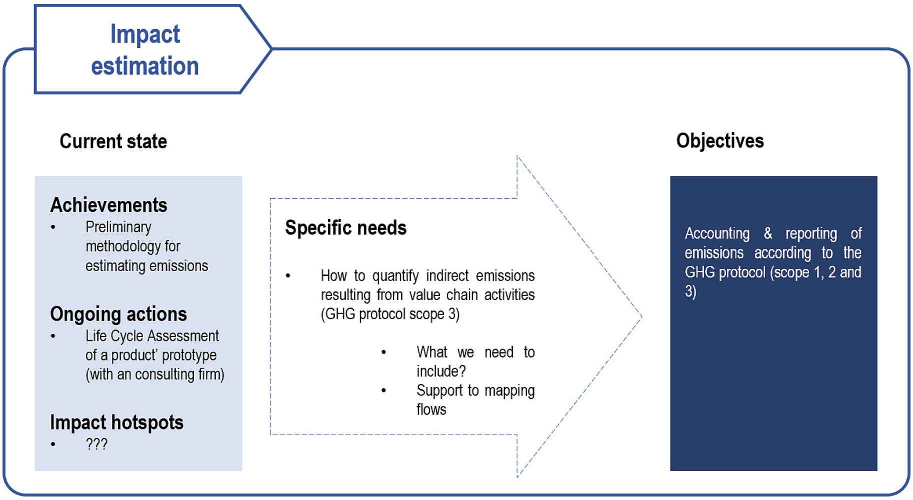

Fig. 3. A specific need of a company in the context of the environmental theme "impact estimation (Type of product is not shown due to confidentiality reasons).

Importantly, doubts and high uncertainty related to strategic sustainability was evidenced in some companies.

4 Matrix for Ecological Transition

Figure 4 synthetizes the central aspects of the literature presented in Sect. 3.1. Figure 4 (right) shows a simplified Maturity Model composed of *n* environmental and *n* operational aspects in lines, and only three maturity levels in columns, which are a synopsis of maturity levels in terms of tactical sustainability (initiatives), process sustainability (changes in transversal core processes) and strategic sustainability (Sustainable Business Models). We call this synopsis the ecological dimension. On the other hand, Fig. 4 (left) shows a simplified Maturity Model composed of the same environmental and operational aspects in lines, but with a synopsis of maturity levels related to data collection, Information and Knowledge. This abstraction reflects the central role of information for the maturity evolution of operational and environmental aspects of firms, evidenced in literature. We call this synopsis the informational dimension.

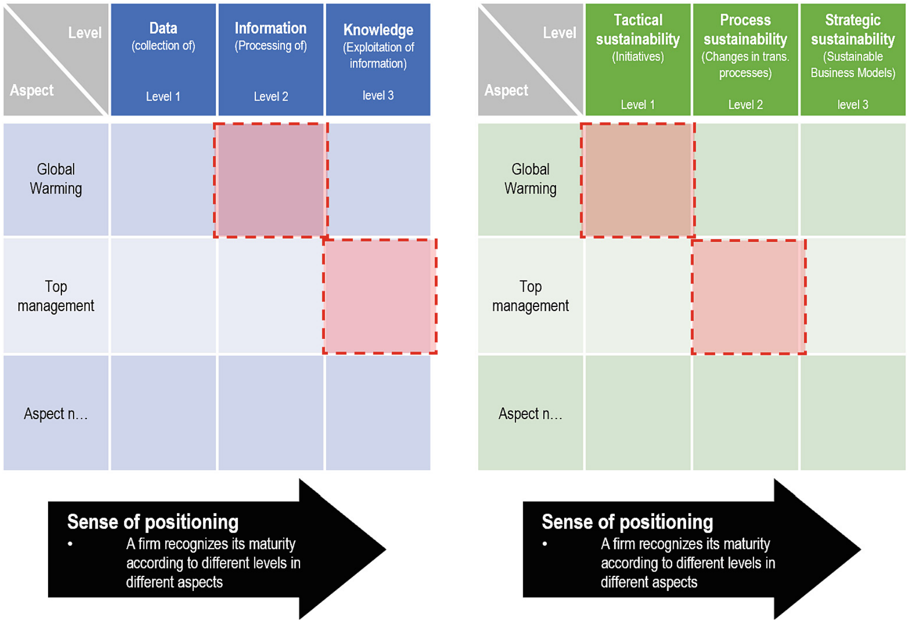

Fig. 4. Dissection of Maturity Models according to the informational and ecological dimensions. The "Global Warming" and "Top management" cells are provided randomly, only for illustrate an instance of an environmental an operational aspect.

Within these two dimensions, a company can recognize its maturity according to different levels in different aspects. For example, it may process information from data related to emissions to apply a particular tactic to reduce its global warming damage, or use previous information from top management to apply changes in transversal processes to solve several hotspots reported in its environmental reports. As observed in the simplified models above, a company can evolve only horizontally in both dimensions, and independently from one environmental or operational aspect to another (as red boxes suggest). In this sense, the idea of Maturity Models promoted so far by literature is recognizing the position of an enterprise within a level-based roadmap, neglecting the transitional procedure from one level to another. In this work, we believe that this transitional procedure happens simultaneously in both the ecological and informational dimensions, as suggested by our proposed transition Matrix showed in Fig. 5.

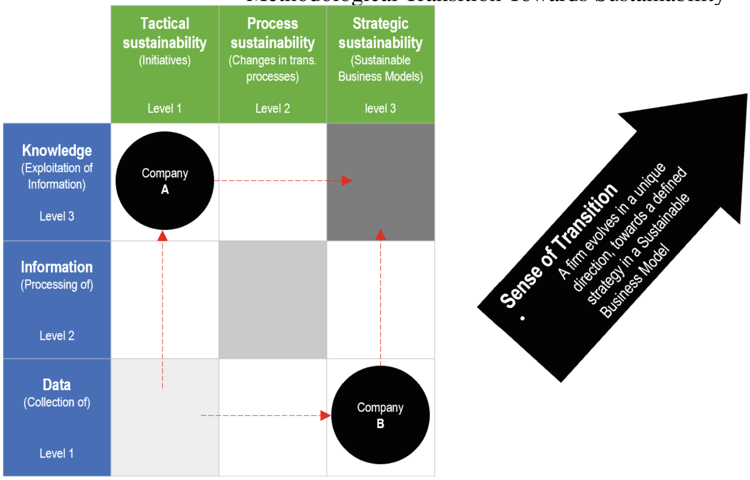

Fig. 5. Matrix for ecological transition of firms

Indeed, our main hypothesis here is that mature firms in the informational dimension (e.g., Company A) have a significant potential to accelerate their evolution in the ecological dimension because both, information or knowledge, can be used for replanning transversal processes or business models, to allow sustainability. Likewise, mature firms in the ecological dimension (e.g., Company B) have a significant potential to accelerate the materialization of their sustainable agendas, if they collect key data to generate and exploit information. In this sense, we bet on a transition model, whose main dynamic aligns environmental and operational aspects in a unique sense towards a defined strategy in a Sustainable Business Model (as showed by the gray boxes, along the diagonal).

To validate this hypothesis, we will conduct in a further work a diagnostic of firms that includes our matrix. This diagnostic will be carried out within the ACCEL4.0 project and it will consist of an iterative diagnostic of the firms' maturity in the ecological and informational dimensions. This diagnostic step is included in the step 4 of a proposed methodology, described in Sect. 5.

5 Methodology for Guiding Ecological Transition

The Maturity Matrix above is an abstraction which is coupled with a methodology oriented to facilitate the construction of environmental roadmaps, towards sustainability (presented in Fig. 6).

Because the results of our qualitative research show high heterogeneity of companies (not only in terms of activity, needs and size, but also in terms of objectives in different themes) this methodology must to be the most flexible to adapt to specific goals; and the most generic to adapt to all types of firms. In this sense, the first step conducts an evaluation of the current state of a firm, considering its global strategy and all its distinct features (specially its short-, mid- and long-term goals and needs). From this, one or many environmental actions can be projected, and the second step —Training, covers the development of necessary skills related to these actions (it may also include raising awareness of sustainability and digital maturity). Then, the methodology classifies environmental actions in two interrelated categories: environmental actions oriented to

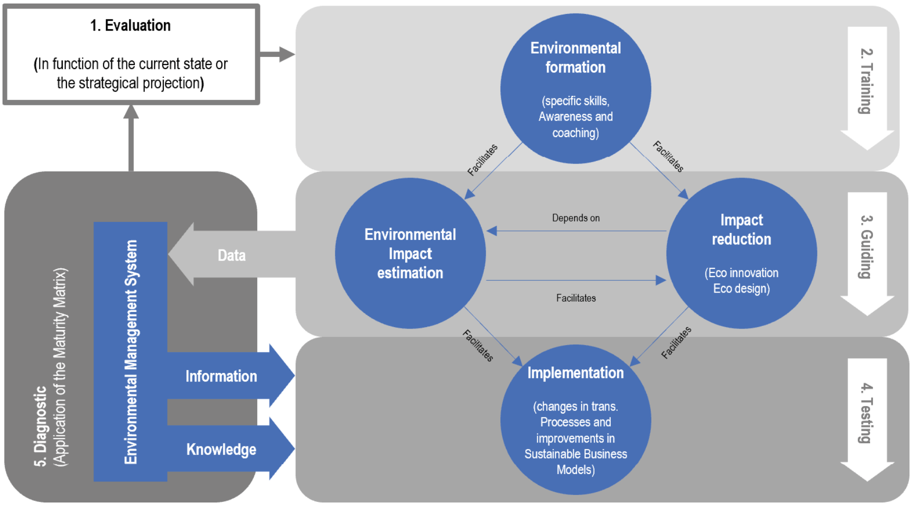

Fig. 6. The proposed methodology for guiding and stablishing flexible roadmaps for ecological transition

impact estimation and environmental actions oriented to impact reduction (including eco design and eco innovation). Guidance for both categories is provided in a third step (guidance). Also, factual data is identified and collected systematically on the way, so that information or knowledge can be generated (manually or automatically) in an environmental management system, and used to modify transversal processes or business models in a four step (implementation). As observed, a firm may start anywhere and skip some steps, but not step five (in which transition is reviewed and confronted to the strategy of the company, closing the loop).

In the first iteration, step five (diagnostic) allows getting a level position in our Matrix and step five and four together allow making a level transition. From this, new iterations may be needed if incomplete maturity is evidenced in the transition Matrix, according to the strategy of the enterprise.

6 Conclusion and Further Work

In recent years, awareness and proactivity allowed significant advancements in reducing the environmental impact of industry. However, embarking in the ecological transition may be complex, as enterprises are heterogeneous and as they embrace sustainability in different ways. This is a crucial aspect that must be studied to avoid failure and hesitation, especially, when first attempts towards sustainability are made. Thus, in this work we intend to give an answer to "how to guide efficiently heterogeneous firms into their successful transitions towards sustainability?" and we organize our investigation in two parts. In the first part, we study the available literature that defines, from our perspective, ecological transition. In the second part, we conduct a qualitative research to understand heterogeneity of enterprises. From the State-of-Art, we find that current methods help firms to recognize their environmental states, but hardly help them to enhance their positions to further states. Also, we observe an evident closeness of these methods to Information science and strategic sustainability. From the qualitative research, we find that firms plan their ecological transition under the context of training, strategic sustainability, estimation and reduction of environmental impacts. Also, we observe a high variability in specific needs regarding these environmental themes, and an unclear long-term vision in some cases.

The results of the first part of our investigation allow to construct a matrix that abstracts the dynamics of change of ecological transition in two dimensions: the informational and the ecological dimensions. Form this, we formulate a hypothesis that links both dimensions. The results of the second part of our investigation (phase I) allow to construct a preliminary version of a methodology for guiding the ecological transition of heterogeneous firms.

Ongoing work is been made to start the phase II of our qualitative research. This work includes the preliminary validation (or redesign) of the proposed methodology, and the evaluation of the current states and strategies of three companies. Simultaneously, assisted planning of concrete actions in the training, guiding or testing steps will be made, all in the context of their specific needs reported in phase I. Results of phase II will allow the beginning of phase III, in which we will test iteratively our proposed methodology and matrix, in the context of individual projects. In this way we expect to answer the research question that led this work and validates our hypothesis.

7 Relationship with the SPI Manifesto

One of the major problems and challenges of industry nowadays are its contribution to the accelerated degradation of our environment and its ecological transition. The SPI manifesto [26] is inherently linked with transition and change, and requires organizations to perpetual improvement in three steps: identify relevant problems and recognize the need for transformation (unfreezing), find and implement solutions (moving); and make correspondent changes a permanent part of how companies work (freezing). In this sense, the "**ecological**" and "**informational dimensions**" revealed in this work unfreeze heterogeneous businesses, and urge to change their current states. Then, our "**matrix for transition**" moves companies along a comprehensive and ecological transition of states, fuelled by the collection of key data and exploitation of useful information. Finally, our "**close-looped-based methodology**" makes permanent the improvement, in an ever-changing strategic sustainability.

Data Availability Statement. The authors declare that the data supporting the findings of this study are available within the paper, its reference section and its supplementary information, which is available online, or from the corresponding author on reasonable request.

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Improvement of Process and Outcomes Through a STEEPLED Analysis of System Failures

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Abstract. Failure of systems occur in all domains of human activity. Apart from identifying who will be deemed accountable, a thorough analysis of a failure also provides understanding of the causes. This is the first step towards learning and future improvement. It has become evident that process improvement improves the resulting products and services. Prevention is always desirable, but more often than not, the predictability of future behavior of systems is difficult. Hence, most of the learning takes place in the analysis of failures. This paper focuses on a STEEPLED analysis of system failures, with particular emphasis on failed systems from the fields of Architecture, Engineering, and Healthcare systems. This transdisciplinary and multi-dimensional view of systems provides a holistic thinking instrument for structuring the analysis of failures and for enabling action in order to avoid or at least minimize future failures.

Keywords: STEEPLED Analysis · Process Improvement · System Failures · Ambiguity · Complexity

1 Introduction

No matter what the level of preparedness is, system failures can still occur. System errors refer to systems that cannot successfully achieve their intended functions and perform in unexpected or unintended ways due to software and hardware issues, malfunctions, and problems that can result in minor or major damage with the severity and consequences being dependent on the function criticality and system nature Chapman (2004); Woolthuis et al. (2005).

Due to the digitalization of modern society, many of the system failures are related to digital infrastructure, information systems, software processes, and project management (Kaur and Sengupta (2013); Lyytinen (1998); Nelson (2007)). Several studies have

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explored and provided insights into information system failures and successes (Dwivedi et al. (2014); Pan et al. (2008)). Taxonomies, frameworks, and performance measurement methods have also been presented (Van Camp and Braet (2016); Woolthuis et al. (2005); Yeo (2002)). Besides the information technology sector, system failures can occur in several other sectors, such as architecture (e.g., bridges Garg et al. (2022); Zhang et al. (2022)), engineering (e.g., spacecraft Bedingfield and Leach (1996); Harland and Lorenz (2007)) and healthcare (Beynon-Davies (1995); Heeks (2006)), affecting people's daily lives and wellbeing. Although artificial intelligence (AI) is progressing and autonomous decision-making systems facilitate the development, monitoring, and maintenance processes (Lampropoulos (2023)), it still remains imperative to identify the sources of system failures, comprehend the reasons why they occurred, and avoid repeating the same mistakes after learning from past experiences (Dalcher and Drevin (2004); Lyytinen and Robey (1999); McManus and Wood-Harper (2007)). No other study has been conducted, as yet, using the STEEPLED multidisciplinary and multidimensional analysis of system failures.

Section 2 of the paper briefly introduces three catastrophic failures from the fields of Architecture, Engineering, and Healthcare. Section 3 presents in tabular form the STEEPLED Analysis of one example from the three domains in tabular form showing the similarities across the disciplines. Section 4 the STEEPLED dimensions to the Values and Principles of the SPI Manifesto.

2 Bridges Over the Ages

Harrington and McIntyre (2020) observed that: "*the world is full of highways and roads that cross over rivers or valleys. For centuries, they have been made passable by bridges, and the oldest bridge in the world is Arkadiko Bridge in Argolis, Greece. It was built by Mycenaean Greeks c.1300-1190 and it is still in use*". Figure 1 shows a selection of bridges built across the world over a period of almost 3,500 years. As shown in 1a the stone bridge is 'primitive', yet it still remains functional and is still in use. Many other stone bridges (built over the preceding 3 millennia are still in use).

Blockley (2010) emphasized that "*Bridges connect people and communities, enable the flow of people, traffic, trains, water,... and many goods and materials*". The significance of bridges is reflected in the expression "bridging the gap" used whenever there a chasm, a dispute, or a disagreement of any type among individuals, communities, or countries signifying connection/reconnection and reconciliation.

3 From Folklore to Scientific Reasoning

3.1 Bridge Failures

In Balkan folklore, a sacrifice of an animal was deemed necessary or especially in the case of a large and complex undertakings such as the building of a bridge a human sacrifice was deemed necessary in order to appease the river gods. To give an example, the Bridge of Arta in Greece (Fig. 2) was built on earlier Roman foundations during the Ottoman period (r. 1230–1268) by 45 builders/stonemasons and 60 apprentices (denoting

 1a) Arkadiko Bridge. Built: c.1300 – 1190 BCE.	 1b) Living root tree in India (unknown date)
 1c) Zhao Zhou Bridge built in 661 BCE	 Id) Pons Aemilius in Rome built in 192 BCE
 1e) Millennium Bridge London built in 2000	 1f) Hong Kong-Zhuhai-Macao Bridge built in 2018

Fig. 1. Bridges through the ages

the enormity of the task at the time). It fell many times and was reconstructed. The legend (still surviving in a Greek folk song) tells us that all work carried out during the day collapsed every night until a bird with a human voice instructed the desperate master builder that his wife should be sacrificed in order for the bridge to be constructed. His wife was sacrificed and the bridge is still in use!

Legends stopped providing explanations of bridge failures whether minor, correctable or catastrophic. Bridge failures continue to occur even in the 21st Century, as is the case of the Millennium Bridge in London. When the London Millennium Bridge was opened in June 2000, it swayed alarmingly. This problem generated huge public interest and the bridge became known as London's "wobbly bridge." The large number of pedestrians that flogged to see it at the same time excited the bridge's lateral vibration modes (David, 2003). The bridge closed, the problem was rectified and the bridge reopened a year later.

Fig. 2. The Bridge of Arta [Source: youimg1.tripcdn.com]

“*Bridge buildi*ng is a magnificent example of a practical and everyday use o*f science. U*nfortunately, there are always gaps between what we know, w*hat we do,* and why things go wrong. Bridge engineers must manage r*isks carefully*” (Blockley 2010).

Olson et al. (2015) in their Quick Study described the collapse of the Tacoma Narrows Bridge as follows:

“*On 7 November 1940 the Tacoma Narrows Bridge in Washington State collapsed during a gale. The remarkable oscillations of its long and slender centre span in the months leading up to the catastrophe earned the bridge the moniker “Galloping Gertie…*”.

The actual collapse can be seen in Fig. 3 and on film [Tacoma Bridge Collapse: The Wobbliest Bridge in the World? (1940) [British Pathé News]. Fortuitously no human loss occurred. Only the dog in the car of a reporter perished in the river. Holloway (2004) described the oscillation and twisting of the Tacoma Bridge: *“the clamps holding one of the added checking-cables slipped in a wind of about 40 miles per hour. When this happened, Galloping Gertie began to move in a new way. Instead of just oscillating up and down as it had before, it started twisting about its centreline.”*

3.2 The Space Shuttle Challenger Disaster

Despite the misgivings and objections by Boisjoly and others the Space Shuttle Challenger was launched on January 28, 1986. It broke apart 73 seconds (Fig. 4) into its flight, killing all seven crew members aboard. The spacecraft disintegrated 46,000 feet (14 km) above the Atlantic Ocean, off the coast of Cape Canaveral, Florida, at 11:39 a.m. EST as the first fatal accident involving an American spacecraft in flight (Boisjoly et al., 1989).

All 7 astronauts died. This disaster impacted on the Space Travel programme, dented the belief in the American dream and infallibility, and shocked the whole world. Six months after the disaster later the Rogers Commission report [Fenman, R, P. (1986)] *“faulted NASA as a whole, and its Marshall Space Flight Center in Huntsville, Alabama, and contractor Morton Thiokol, Inc., in Ogden, Utah, for poor engineering and management.* Marshall was responsible for the shuttle boosters, engines, and tank, while

Fig. 3. The collapsed Tacoma Bridge

Fig. 4. The Challenger Disintegration

Morton Thiokol manufactured the booster motors and assembled them at the Kennedy Space Center at Cape Canaveral, Florida. The Rogers Commission heard *disturbing testimony from a number of engineers who had been expressing concern about the reliability of the seals for at least two years and who had warned superiors about a possible failure the night before 51-L was launched*. One of the Rogers Commission's strongest recommendations was to tighten the communication gap between shuttle managers and working engineers. In response to this implied criticism that its quality-control measures had become slack, NASA added several more checkpoints in the shuttle bureaucracy, including a new NASA safety office and a shuttle safety advisory panel, in order to prevent such a "flawed" decision to launch from being made again. Aside from these internal fixes at NASA, however, the Rogers Commission addressed a more fundamental problem. In NASA's efforts to streamline shuttle operations in pursuit of its declared goal of flying 24 missions a year, the commission said, the agency had simply been pushing too hard. The shuttle program had neither the personnel nor the spare parts to maintain such an ambitious flight rate without straining its physical resources or overworking its technicians".

3.3 The London Ambulance Service Computer Aided Dispatch Failure

The London Ambulance Service (LAS) Computer Aided Despatch (CAD) system failed dramatically on October 26th 1992 shortly after it was introduced. The system could not cope with the load placed on it by normal use. The response to emergency calls took several hours. Ambulance communications failed and ambulances were lost from the system. A series of errors were made in the procurement, design, implementation, and introduction of the system (Sommerville, 2004).

Dalcher (1999) summarised "*the failure of the 1992 London Ambulance Service's computer-aided dispatch system arguably caused several deaths soon after its deployment, from failing to deliver emergency care in time, including an 11-year old girl dying from a kidney condition after waiting for an ambulance for 53 minutes and a man dying from a heart attack after waiting for two hours*."

Information Systems Failure have been occurring regularly, especially as systems became large and complex. Since 1994, the Standish Group publish the CHAOS report where they identify the most important reasons for IS failures. In the first Chaos Report by the Standish Group (1994 failures in bridge building and in software were juxtaposed. Bridges are mostly delivered on-time, and on budget and do not usually fail. The design is frozen and the constructor has hardly any flexibility in changing the specifications. When a bridge fails a report is written on the cause(s) of the failure. This is not so in the computer industry (which 3,000 years younger than bridge building) is plagued by computer systems which are often covered up, ignored, and/or rationalised. The same mistakes are repeated over and over. As the years progressed the Standish Group observed an increased in the number of computer systems failures.

Cases of system failures suggest that the development of appropriate software is a complex task. Projects frequently result in unfinished projects, project overruns and system failures. Software Process Improvement (SPI) approaches are viewed as potential solutions to address such instances. The SPI methodology plans and implements improvement activities to achieve specific goals, such as increase development speed, achieve higher product quality, and reduce costs (Winkler et al., 2011).

4 Research Methodology and Product Life Cycle

In this paper the authors carry out a STEEPLED (Sociocultural, Technical, Economic, Environmental, Political, Legal, Ethical and Demographic) analysis of three systems from Architecture, Engineering, and Medical Systems failures with the purpose of identifying multivariate causes and effects of each failure. The aim of a STEEPLED Analysis is to help organizations to understand the rich contextual situation in which they are operating (Georgiadou et al., 2020). STEEPLED is a multidimensional and multi-faceted analysis tool which assists in identifying causes, effects, strengths, gaps and impact of failures (Georgiadou et al., 2019).

The quality of the process is inextricably linked to the quality of the resulting products and services. (Siakas and Georgiadou, 2005). For example, the SPI manifesto which is based on values and principles guides practitioners and researchers in their process software improvement efforts so that the resulting products and/or services are also of a high quality. Fig. 5 shows the life cycle of a product. There are different variations existing of lifecycles. This life-cycle is derived from the combined experience of the authors. Different processes are showed in a sequence with feedback loops in all stages in two directions. The feedback from all phases must always go back to the concept development which is kept as a historical document for learning of the failures and improving future product developments.

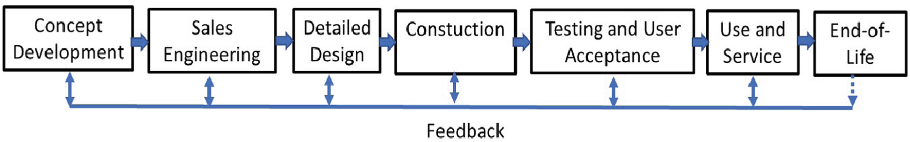

Fig. 5. Product Life Cycle

The product concept is the first stage followed by a preliminary design, often called sales engineering because the concept is developed depending on potential sales. The sales engineering uses the product concept and modifies it to fulfil the tender requirements. If the sales contract gets signed the detailed design starts, followed by construction, testing and user acceptance. After the product is handed over to the customer usually a guaranty and service agreement is agreed upon. Through the service agreement feedback is received about the product's performance and failures discovered in the different phases.

In most of the cases the end-of-life is not taken into consideration. Because of this the feedback arrow in Fig. 5 below the End-of-Life process is dotted. However, in today's world of sustainable requirements this stage is of utmost importance for calculating the value of the cost of environmental impacts, demolition and environmental restoration.

The European Commission is preparing a '*green claims*' regulation to make the environmental labels and credentials listed by companies – like their recyclability or biodegradability – reliable, comparable and verifiable across the EU[1]. It aims to be

[1] https://www.euractiv.com/section/circular-economy/news/eu-to-tackle-green-claims-with-unified-product-lifecycle-methodology/

an instrument to tackle 'greenwashing', or companies making false claims about the environmental footprint of their products. This is likely to help consumers to make better-informed choices about the products they buy.

The customer takes part to various degrees in all stages of the life-cycle. Customer involvement improves final products (Berki et al., 1997; Chen et al., 2021). When developing new product concepts, it is also important to look at end-of-life feedback from similar earlier products and projects to minimize environmental exposure. The feedback in addition to failures also includes e.g. delays, costs, product optimization, other competitive products in the market etc. Also, positive feedback needs to be taken into consideration.

Tables 1 and 2 summarizes findings from published reports and research papers. Each entry in the table is either a cause or an affect, and is categorized by the authors as Sociological, Technical, Economic, Environmental, Political, Legal, Ethical, or Demographic i.e. one of the 8 STEEPLED dimensions.

5 Thematic Analysis

Braun and Clarke (2006) state that Thematic Analysis is a method of analysing qualitative data. The method is typically applied to texts, e.g., interviews or transcripts. In the analysis, the researcher is tasked with examining the data to identify common *"themes, topics, ideas and patterns of meaning that come up repeatedly"*.

Maguire and Delahunt (2017) suggest that there are various approaches to conducting thematic analysis, but the most common form follows a six-step process, as advocated by (Braun and Clarke, 2006):

- Familiarisation
- Coding
- Generating themes
- Reviewing themes
- Defining and naming themes
- Writing up

However, thematic analysis is a flexible method that can be adapted to many kinds of research. Based on the qualitative data presented in Tables 1 and 2, above, a thematic analysis is conducted to identify commonalities between the three cases. The aim of this paper is to Generate Themes

STEP 1: Familiarisation: A thorough overview of the data collected from the STEEPLED analysis of the three cases in presented in Tables 1 and 2. The data has got from second hand sources (references) and presented accordingly.

STEP 2: Coding: To complete coding sections of our text presented in Tables 1 and 2 are highlighted, typically specific phrases or texts, so that shorthand labels, or codes to describe their content. Table 3 below, shows examples of extracted data and the corresponding codes.

STEP 3: Generating Themes: The codes that have been created and presented in Table 4, are further analysed to help identify patterns among them, and therefore declare themes. Themes are generally broader than codes. Most of the time, several codes are combined into a single theme.

Table 1. STEEPLED Analysis (Sociocultural, Technical) of failures from three different domains

	Examples of Systems Failures		
Disciplines **Dimensions**	**Architecture** (Tacoma Bridge Collapse, 1940)	**Engineering** (Space Shuttle Challenger Disaster 1986)	**Health Service Systems** **(**London Ambulance Service Disaster, 1992)
Sociocultural	**Causes** • Overconfidence of Engineers (not following regulations) • Unforeseen human behavior • Multidisciplinary team misunderstandings • Lack of social responsibility • Career advantage or disadvantage **Effects** • No loss of life in this case but high danger • Loss of product services (e.g. you cannot use the bridge)	**Causes** • Cultural conditioning • Organizational hubris • Pressure to launch • Psychodynamics • Transdisciplinarity • Accountability • Bureaucratic decisions • Whistleblowing • Poor management control • Different teams, different locations • Confusion with measurements and specification **Effects** • Loss of life • Loss of credibility • Worldwide chock	**Causes** • Bad communication • Poor relations between stakeholders • Low user participation • Incomplete requirements • Inexperienced software engineers • Underestimation of the impact of systems failure on the local population **Effects** • Chaos • Loss of lives • Mistrust in system • Anxiety • Stress • Depression • Anger
Technical	**Causes** • Overemphasis on aesthetics instead of robustness • Design mistakes • Limited or no checking off system • Theory but no prior data - Untested innovation • Ambiguities in design specs • Implementation deficiencies • Underestimation of danger • Unknown risks in materials • Designers without personal	**Causes** • Poor Engineering • Design mistakes • Limited or no checking system • Theory but no prior data - Untested innovation • Ambiguities in design specifications • Implementation deficiencies • Underestimation of danger • Unknown risks in materials **Effects** • Loss of credibility	**Causes** • Incomplete system released • Testing was only carried out on individual modules and subsystems • Miscalculation of variations in traffic congestion and obstacles like bridges **Effects** • Mistrust in automation • Loss of credibility • Failed to adopt stepwise approach to deployment of system. • Configuration issues • No paper backup system
	experience of bridges **Effects** • Destruction of bridge • Non-availability of bridge • Man-made reef		• Poor interface between users and system • Inaccurate data feeds • Delays in training • Lack of clarity in development of original requirements
Economic	**Causes** • **Effect** • Cost for rebuilding	**Causes** • Loss of productivity **Effect** • Cost for rebuilding	**Causes** • Procurement, the cheapest contractor was employed • Unrealistic budget **Effect** • Cost for improvement / re-development

Table 2. STEEPLED Analysis (Economic, Environmental, Political, Legal, Ethical, Demographic) of failures from three different domains

Examples of Systems Failures			
Disciplines **Dimensions**	**Architecture** (Tacoma Bridge Collapse, 1940)	**Engineering** (Space Shuttle Challenger Disaster 1986)	**Health Service Systems** (London Ambulance Service Disaster 1992)
Environmental	**Causes** • Terrain • Weather **Effects** • Unforeseen impact (e.g. reef rubble)	**Causes** • Melting sills **Effect** • Energy Waste	**Causes** • Miscalculation of congestion • Inadequate management organization • Poor communication channels between various stakeholders **Effects** • Distrust in Management
Political	**Causes** • Unrealistic deadlines • Ambition **Effects** • Reputation • Fear of blame	**Causes** • Pressure from politicians • Press concerning time and cost **Effect** • Reputation	**Causes** • Procurement • Pressure from politicians • Press concerning time and cost • Poor relations between management and staff **Effects** • Loss of trust in health system / political system • Fear of lawsuits
Legal	**Causes** • Mismanagement **Effects** • Fear of lawsuits • Financial loss • Loss of reputation • Fear of blame	**Causes** • Fear of contractual violation **Effects** • Fear of lawsuits	**Causes** • Testing deficiencies • Ambiguities **Effects** • Fear of lawsuits • Testing deficiencies • Lack of systems development knowledge and experience in key stakeholders including consortium
Ethical	**Causes** • Pressure of time • Ambition • Disregard of danger **Effects** • Potential loss of life	**Causes** • Ambition instead of safety **Effects** • Loss of life	**Causes** • Pressure of time • Ambition instead of safety **Effects** • Testing deficiencies • Loss of life • Loss of trust • Lack of Autonomy and Informed Consent felt by end users • Increase sense of ownership for all stakeholders
Demographic	**Causes** • Miscalculation **Effects** • No loss of life (in this case)	**Causes** • **Effect** • Loss of young scientists	**Causes** • Stakeholder mainly male in latter stages of career • *'Us and them'* culture between stakeholders **Effects** • Pressure due to potential personal claims (delays, causing harm to the patient or death) • Loss of life • Emergency care affected young and old • Loss of trust

Table 3. Examples of extracted data and the corresponding codes

Extracted Data	Codes
"Organizational hubris" "Poor relations between stakeholders" "Bureaucratic decisions" "Us and them"	Poor industrial relations
"Fear of lawsuits" "Fear of blame" "Fear of Failure" "Whistle blowing"	*Fear of Failure* Culture
"Ambiguities in design specs" "Inaccurate data feeds"	Poor Design
"Multidisciplinary team misunderstandings" "Lack of clarity in development of original requirements"	Ambiguity
"Need to meet Unrealistic Deadlines" "Unrealistic Budget"	Unrealistic Project Deliverable Indicators
"Distrust in Management"	Trust
"Underestimation of the impact of systems failure on the local population" "Underestimation of danger"	Poor risk analysis
Etc…	

Table 4. Examples of extracted codes and the corresponding themes

Codes	Theme
• Poor Risk Analysis • Unrealistic Project Deliverable Indicators	Lack of Project Management (Time, Budget and Risk)
• Poor Industrial Relations • Trust • Fear of Failure Culture	Management Oversight
• Poor Design • Ambiguity	Poor adoption and deployment of systems development methodology
Etc…	

These themes are got from the STEEPLED analysis of the three cases of failure described in Section 3, above. The themes are present in the cases that were analyzed. We cannot suggest that these are universal themes in all projects that involve human endeavor. Further research would have to be completed, based on a substantially greater number of cases.

6 Future Work

6.1 Case-Based Reasoning

Kolodner (1992) defines Case-based Reasoning CBR as *"a means of using old experiences to understand and solve new problems"*. A reasoner calls to mind a previous situation, like the current one, and uses that to solve the new problem. CBR can mean *"adapting old solutions to meet new demands; using old cases to explain new situations; using old cases to critique new solutions; or reasoning from precedents to interpret a new situation or create an equitable solution to a new problem"*. Case-based reasoning is rooted in artificial intelligence theory and cognitive psychology. It describes the pervasive behavior in everyday human problem solving; that most people assemble solutions based on earlier experiences with similar situations.

Rahanu et al. (1999) report that the key conclusion to be drawn from the study of failed computer systems development and implementation cases is that the idea of failure can rarely be understood satisfactorily solely from a technical perspective. This is because a definition of the success or failure of a given case of computer systems development and implementation is as much reliant on the social, economic, political, and ethical setting within which it is developed as it is on the technical quality of its construction. The authors advocate that case histories are a particularly valuable means of helping to understand the success or failure of computer systems development and implementation in terms of professional ethics. The analysis of case histories was the backbone for the development of a case-based reasoner (CBR) computer system, which can offer ethical advice with reference to cases of failed IS projects. This was accomplished by ethically analyzing cases of failed IS projects to determine whether and to what extent a neglect of professional ethics contributed towards their failure. This case library formed the basis for development of the base-cased reasoner.

The novelty of this paper is the proposal that not only can failed information systems projects be understood in terms of technical failure, and professional ethics, but also in a much wider context, i.e., a social, economic, political, and ethical setting within which it is developed. Therefore, this paper advocates the use of a STEEPLED multidisciplinary and multidimensional analysis of cases of system failures. The hope is that by showing the STEEPLED analysis of 3 cases, reported in Section 3, that these could become case histories, which are the backbone for the development of a case-based reasoner (CBR) computer system, which can offer STEEPLED advice with reference to cases of failed IS projects.

7 Conclusion

Failures continue to happen often causing disruption, economic losses, political upheaval and worse of all loss of life. If the causes of failures can be identified are identified and understood the first step towards ensuring prevention of failures is ensured. Pressure to change protected completion date, reduce costs, modified design for additional usage, and respond to upgrades of software, hardware and design methods, compared with earlier times, with less immediate communication with stakeholders and press. Decisions to oversee warnings as is the case of the Space Shuttle launch, may be legal but not ethical. Similarly, the economic factor, although important, should not be judged as more important than the safety of people. Employing the cheapest contractor should never be the overarching criterion. The trust placed on automatic generated measurements, such as with the ambulance system, does not take account of the traffic problems with some of the bridges, where the shortest Geographic distance is not the shortest in time. Political ambition or expediency should never come before safety. As Parfitt (2012) concludes *"Fear of blame, lawsuits, damaged business opportunities and ruined reputations are all often cited as reasons for keeping failure cases and actual examples under legal non-disclosure agreements and in insurance company files. But we need to find a way to at least generically share the lessons through more comprehensive failure dissemination methods and educational repositories".*

One of the problems is that the full details of many failure examples are not published so the appropriate lessons cannot be learned.

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Supporting Product Management Lifecycle with Common Best Practices

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Abstract. Product Lifecycle Management is a process that helps projects to pass through various phases of software development and maintenance. Since phases are usually associated with entry- and exit-criteria that could be considered onerous or excessively effort-prone, implementation of PLM poses various risks. In this paper we show how Common Best Practices could support the software teams in meeting PLM requirements and facilitate smoother transition between phases.

Keywords: best practices · software process improvement · product lifecycle management

1 Introduction

Product Lifecycle Management (PLM) is a process that comprises all phases of a software product, from inception, through conceptualisation and development, up to maintenance and retirement. A defined PLM facilitates a streamlined development and delivery of software products, with predictable quality, within the assumed cost and budget. It also introduces entry criteria which allow for smooth, but also verifiable progress of a project in line with the process. For that reason, PLM is frequently adopted by organisations with a diverse portfolio of products, with the objective to manage them in an efficient, predictable and repeatable way.

However, the PLM adoption may not be easy and comes at a price. As any other process, it requires investing time and effort to define, adjust, tune and monitor all its activities. In addition, the process is usually not very flexible and cannot be easily adapted by addressing specific requirements or contextual factors. For that reason, the users that

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manage their projects may find overly complex and excessively formalised approach for delivering products and services.

In GÉANT, the Software Process Improvement is based on the Common Best Practices for Software Development [13, 14]. Best practices primarily originate from the teams' experience, supported by guidelines and observation. From 2021, the framework is gradually adopted by SDTs in GÉANT, with promising early results [15].

In this paper we propose an approach for supporting the PLM adoption by implementing the best practices. Best practices refer to the requirements defined for PLM gates and are expected to facilitate passing them more easily and at a lower cost.

The remainder of the paper is structured as follows. In Sect. 2 we shortly overview the literature on PLM. Sect. 3 presents basic facts about GÉANT and its objectives, while the PLM in GÉANT is elaborated in Sect. 4. Next, in Sect. 6 we present the approach used to support the PLM with best practices. Sect. 7 summarises the work.

2 Related work

PLMs are usually organised as a sequence of stages in the product's lifecycle. Three of them indicate key points: *beginning of life* (BOL), which includes the design and manufacturing, *middle of life* (MOL) which includes use, active service and maintenance, and the *end of life* (EOL), when the product is put out of use, i.e., retired [3, 17].

Proper implementation of the PLM is intended to bring reduction in cost, as well as shortening the implementation time, in order to be achieved the main goal of increasing the end quality of the product and in some commercial products overall revenue increase [9]. The cost of implementation mostly is measured by the effort needed for the overhead complexity added in all of the processes in order for the PLM to be implemented properly [10].

Albeit many PLM processes have similar general structure to the industrial production PLM processes [5, 7], the majority of them are customised and fine- tuned by the end-products delivered (e.g., software products and platforms) and the organisation itself that is implementing the PLM (in our case GÉANT).

PLM implementation may include several possible metrics or KPIs that can be tracked in order to monitor PLM implementation, like the number of use cases, number of approved deliverables against the road map, scope deviation and change requests, number and type of customisation's and integrations, number of continuous improvements, planned vs implemented (path through backlog), number of test cases validated [4], in operations the PLM success has some slightly different metrics like: number of enhancement requests/issues, projected vs actual system performance, number of new user methods, new roles. Many other metrics can be considered mainly based on scope and maturity of the project [12] and of the organisation itself [11].

Achieving a PLM implementation that is correctly aligned to the business and project requirements is challenging and expensive, both in cost and complexity [5]. The cost factor is somewhat easier to be measured and expressed but the technical cost from the added complexity is harder to be recognised and expressed.

A PLM implementation is successful when the most relevant and applicable model that can be adapted to the context of the business and the project at hand. These models offer a starting point to create a systematic approach and understand the PLM transformation (current state vs. to-be state) [2].

Noteworthy, a proper PLM implementation also is needed to manage the Intellectual Property Rights (IPR) of the information within the extended enterprise. The enterprise's PLM system can be used to effectively manage IPR and ensure it does not get shared inappropriately [5].

3 Background

GÉANT is an organisation that gathers National Research and Education Networks (NRENs) from al countries in Europe, created to develop and manage distributed optical network for academic- and research-related activities. It stimulates development of innovative products by building them atop existing network infrastructure. Many software-intensive, network-backed products have been developed, deployed and are in current use, mostly by small international software development teams (SDTs).

To streamline the processes of software development and maintenance, several processes and frameworks have been developed. It includes both the PLM, which provides a backbone process for software delivery, a Software Maturity Model that provides a custom framework for improving the teams' maturity, and Common Best Practices that serve as a platform for exchanging experience and knowledge in the form or ready-to-use, directional and actionable recommendations [8].

More details about GÉANT specifics have been presented in previous works, e.g., [13–16].

4 Product Lifecycle Management in GÉANT

GÉANT designed its custom PLM based on the business model and the environment it operates in, which are specific for innovation-driven organisations. The fundamental requirement was to create a framework which would be flexible to provide effective coordination and a process structure to many Software Development Teams (SDTs) that enjoy a large degree of independence and freedom in adopting specific procedures, methods and tools, and have different maturity in various areas.

GÉANT projects typically have relatively short project phases, which is unusual for large, established companies with a diverse product portfolio. The innovative focus on the service development requires it to be dynamic, agile and, simultaneously, address the objectives and constraints of EU funding programmes.

The original GÉANT PLM, presented in Fig. 1, included several phases and gates. A detailed internal review revealed that was difficult for SDTs to implement and follow, mainly due to its complexity and required effort (Fig. 1).

Having that in mind, GÉANT management decided to simplify the PLM process in an attempt to provide more freedom and support innovation. The new schema, depicted

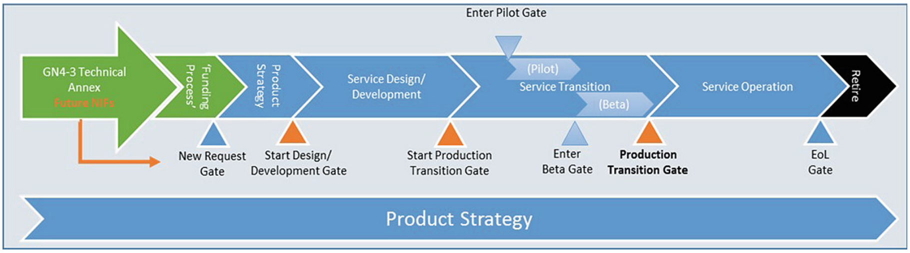

Fig. 1. Historical PLM process in GÉANT

in Fig. 2, is also aligned with ITIL Continual Improvement [6], in which a metrics-driven methodology is applied to identify improvement opportunities in an attempt both to support the business processes and to measure the impact of those improvements.

There are four phases in the product's lifecycle: *Research*, *Development*, *Service operation* and *Retirement*. To reach the *Service operation*, which is objective for each development, a project needs to pass through two preceding phases and to be evaluated on a set of associated criteria. At these coordination points, called *gates*, the project is reviewed to build a complete picture of its current maturity. Only after successful addressing of these factors, a product is allowed to advance in the next phase. The new PLM with a schema of transitioning between the phases is presented in Fig. 2.

Fig. 2. Current PLM process in GÉANT

5 Framework of Common Best Practices

Catalogue of Common Best Practices (CBPs), together with Software Maturity Model (SMM), serve as two pillars for the software process improvement framework in GÉANT. They represent two distinct perspectives of process optimisation:

– *WHAT* to achieve, which define the goals and focus on specifying the target status of expected process properties;
– *HOW* to achieve the objectives by providing guidelines and recommendations concerning methods (high- or low-level) that allow for addressing the WHAT.

In the GÉANT SPI framework, the *WHAT* is covered by Software Maturity Model (SMM), while CBPs are responsible for the *HOW*. Therefore, specific goals in SMM have corresponding practices in CBP catalogue that provide guidance on how to address them.

Best practices have been extracted by Software Management Team (SwM) in collaboration with Software Development Teams (SDTs) using a survey, conducting interviews and based on publicly available literature. Many SDTs have their own methods and approaches of addressing the goals, including specific, idiosyncratic habits, routines and approaches that work well in their context, but have not been verified in different settings. As a result, they need to be refined and standardised first to be included into the catalogue, and then, before implementing them by specific SDTs, adapted and customized to their context. The catalogue of high-level practices constitute a way of sharing the knowledge and experience among the SDTs.

From managerial point of view, the practices are organized into five Target Areas (TAs), i.e., categories focused on a single aspect of the team work. Currently, the catalogue comprises 24 practices grouped in 5 TAs. Specific target areas are related to three main dimensions of each GÉANT software project:

- *Engineering*: B. Development, C. Quality, E. Maintenance
- *Organisation*: D. Team Organisation
- *Business* A. Requirements

The process that led to defining the catalogue has been presented in more detail in [13].

6 Supporting PLM with best practices

There is a wide spectrum of products and services in terms of size and complexity, being developed and maintained by the project with a wide variety in team size and organisation of the effort. Therefore, the PLM process – the main tool for management and monitoring of the product development in GÉANT – can only recommend implementation of specific CBPs for the transition of project between the different phases. It is difficult (or even impossible) to define a single approach or a global set of CBPs for the respective PLM gates that would match each SDT's expectations and needs.

Noticeably, the implementation of best practices in teams' practice is not the objective by itself; CBPs framework is just one of possible methods of addressing the requirements for PLM gates. Teams could have implemented addressed the requirements in their idiosyncratic, but equally valid way.

6.1 PLM gates

Each PLM gate defines a set of criteria that formulate requirements for the product before it is allowed to pass enter the given phase. The criteria mostly express business perspective and expectations for a viable solution that will not only solve a problem, but will keep the solution within the borders delineated by budget, time and quality.

Start Development is a gate that initiates a project and puts it into a framework. It seeks to asserts the market viability of the proposed development effort in the term of interest in the public or GEANT community in the terms of Users, Benefits, Service description, Market analysis, Costs, Funding, Roadmap, Planning and Resources. All those items provide a foundation for growing the product and preparing it to be deployed in the future.

At beginning of the Service Operation phase the focus of the assessment shifts towards the factors that assure a successful service or product launch. The **Enter Service Operation** gate now encompasses more operational aspects: Code quality, Marketing and visibility, Service policy, IPR, GDPR, Operational support, Roadmap, KPIs, and Resources.

Following the model of generic PLM processes, the **Retirement** phase demarcates the end of the product's lifecycle. Its goal is to verify if the product's artifacts and processes have been properly finished and their outcomes have been archived. Specifically, following items are considered: User Uptake, Market Landscape, Competitors, Business Model, Financial Impact, User Impact, Alternatives, Support, and EOL timeline.

6.2 Priorities

Various practices may have different relative importance at various stages of the project. For example, while an *Artifact management* process could be established at the project inception, prior to passing the Start Development gate, it becomes much more important at the Enter Service Operation gate. Then, although the practice implementation can be postponed at the SDT's discretion, it is getting more urgent. To reflect this observation, best practices could have different priorities, depending on the stage of the project. Based on that, we propose three levels of priority, loosely inspired by the MoSCoW model [1]:

- *Should* – recommendations included in the practice are adopted by the majority of teams (implicitly or explicitly), and are essential to passing the gate successfully;
- *Could* – the practice appears helpful for some teams, so it is advised to be implemented before passing the given gate;
- *N/A* – the practice is not (or only to a small extent) applicable at this gate.

6.3 Supporting the PLM with best practices

In Table 1 we present the proposed assignment of specific best practices, widely presented in [14], to gates in PLM. Three events are captured: *init*, which indicates the launch of the project, *Start Development Gate (SDT)*, when the software work begins, and *Start Production Gate (SPG)*, when the product is transited to production, either as an independent system or a service.

For each gate, we provide also the recommended priority of a specific practice. The priority evolves throughout the product lifecycle, which gives a hint for the SDT about the possible order of implementing the practices.

Implementation of each practice should be considered well before the respective PLM gate review, since results in the quality of the product and efficiency of the software development process cannot be immediately determined and measured. The effect of their implementation appears as reduced risks of flaws, user experience and confidence.

Table 1. Proposed assignment of best practices to PLM gates (init – project initiation; STD – Start Development Gate; SPG – Start Production Gate

Practice	(init)	SDGSPG
BP-A.1. Identify stakeholders	Should	Should Should
BP-A.2. Establish communications with stakeholders	Could	Should Should
BP-A.3. Collect requirements	Could	Should N/A
BP-B.1. Assess available technologies	N/A	Should N/A
BP-B.2. Set up documentation	N/A	Should Should
BP-B.3. Manage artifacts	N/A	Should Should
BP-B.4. Automate build & delivery	N/A	Could Should
BP-B.5. Manage product issues	N/A	Should Should
BP-B.6. Manage sideground IPR	Could	Should Should
BP-C.1: Manage risks	Should	Should Should
BP-C.2: Identify product success criteria	Should	Should Should
BP-C.3: Implement a quality plan	Could	Should Should
BP-C.4: Verify outcomes	N/A	Should N/A
BP-C.5: Monitor quality	N/A	Should Should
BP-C.6: Validate the product with stakeholders	N/A	N/AShould
BP-C.7: Refine the quality assurance process	N/A	N/ACould
BP-D.1: Manage team skills	N/A	Could Could
BP-D.2: Establish internal comms	N/A	Should Should
BP-D.3: Implement a decision-making process	N/A	Should Should
BP-D.4: Manage team assignments	N/A	Should Should
BP-E.1: Design for maintainability	N/A	Could Should
BP-E.2: Manage maintenance issues	N/A	N/AShould
BP-E.3: Implement a change request process	N/A	N/AShould
BP-E.4: Define a change implementation procedure	N/A	N/AShould

Although Retirement gate concludes the active use of a product or a service, it still needs to be properly supported from organisational, technical and operational perspective, to safely deposit remaining artifacts and data. Currently the catalogue does not include any best practices that are would support the teams to transit the product through the Retirement gate, but they could be added in the future.

7 Summary

Product Lifecycle Management is a process used for guiding and monitoring products at different stages of their lifetime. In large software organizations it is an indispensable part of operations that facilitates portfolio management. On the other hand, it introduces several requirements and expectations that could be difficult to implement or address. In the paper we proposed how the Common Best Practices framework could be used for easier traversal of PLM gates. While the proposal has not been fully validated yet, early reaction from the Project Management Office and software development teams are positive.

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SPI and Recent Innovations

The New ISO 56000 Innovation Management Systems Norm and ISO 33020 Based Innovation Capability Assessment

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Abstract. TIMS is an EU Erasmus+ project which develops a competence matrix, and a set of training materials for ISO 56000. It developed in 2022 an ISO 56000 assessment method and tool which integrates ISO 56000 and ISO 33020 for an innovation management system capability assessment. This paper provides an overview of the new ISO 56000 norm, explains how the norm has been used as an input to elaborate a process assessment model with a set of base practices and outcomes per part and process of ISO 56000. It also describes how the assessment works and how to participate in an innovation benchmarking strategy in Europe.

Keywords: ISO 56000 · Innovation management system · ISO 33020 · Capability assessment

1 Introduction

TIMS is an Erasmus+ project (2022–2023) which analyses the new Innovation Management System norm from ISO and which develops a competence matrix, training materials and an assessment system which allows self assessment, assessments by innovation experts and benchmarking.

The project results planned include:

- Development of an ISO 56000 [12–21] based assessment tool which supports innovation assessment and is based on a method that allows a benchmarking across European (and worldwide) industry.

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- Developing of a competence matrix with skills and structuring skills also into microskills based on the required knowledge for understanding and implementing ISO 56000.
- Developing training material for the skills and micro-skills for innovation agents [1–6, 8–11, 27–37, 42–47] (to implement ISO 56000) in the set up competence matrix.

The ISO 56000 IMS (Innovation Management System) norm comprises different parts:

- [12] ISO 56000 – Innovation management – Fundamentals and vocabulary, 2020
- [13] ISO 56001 – Innovation management – Innovation management system – Requirements, Draft, 2022
- [14] ISO 56002 – Innovation management – Innovation management system – Guidance, 2019
- [15] ISO 56003 – Innovation management – Tools and methods for innovation partnership – Guidance, 2019
- [16] ISO TR 56004 – Innovation Management Assessment – Guidance, 2019
- [17] ISO 56005 – Innovation management – Tools and methods for intellectual property management – Guidance, 2020
- [18] ISO 56006 – Innovation management – Tools and methods for strategic intelligence management – Guidance, 2021
- [19] ISO DIS 56007 – Innovation management – Tools and methods for idea management – Guidance, 2022
- [20] ISO 56008 – Innovation management – Tools and methods for innovation operation measurements – Guidance
- [21] ISO DTS 56010 – Innovation management – Illustrative examples of ISO 56000, under development, 2022

When developing an assessment tool which allows a benchmarking and shall be used to assess ISO 56000 the project decided to use the ISO 330xx series [22–24] as a basis and to develop a process assessment model for ISO 56000. The norm part ISO TR 56004 – Innovation Management Assessment proposes a number of metrics and leaves it open which assessment process and which rating method is used. Figure 1 shows one of the rating examples in ISO 56004 and that we mapped this scale to the capability level scale in ISO 33020 [22–24]. Moreover the project used the ISO 33002 Information technology – Process assessment – Requirements for performing process assessment norm to set up an assessment process supported by an assessment tool.

One of the major reasons to use the ISO / TR 33020 scale for TIMS was that the project required a consistent assessment approach across all regions of Europe and a benchmarking option for industry.

This resulted in a process assessment model and assessment tool development in 2022 and the results of that work and lessons learned are described below.

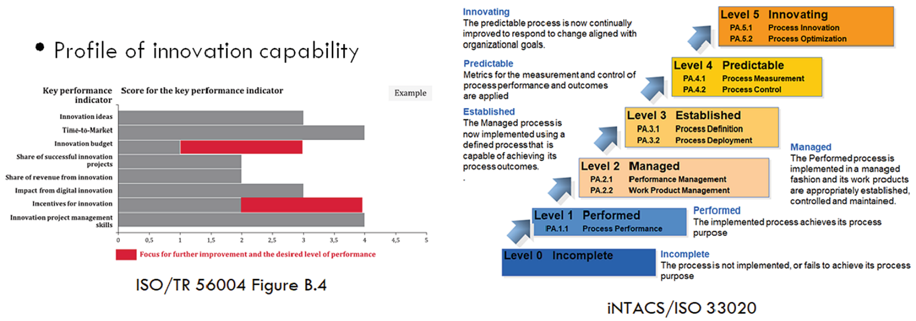

Fig. 1. ISO 330xx Scale Used for ISO/TR 56004 in TIMS

2 The Assessment Model and System Development

The TIMS project analysed all chapters and content of the norm parts and grouped them by areas and innovation processes to be assessed. Each part of the norm represented an area and specific groups of sub-requirements were consolidated to processes of that area. This resulted in a process landscape. This step required 3 iterations because (1) some norm parts are overlapping and (2) inside a norm part it was too easy to just make a chapter a process. And (3) the processes need to be separate activity groups that can be rated separately with a capability.

e.g. ISO 56001 and ISO 56002 have 90% overlapping content so that these areas should appear only once.

e.g. ISO 56004 is not a very strict guidance, it looks rather like a collection of potential metrics. So the project had to decide which metrics for assessment TIMS would use for a European strategy, and thus the processes are already based on the concept of an integration of ISO 56000 and ISO 33020 [7, 22–24, 38–41].

e.g. ISO 56010 contains examples that can be added as notes or examples to processes but will not deliver own processes that can be rated with a capability.

This resulted in a process landscape shown in the below Table 1.

Table 1. Innovation Processes Landscape

IMS	Innovation Management System
IMS.1	Leadership
IMS.2	Planning
IMS.3	Resources Management
IMS.4	Competence Management
IMS.5	IMS Implementation and Operation
IMS.6	Performance Evaluation

(*continued*)

Table 1. (*continued*)

TAM	Tools and Methods for Innovation Partnerships
TAM.1	Innovation Partnership Framework
TAM.2	Entering an Innovation Partnership
TAM.3	Partner Selection
TAM.4	Partner Alignment
TAM.5	Interaction between Partners
ASM	Innovation Assessment
ASM.1	Assessment Process
ASM.2	Perform Assessments
ASM.3	Benchmark and Improve
IPM	Intellectual Property Management
IPM.1	IPM Framework
IPM.2	IP Strategy
IPM.3	IP Management in Innovation Process
SIM	Strategic Intelligence Management
SIM.1	Strategic Intelligence Management Setup
SIM.2	Strategic Intelligence Cycle
SIM.3	Intelligence Communication
TIM	Tools & Methods for Innovation
TIM.1	Preparing for Idea Management
TIM.2	People and Organisation
TIM.3	Idea Management Process and Activities

The next step was to extract per process from the norm the essential information and design per process the purpose statement, the base practices, and the outcomes. Also, this step required a number of review meetings because the norm has a lot of requirements and text and the TIMS project had to identify in review meetings what are now exactly the to-dos in form of base practices, and what are the set of expected outcomes required. Topics to solve included:

e.g. the ISO 56000 series contains a number of requirements and guidelines but does not contain expected outcomes.

e.g. the ISO 56000 norm parts provide guidance and examples but no concrete method to follow.

While the development was ongoing the Swedish national norm institute published a national innovation assessment norm [68]. A review of that norm showed that they also used an ISO 33020 based approach and lean questions compared to what TIMS developed. The project then decided to continue with a full process assessment model based on ISO 56000 and ISO 33020 and develop a complete elaborated set of base practices and outcomes.

This then resulted in an assessment model with processes and outcomes described applying a PAM (Process Assessment Model) template and the configuration of an assessment portal system Capability Adviser [7, 38–41] with that assessment model.

Example:

Process Group: IMS (Innovation Management System)

Process ID: IMS.1

Process Name: Leadership

Process Purpose: The purpose of the leadership process by top management as described in ISO56002 is to demonstrate proper leadership while also implementing an innovation management system.

Outcome List:

1. Top management demonstrating leadership.
2. The establishment of an innovation process with phases idea creation, selection, implementation and exploitation.
3. An established innovation vision.
4. A documented innovation strategy.

Base Practices:

IMS.1.BP1 Top management should demonstrate leadership and commitment with respect to the innovation management system by being accountable for the effectiveness and efficiency of the innovation management system.

This is done by:

a) establishing the innovation vision, strategy, policy, and objectives
b) fostering a culture supporting innovation activities;
c) integrating the organization's innovation management system requirements into the organization's existing structures and business processes, as appropriate;
d) creating awareness and communicating the importance of effective innovation management and supporting persons to contribute to the effectiveness of the innovation management system; (learning from both successes and failures)
e) ensuring that the innovation management system achieves its intended outcomes and promoting performance evaluation at planned intervals for continuous improvement [Outcome 1]

IMS.1.BP2 Focus on value realization. Top management should demonstrate leadership and commitment with respect to value realization, by:

a) identifying opportunities, through exploitable insights, based on current or future, stated or unstated needs and expectations;
b) considering the balance between opportunities and risks, including the consequences of lost opportunities;
c) considering risk-appetite and tolerance for failure;
d) allowing for conceptualization, experimentation, and prototyping, involving users, customers, and other interested parties to test hypotheses and validate assumptions;
e) promoting perseverance and ensuring the timely deployment of innovations.

[Outcome 2]

IMS.1.BP3 Create an innovation vision. Top management should establish, implement, and maintain an innovation vision that:

a) is a description of a future state that the organization is aspiring for, in terms of innovation activities, including the future role of the organization and the desired impact of its innovations;
b) is consciously ambitious, challenges the status quo, and is not constrained by the organization's current capabilities;
c) serves as a guide for strategic choices and provides a framework for setting the innovation strategy, policy, and objectives;
d) can be communicated and understood internally to inspire people to commit and work towards;
e) can be communicated externally to enhance the reputation of the organization and to attract relevant interested parties;
f) is available as documented information.

[Outcome 3]

IMS.1.BP4 Create an innovation strategy. Top management should establish, implement, and maintain an innovation strategy, or several innovation strategies, if appropriate, and ensure that it:

a) describes why innovation activities are important for the organization;
b) is flexible and adaptable, and allowed to change or emerge as a result of feedback and performance of innovation activities;
c) is communicated to, and understood by, relevant interested parties;
d) maintained as documented information.

[Outcome 4]

Using the same structured approach all processes have been defined.

3 Assessment System Set Up and Example

Once the innovation assessment model had been integrated and reviewed, the model was imported and configured and tested in an existing assessment portal system Capability Adviser [7, 38–41]. This allows to support process capability assessment based on ISO 33002 and ISO 33020. Capability Adviser system is already used for ASPICE, functional safety and security assessments and has been configured for innovation management system assessment in this project.

Project partners on TIMS are members of the ISO 56000 working group. Also TIMS promised benchmarking for the participating regions. This was the reason that the portal has been enriched by a function to register for self-assessment and to benchmark.

The assessment system has been set up inside the EuroSPI platform at https://iso56000.eurospi.net [50–67]. Organisations can register in the system (see Fig. 2) for self assessment. The system also allows an independent expert assessment, in this case an assessment with an external assessor is created. After login the assessment is displayed based on the ISO 33020 concept of an assessment model and the standard rating scale N(ot)/P(artially)/L(argely)/F(ully).

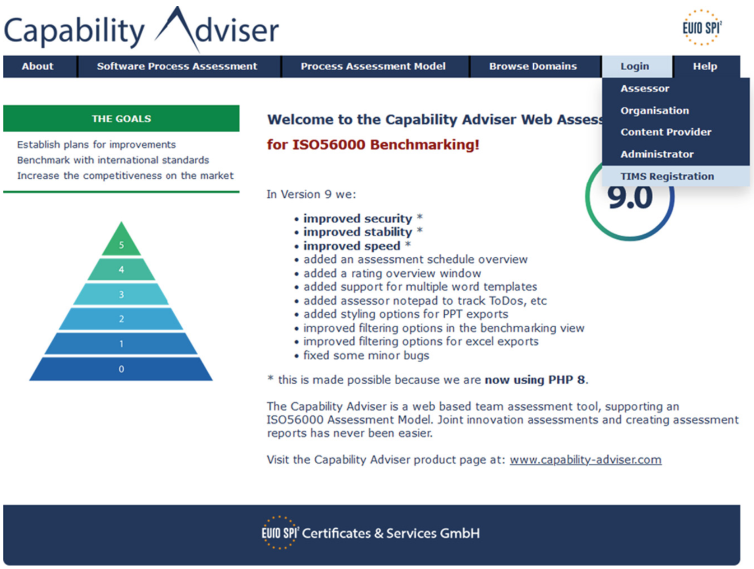

Fig. 2. The ISO 56000 assessment portal system by TIMS

The structure of the process assessment model and rating schema is based on ISO 33020 (see Figs. 3 and 4).

At level 1 the base practices are configured and per base practice the outcomes and also the underlying related norm chapters can be displayed.

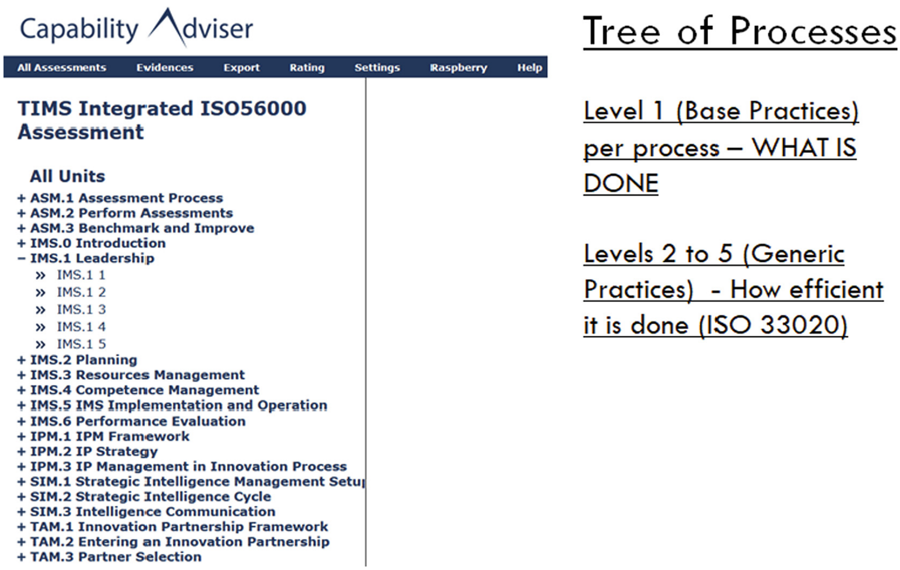

Fig. 3. The ISO 56000 processes – levels 1 to 5 per process

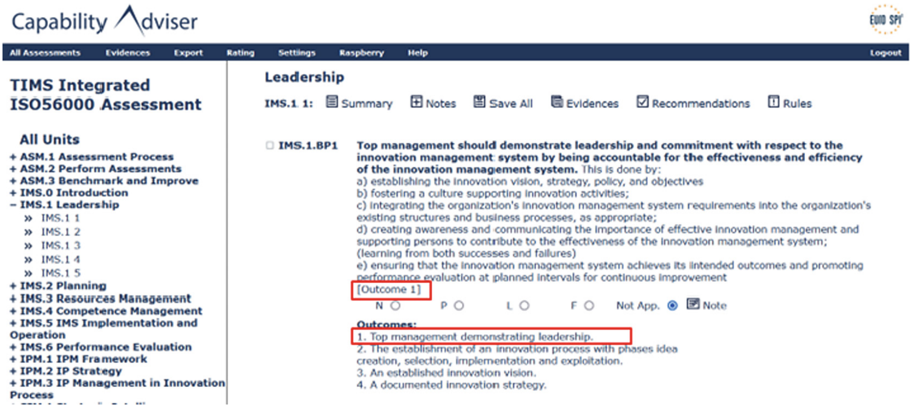

Fig. 4. Base Practices with the N/P/L/F rating scale and outcomes

Also, the typical assessment results based on ISO 33020 can be generated for innovation management system process assessments. This allows to generate process attribute and capability level profiles for an innovation management system.

Note: In this paper the basic (and widely known) procedures and algorithms to calculate from the ratings an attribute profile or capability profile is not explained, this is outlined in ISO 33020 in detail (Figs. 5, 6 and 7).

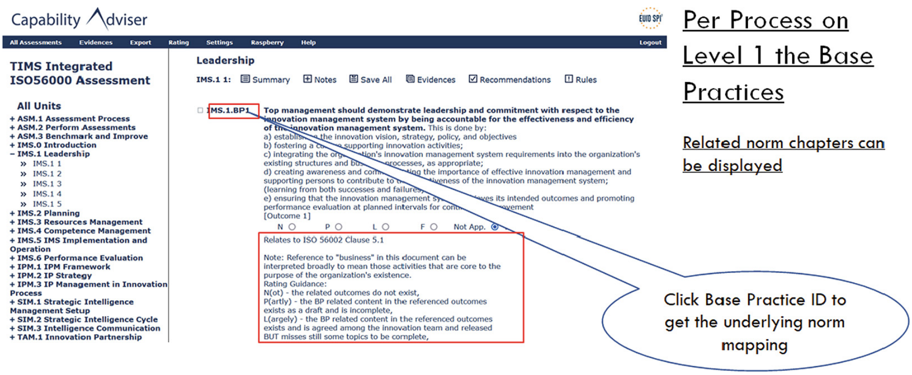

Fig. 5. Display of relationship to norm parts per base practice

Using the new process assessment model and tool such assessments can produce an innovation capability profile for organisations and that can be used to derive improvement action plans. Moreover, these profiles can be compared and used to benchmark.

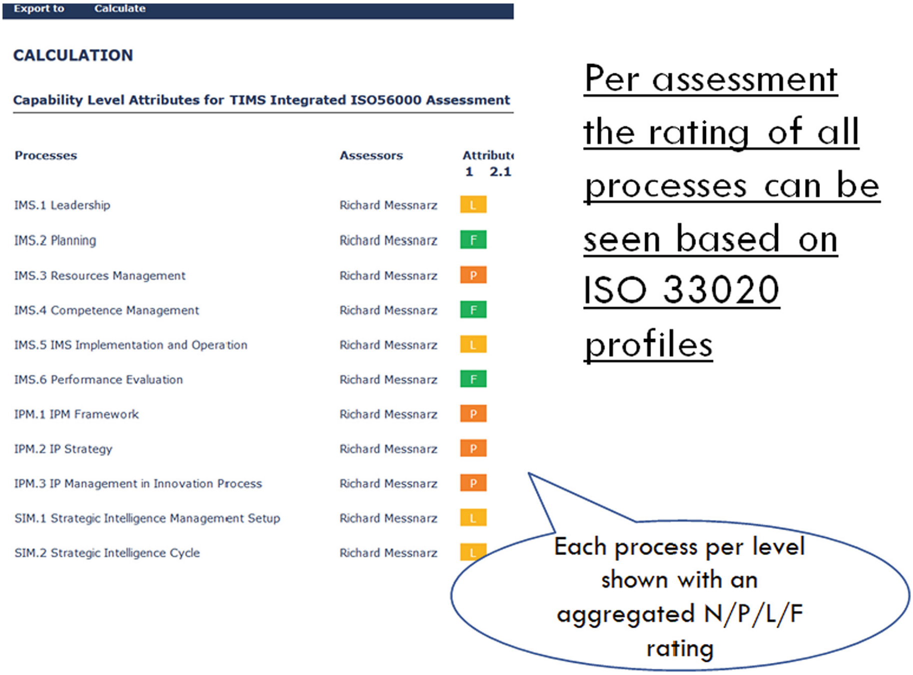

Fig. 6. Attribute profile for innovation management system assessment (ISO 33020)

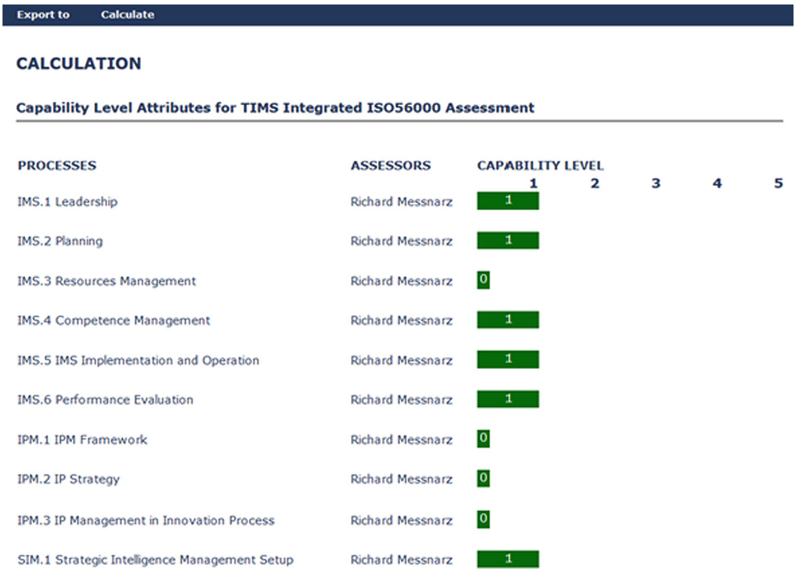

Fig. 7. Capability profile for innovation management system assessment (ISO 33020

4 Lessons Learned So Far

The project demonstrated the system to innovation partners and that led to the following feedback that will influence how the innovation assessment is used:

In case of self assessment it cannot be expected that the organisations attended an assessor training before. This means that questions on level 2 to 5 (focus on efficiency – how well the process is managed, defined, …[48]) require an expert level of ISO 33020 understanding. This means that for self assessment of organisations (and registration in the system) only level 1 (and the rating of base practices) will be used. The benchmarking across self assessments will then base on percentage and N/P/L/F profiles.

To use a full scale capability level assessment (e.g. asking also level 2 and 3 questions [48]) requires expert training in assessments and the use of ISO 33020. For independent expert assessments the full scale capability assessment will be used. Benchmarking in case of expert assessments will be based on the capability level profiles and process attribute profiles according to ISO 33020.

Not every region in Europe has the same interest profile. This means that regional agencies consider creating assessments in the system only for a subset of processes which are of interest for their area. It was specifically discussed that for SMEs e.g. only the IMS process group will be asked and used for benchmarking.

The ISO 56000 norm provides guidance and examples but does not provide a list of concrete methods or work products to use. Therefore the project team had to propose outcomes per process. The list of outcomes might change based on the feedback from the assessments.

5 Outlook for TIMS

The capability assessment tool for ISO 56000 developed in TIMS supports a PAM (Process Assessment Model) for innovation management systems. This allows to measure the capability of an organisation in specific areas of an innovation management system based on ISO 56000. Since ISO 56000 is an international norm the platform can be used for benchmarking in future.

The norm (and inherently the assessment model) contain up-to-date best practices of how to set up innovation management successfully. In TIMS in six regions of Europe the assessment will be applied and compared. Through iso56000.eurospi.net the service will be continued in cooperation with existing sectoral networks [49] that have been established at a European level.

6 Relationship with the SPI Manifesto

A platform were such new cross-cutting approaches can be discussed is EuroAsiaSPI[2]. Its mission is to develop an experience and knowledge exchange platform for Europe where Software Process Improvement (SPI) practices can be discussed and exchanged and knowledge can be gathered and shared [25, 26]. The connected SPI manifesto defines the required values and principles for a most efficient SPI work.

The principle "**Use dynamic and adaptable models as needed**" means that cybersecurity norms and views in future need to be integrated into the existing processes.

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Frugal Innovation - A Post Mortem Analysis of the Design and Development of a Cyber-Physical Music Instrument

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Abstract. Frugal approaches empower individuals with limited budgets or lacking support from powerful organizations to engage in innovation. By rigorously focusing on key aspects of Frugal Innovation, it becomes possible to create products and services. Frugal approaches also facilitate the creation of specific Intellectual Property associated with the developed products and services. In a post-mortem analysis, relevant aspects of the frugal methodology are presented as a case study, demonstrating its application. The analyzed project employs a combination of iterative and incremental approaches within the frugal framework to design and develop a cyber-physical music instrument. The objective of this new music instrument is to provide a cost-effective hardware solution that can be played using gestures. Looking ahead, artists can embrace the instrument's features and characteristics, allowing them to become prosumers by incorporating it into their performances. To facilitate knowledge sharing, a "cheat sheet" is proposed as a guide through the Frugal Innovation process that led to the development of the music instrument. Furthermore, a discussion delves into whether Intellectual Property rights derived from Frugal Innovation remain an integral part of the frugal concept and mindset, or if they reinterpret frugal approaches as a new form of cheap development. Additionally, the discussion explores the potential for Frugal Innovation to surpass established Lean and Agile approaches as the next step in the evolution of innovation practices. Lastly, the proposed Frugal Innovation process is examined as a building block for sustainable development approaches that address more than just sufficiency aspects inherently and by design.

Keywords: Frugal innovation · intellectual property · lean development · agile development

1 Introduction

Frugal Innovation has evolved over more than a decade, transitioning from a product-oriented definition to a process- and market-oriented one and currently it is defined criteria-oriented [1]. In [2] a criteria set for frugal innovation is proposed with substantial cost reduction, concentration on core functionalities and optimized performance level.

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Since these three criteria are also relevant in general product and service development, the context of Frugal Innovation is changing [3]. Consequently, Frugal Innovation has been discovered and adopted by global enterprises like General Electric [4]. According to [5], Frugal Innovation is defined as a „resource scarce solution (i.e., product, service, process, or business model) that is designed and implemented despite financial, technological, material or other resource constraints, whereby the final out-come is significantly cheaper than competitive offerings (if available) and is good enough to meet the basic needs of customers who would otherwise remain un(der)served“. Building on this, [6] identifies four dimensions of frugality: basic quality, cost of consumption, simplicity, and sustainability. Additionally, [7] defines „FIs have significant and different types of outcomes that conventional products may not have. These products are affordable, sustainable, and resource-efficient, and they create a new market for new customers with a new type of product."

Taking these definitions into consideration, we examine the innovation of a music instrument within a scholarly project framework. Our research aims to address the following questions:

RQ1: To what extent is Frugal Innovation intuitive?

RQ1.1: What constraints contribute to the facilitation of the Frugal Innovation setup?
RQ1.2: Which resources (such as skills, knowledge, funding, etc.) are considered fundamental necessities?

RQ2: Which design and development procedures foster Frugal Innovation?

The next sections are structured by presenting the research approach and context section, followed by the analysis of the post mortem data. The results and discussion section is followed by the presentation of contributions and outlook.

2 Research Method and Context

The research approach used in this study is a post-mortem analysis [8], which incorporates a survey and a case study component, aligned with [9]. The investigation and analysis draw upon documentation from the case study project and input from the individuals involved in the case study. Since the scholarly project team lacked prior experience with Frugal Innovation, this setup serves as a solid foundation for analyzing the intuitiveness of Frugal Innovation (RQ1). No synthetic setup, such as a Living Lab or Design Thinking-driven user research, was employed. Introducing synthetic and additional measurement and observation setups can introduce complexity and the risk of manipulating the measurement object(s).

The analysis is conducted through a post-mortem analysis of the case study project. The advantage of using a post-mortem analysis is that it avoids influencing the decision-making and direction of the case study team through retrospective questioning and interactions. Additionally, a post-mortem analysis does not necessarily have to be conducted at the end of the project [9]; it can also be carried out during the project. This aligns well with the nature of the project, which operates as a scholarly competition, where the best projects are selected to advance to the next level. The competition consists of three levels: regional, state, and national [10]. The post-mortem analysis was performed on the prototype developed for the regional competition. However, no issues were identified during the post-mortem analysis that required addressing for the preparation of the prototype for the state competition.

The case study revolves around the design and development of a cyber-physical music instrument within the context of the maker scene. The project has a connection to the local Coder Dojo [11], which provided initial coding knowledge as a prerequisite for the project and offers expert guidance for maker projects. Initially stemming from a scholarly art lecture topic, the project has evolved into a youth research competition project. The competition project setup necessitates the maintenance of a research log, which serves as a valuable resource for identifying pivots and insights gained during the four-month project duration. Moreover, the project documentation and prototypes have facilitated the mapping of Frugal Innovation aspects to different project phases and artifacts. As per the competition presentation rules, a functional and performing product—the cyber-physical music instrument—must be showcased in February 2023, following the submission of the project report to the competition jury in January.

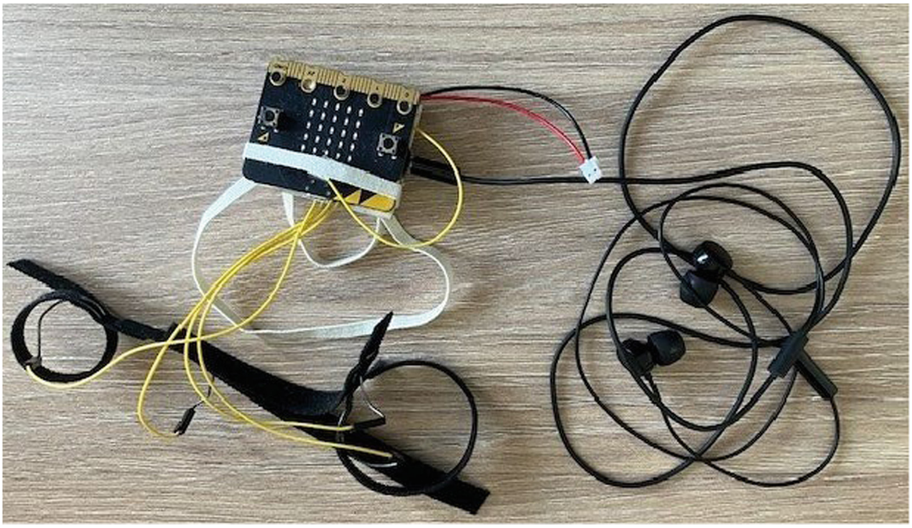

Fig. 1. Prototype of the sensor hardware unit for arm-/hand-mounting (white band) and fingers sensors (black).

Figure 1 presents a prototype of the music instrument, showcasing its hardware configuration. The hardware setup includes four finger sensors, adjustable to different finger sizes using black hook-and-loop tape connected by a yellow cable. The skin contact on the bottom of the instrument mounting plate (not visible), headphones, and a battery (not visible) are also utilized. The mounting plate offers standard connectors, allowing for easy customization of the configuration. Depending on the desired characteristics and functionality, the music instrument responds to defined gestures to produce sound.

The standard microcontroller board integrated into the instrument mounting plate includes sensors such as an accelerometer. The music instrument can be powered by a small 3V battery (e.g., CR2032) directly mounted on the plate or through a USB cable (e.g., via a power bank). Additionally, multiple music instrument modules can be combined, forming a larger respectively more feature-rich instrument by connecting them via Bluetooth. The application software stack utilizes a low-code approach, providing function blocks and specific libraries tailored to the music instrument. This allows for the adoption of (musical) features and capabilities without extensive software engineering expertise. The sound output can be accessed through the Aux connector, internal speaker, or wirelessly via Bluetooth, depending on the instrument's configuration. Elastic bands are provided for mounting the instrument on arms and hands. The presented hardware is constructed using standard components, making the core instrument affordable for individuals on a tight budget. However, certain parts, such as 3D-printed cases, can be added to enhance the instrument's professional appearance. The usage and playing of the music instrument depend on the software configuration. A simple approach involves using the four fingers (index to pinky) as "keys" assigned with notes based on their spatial position. The thumb is used to trigger a finger-key by pushing it. In Fig. 2, a performance of the music instrument is depicted, showcasing a meshed two-hand configuration. The left hand is configured to handle six octaves and the volume.

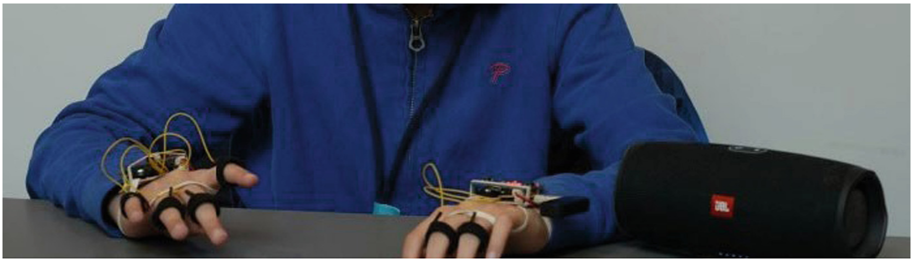

Fig. 2. Prototype during music performance with the music instrument connected with a Bluetooth speaker at the state competition.

The questions of the survey are oriented on the key aspects of Frugal Innovation from [12] and the development methods and procedures which are handling these aspects:

- What 3 main constraints do you have?
- What development methods and procedures are applied?
- How human-centric design was realized?
- How simplification was addressed?
- How adaption was used?
- How rugged design was integrated?
- How sustainability and environmental aspects are considered?
- How the product was designed to be affordable?
- How mobility was considered during design?
- What are the concepts for local design and production?
- What are the concepts for lightweight products and last-mile distribution?

– What learnings you made about the product and its technologies?
– How you build your specific intellectual property assets?

Based on these questions the survey was conducted and the project documentation analyzed. The following section summarize the analysis of the survey and documentation results.

3 Analysis

3.1 Constraints of the Project Setup

The project encountered several main constraints, which influenced its development and implementation:

a) Limited knowledge and experience regarding the required technologies needed to execute the idea, resulting in the adoption of simpler implementation options.
b) Time restrictions, necessitating the prioritization of options and possibilities and the implementation of timeboxing techniques to avoid excessive time spent on fine-tuning.
c) Financial limitations, which required cost-cutting measures whenever feasible.

These first two constraints were further exacerbated by the competition deadlines and the team's limited size, putting additional pressure on the project's progress and outcomes..

3.2 Development Procedure

The project's constraints necessitated the adoption of short timeboxes, with each progress step limited to a few hours. To meet the objectives within these timeboxes, the work was divided into smaller units, focusing on implementing specific function blocks aligned with the usability concept. The implementation approach favored simplicity over complex and sophisticated generic patterns. Evaluation and integration of the unit outcomes were carried out, and subsequent topics or enhancements were addressed based on the integrated results. To ensure continuous progress and prevent bottlenecks, the software, hardware, and mechanical development were separated whenever possible. A hardware emulator was utilized, enabling software development to proceed in-dependently. The hardware selection was based on this emulation feature. Methodologies from Scrum [13], such as using a *board* and *stories*, were employed to foster iterative and incremental work. However, the board and stories were not strictly aligned with established best practices, such as formatting them with "As an instrument player..." or including always a set of acceptance criteria for each story. Human-centered working practices were implemented through frequent integration and experimentation to observe the instrument's behavior and identify areas for improvement. Feed-back from external sources was also sought to gain different perspectives. Simplification was achieved through refactoring and backward steps when necessary, aiming to establish an improved current state for faster and more efficient development. Examples of simplification include eliminating the need for a glove that only fit one hand size and offering two-hand usage to facilitate learning for non-experts. In some cases, features were deferred to future versions, such as the implementation of a specific gesture using the magnetometer. Adapting to an existing development platform and its corresponding environments was crucial to focus on valuable outcomes and avoid time wasted on building a custom build pipeline. Leveraging open-source software played a key role in delivering new versions quickly and reliably, thanks to the support of the large online community associated with the established platform. Weak points in the design were identified during testing and replaced with more robust alternatives. For example, the design of mechanical parts, such as finger contacts, was completely redesigned and iteratively improved. Each iteration of improvement considered cost reduction to make the product more affordable. Various microcontroller platforms, including Calliope, micro:bit, and M5stack Atom, were evaluated, and the micro:bit was selected as the final choice. Sustainability was also a consideration, with every selected material or component reflecting on its ecological impact. Material reduction and the use of more "natural" alternatives were pursued, while additional materials, such as connectors, were incorporated to enhance durability or repair options. For mobile usage, established interfaces like Aux and cinch connectors, Bluetooth, or MIDI were evaluated to ensure compatibility and flexibility.

Considerations for scaled production were taken into account during the prototyping phase, although it has not been fully established yet. The objective is to develop a component-based approach and prioritize the use of standard components and materials that are widely available globally. The music instrument's small size facilitates easy distribution, and certain constraints, such as not including a battery in the shipping package for safety reasons, have been addressed.

3.3 Resources

Due to limited financial resources, the selection of materials and components was influenced, and following strategies and principles were applied within the available degrees of freedom.

The first crucial aspect, particularly in the current competitive environment for skilled professionals, was the constraint of limited engineering resources. In this context, engineering refers to the knowledge and expertise required for mechanical, hardware, and software technologies, as well as music instrument design skills. Design plays a significant role in the usability of the instrument and its compatibility with sheet music composition. For example, specific sequences in sheet music may be challenging to perform if the design or usage concept of the instrument is not optimized. The allocation of engineering resources primarily focuses on the development and improvement of the music instrument. The outcomes of the engineering efforts have a significant influence on resource allocation throughout the product's entire life cycle, including production and decommissioning

The second aspect are the resources needed to build respectively to produce the music instrument. Here the focus is on methods and tools which are used to manufacture parts and assemble the music instrument. From the frugal perspective simple methods and tools which are standardized are the objective. Furthermore, it is acceptable to have product specific tools as long as they are simple to produce and use, too. This specific tool category includes, e.g., a template or gauge for mechanical aspects of the music instrument. Electrical aspects are „simplified“ to plug connectors instead of soldering. Because soldering is much more difficult to learn and it is not trivial to perform soldering with a constant high quality. The overall objective is to design a production flow which can performed without high qualifications and which is easy to quality assure by establishing the option to scale the throughput up and down fast to avoid inventory (costs).

Lastly, the resources incorporated into the instrument are crucial as they will be scaled. The ultimate objective is to utilize standard components wherever possible. The underlying paradigm or assumption is that nothing is more cost-effective than standard components. Additionally, standard components are available at a well-defined quality level for an extended period. This provides a foundation for a potentially stable and long production life cycle without significant changes. Moreover, the use of components and modularization can facilitate product repairability by offering spare parts to extend its lifespan. In the case study, the music instrument features connectors that allow for the individual repair of broken cables or finger sensors. Another significant aspect is the selection of environmentally friendly and sustainable materials and components whenever feasible. Establishing a simple and transparent material selection strategy, such as using plywood instead of plastic for the mounting plate in this case study. If the use of plastic is unavoidable, efforts should be made to employ recycled plastic or at the very least, plastic with a high sorting accuracy to facilitate circular usage.

Currently, decommissioning is not explicitly addressed. However, the selection of sustainable materials and the inclusion of repair options during development serve as a solid starting point for considering this aspect in the future, when the life cycle of the presented case study reach that phase.

3.4 Pivots and Learnings

An essential aspect of an innovation project lies in the learnings and pivots that occur during the design and development processes. While not all learnings and pivots from the analyzed project are directly relevant to the research questions, some are presented here to provide insights into the project.

Selected pivots include:

– The realization that incorporating a glove as an integral part of the music instrument proved too specific and necessitated offering a wide range of different-sized product variants. To address this, a hand-size independent solution was sought to accommodate small child hands as well as “atypical over-sized” hands. Additionally, the solution aimed to promote inclusion, considering factors such as physical mobility differences between children and older adults. This led to the development of adjustable finger sensors that could be attached at varying distances from the fingertips. Inclusion has the potential to expand the market, but no market analysis currently exists regarding the adoption rate of cyber-physical music instruments among older adults.
– The decision to change the micro-controller was prompted by certain libraries not functioning as expected. Although this pivot required time to port the existing software to the new platform, it ultimately expedited later development stages by leveraging existing and tested open source software libraries.

Selected learnings include:

- The mapping of gestures to play the music instrument underwent more iterations than initially planned in order to find a suitable solution. These adjustments also influenced the mechanical design of the instrument to enhance ease of performance. Furthermore, the rapid rate of changes prompted the adoption of a different software architecture, enabling easier adaptation to new insights regarding usability.
- Starting with the software increment as the core of the cyber-physical music instrument proved to be the right decision. However, the mechanical development increment required more time than expected, based on feedback from user experiences. Additionally, the mechanical aspect, being directly visible and tangible to customers or users, proved to be more important in terms of factors such as appealing design and perfect fit, contrary to initial assumptions.

3.5 Intellectual Property Generation

During the development process, numerous learnings are generated. At an early stage of the project, the decision was made to identify Intellectual Property (IP), triggered by the competition's provision of selected facilitation for IP development and management. However, it should be noted that this is a time-consuming journey. One time-consuming aspect was the investigation of IP databases to determine existing and new IP, as well as gaining knowledge on writing IP claims. Another significant time allocation was devoted to formulating the IP claims. In the low-budget approach, there is a high risk that mistakes or errors may go unnoticed and only become apparent in the future, potentially becoming issues.

The three key areas of generated Intellectual Property are as follows:

- Novel design and development procedure: This pertains to the unique approach taken in the design and development processes, which resulted in innovative insights and methodologies.
- Novel hardware and software architecture: This refers to the original and distinctive architecture implemented in the hardware and software components of the project.
- Novel tool for a specific production step or activity: This highlights the development of a new tool respectively method that contributes to a specific production step or activity.

The key observation is that within a short timeframe and with restricted budget, it is possible to generate novel insights and knowledge. However, it is crucial to make strategic decisions about which insights and knowledge are strategically relevant and how to manage the acquired Intellectual Property. It should be noted that there is only a limited timeframe to initiate the patent processes, and this process requires allocation of resources.

4 Results and Discussion

4.1 Setup for Frugal Innovation

Not all aspects of Frugal Innovation have been fully adopted in the presented project, particularly in terms of production and shipping, which remain open topics. However, most of the aspects of Frugal Innovation have been intuitively handled. The key factor in enabling this intuitive handling was the project setup, which established the right environment with its constraints and limitations.

To summarize the learnings, a cheat sheet for Frugal Innovation in the context of product or service development can be derived:

- Know your main constraints and actively manage them: Establish a development flow to effectively manage resource limitations in the project setup and its corresponding outcome dependencies.
- Continuously align (interim) outcomes with the business idea: Regularly reflect on and adjust the business idea or business case based on identified opportunities or significant risks.
- Embrace iterative and incremental development: Adopt an Agile culture and mindset in the project to enable continuous progress through the development of micro-outcomes.
- Determine the scope of the product or service life-cycle: Decide which phases of the holistic life-cycle are in focus to ensure adequate attention and resources (e.g., circular economy objectives).
- Prioritize outcomes and break them down: Prioritize capabilities or features and break them down into micro-outcomes whenever possible, ensuring that outcomes are usable. In some cases, outputs may need to be accepted, such as a software component tested only in an emulator.
- Select standard components with strong communities: Whenever possible, choose standard components with active online communities and utilize open-source components and development tools with adequate licenses for the specific product and service.
- Balance characteristics and considerations: Balance factors such as costs, sustainable materials, and repair options for each module or component of the product or service. Consider their effects to frugal aspects like human-centric design, affordability, ruggedness, simplicity, and sustainability. Modularization can offer future selling options.
- Find the right balance between "good enough" and predictable refactoring efforts: If an outcome, such as a mechanical sensor handling solution, does not meet ruggedness requirements, consider refactoring or, in more severe cases, a complete redesign.
- "Play" with the interim product or service and be open to change: Encourage experimentation and openness to change or pivot. Involve team members and even "friends and family" in testing and providing feedback.
- Determine the need for strategic Intellectual Property development: Decide if strategic Intellectual Property development and rights claiming are necessary objectives of the project, and allocate resources accordingly.

– Evaluate target market regulations: Assess regulatory requirements for product or service conformity in the target market.

A bonus for success: Find a good mentor who can ask the right questions at the right time or provide valuable advice in crucial situations. Figure 3 summarize and groups the presented learnings as Frugal Innovation Design and Development (FID^2) approach sheet cheat with its four key-areas.

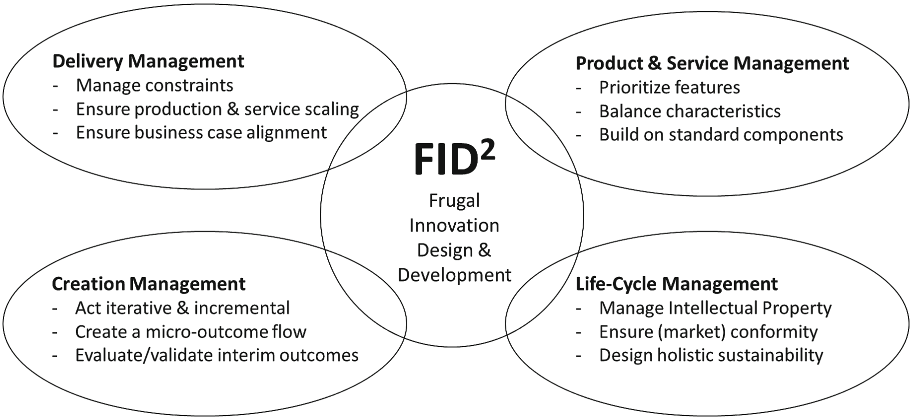

Fig. 3. visualization of the cheat sheet facts of the Frugal Innovation Design and Development approach with its four management key-areas.

4.2 Sustainability Within Frugal Innovation

One observation is that while sustainability is often claimed by Frugal Innovation approaches, the basic Frugal Innovation approach itself does not explicitly address the topic, such as the use of Sachet package sizes and their additional plastic [14]. While some of the United Nations Sustainable Development Goals (UN SDGs) [15] are often indirectly addressed, such as responsible consumption and production or decent work and economic growth, there is no explicit focus on higher goals like CO2-neutral products or services. Frugal approaches and established design and engineering approaches differ in their treatment of higher goals like circular material flows, as it is a complex topic that requires significant engineering capacity within the product or service design. Incorporating life-cycle planning early in the project is not inherent in the "frugal mind-set."

This highlights that while Frugal Innovation partly fosters sustainability by design, it does not guarantee that final outcomes are truly sustainable in terms of typical environmental footprints. Achieving a holistic life-cycle view requires explicit efforts. However, the analyzed project explicitly incorporates selected sustainable aspects into its agenda to provide a basis for a life-cycle view. In the case study, sustainability was addressed explicitly through the repair and spare-parts strategy and the selection of organic materials where possible. Reuse was also a topic, leading to the utilization of waste from the metal band of connectors as electrical contacts. It was a fortunate coincidence that the size and amount of the metal-band waste precisely matched the requirements of a later manufacturing step.

4.3 Intellectual Property Within Fugal Setup

To initiate the discussion, it is important to acknowledge that the topic of Intellectual Property was triggered by the registration process of the competition [10]. The inclusion of a checkbox for activating the Non-Disclosure Agreement (NDA) prompted active consideration of the topic. Without this checkbox, it is highly likely that the project would not have addressed Intellectual Property. This highlights the significant influence of asking the right questions at the right time on project outcomes. Furthermore, the facilitation provided by the competition setup guided the project through the Intellectual Property process to some extent. However, the process remained complex and resource-intensive within the frugal project setup. It is evident that the timeframe for claiming Intellectual Property is short—before the product enters the market or communication begins.

It is crucial to include Intellectual Property on the checklist or cheat sheet for frugal innovation projects. By listing it, there is a guarantee that it will not be overlooked in the fast-paced project with limited resources. Each innovation project team must make an early decision regarding the relevance of Intellectual Property, and if chosen, allocate sufficient resources to the Intellectual Property aspect, which typically runs in parallel with the entire design and development phases.

Frugal Innovation, according to its defined criteria from [2], does not exclude the creation and management of Intellectual Property. However, it also does not actively promote it—it becomes a part of the team's decision-making process based on the product's relevance and its domain. An analysis of music instrument patents in the relevant area reveals that both large global enterprises and small startups in the music instrument manufacturing industry have built their patent portfolios over decades. This suggests that similar actions need to be taken to have a chance of becoming a significant player in the market segment in the future.

In conclusion, it is worth to consider that Frugal Innovation, with its rigorous focus, also imposes self-constraints on aspects such as Intellectual Property and holistic life-cycle views regarding sustainability. The missing elements need to be identified and explicitly incorporated into Frugal Innovation practices. To identify these potentially relevant aspects, checklists or cheat sheets can be useful tools. Building on these considerations, additional tasks or threads can be derived to ensure proper and adequate management of strategically defined outcomes beyond the initial objective of fast product delivery.

5 Limitations

The case originated from a scholarly art lecture project and later expanded into a competition project, which imposed additional constraints on resources, such as time (deadline) and team size. However, the competition did not limit the team's ability to work; it only restricted changes to the team size during the competition phase. The competition deadline encouraged continuous work on the project, ultimately facilitating the possibility of delivering a market-ready product in a shorter time frame.

The analyzed case did not evaluate compliance aspects, such as product safety. For example, it did not consider whether there are any safety risks for users while playing the instrument in the intended use case or any additional safety risks in unintended usage scenarios, such as by small children. Furthermore, market regulations, like CE conformity in the European Union, were not assessed. These limitations can have significant implications as they may require time-consuming and costly redesign efforts. However, it is worth noting that other innovation approaches, such as Design Thinking [16], also do not explicitly focus on these aspects.

The analyzed case does not assess the business model and its scalability. These mentioned limitations can have a significant impact as they may necessitate extensive time and cost for redesign. However, it is important to note that other innovation approaches, such as Design Thinking, also do not explicitly emphasize these aspects.

The case study did not evaluate other "maker teams" and it remains unknown to what extent the identified learnings depend on the team's specific characteristics, skills, and mentoring. However, individual factors play a crucial role in all innovation endeavors. The specific and individual creativity of the innovation team is the key ingredient, and it is not possible for anyone to innovate everything using the same innovation approach. Neither Frugal Innovation nor other approaches like Design Thinking enable everybody to innovate everything. In other words, different innovation teams pursuing the same "innovation objective" will produce different outcomes, even if they employ the same innovation approach within a similar setup or environment.

In summary, Frugal Innovation is intuitive as long as the project maintains sufficient constraints and limitations throughout its lifecycle. Specific skills, such as knowledge of music instrument characteristics, can be valuable and acquired through learning. Basic funding is essential for realizing different prototype versions to evaluate and facilitate design and development progress. The required level of funding depends on the product, and for a cyber-physical music instrument, large budgets are not necessary. Project progress is feasible without external venture capital.

Frugal Innovation benefits from the absence of predefined sets of requirements, particularly at the project's outset, as it allows for exploration and open-ended possibilities. In the case study, the initial objective was to develop an affordable cyber-physical music instrument with gesture control. The readiness to learn and pivot is crucial. Additionally, asking the right questions is important for exploring fruitful areas. To operationalize these abstract observations, an iterative and incremental procedure is valuable.

6 Contribution and Outlook

The post-mortem analysis of the design and development of a cyber-physical music instrument presented in this study demonstrates that Frugal Innovation aspects can be intuitively fulfilled by the project, provided that the necessary frugal project setup and environmental conditions are in place. Additionally, the case study reveals that Frugal Innovation enables the creation of Intellectual Property, similar to other established innovation approaches. This positions Frugal Innovation as a first-class approach for product and service innovation, including design and development across various markets and enterprise sizes.

Contributions to practice include:

- A cheat sheet designed to facilitate Frugal Innovation by considering relevant strategic aspects and establishing a comprehensive perspective.
- Frugal Innovation can also serve as an approach to generate Intellectual Property. However, applying Intellectual Property processes systematically can be resource-in-tensive.
- Frugal Innovation is an intuitive approach that does not necessitate specific methods or knowledge for its application. It can be effectively employed as long as the setup and environment of the innovation project align with the requirements and definitions of Frugal Innovation.

Contributions to theory include:

- Frugal Innovation can be applied in various setups beyond its initial emerging market context, including music instrument design and development in a competition setup.
- Frugal Innovation is a first-class approach for innovation in terms of cost, functionality, and performance, regardless of the context or industry.
- While Frugal Innovation emphasizes the idea of using fewer resources, the sustainability aspect is not automatically achieved from a holistic life-cycle perspective. Additional efforts, such as aiming for sustainability goals like CO2 neutrality, need to be explicitly addressed in the design.
- Frugal Innovation is inherently self-constrained when it comes to strategic and life-cycle aspects, such as Intellectual Property management, which must be consciously initiated and managed.

The presented music instrument concept was developed within a short timeframe of a few months, facilitated by the FID^2 approach, which can democratize music instrument design and development. The instrument itself has the potential to democratize the design and adoption of cyber-physical music instruments by fostering a prosumer community.

However, there are unresolved questions for future investigation, such as: Is it feasible to utilize the suggested cheat sheet to artificially constrain a non-frugal environment in order to establish a more cost-effective product and service development setup? Additionally, is the proposed cheat sheet comprehensive and applicable to other domains beyond IT technology-driven products or services?

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Insights into Socio-technical Interactions and Implications - A Discussion

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Abstract. Information and communication technologies have dominant impacts in all spheres of modern life. While these technologies offer the possibility to make the world a richer, more efficient and interactive place, they increase fragility as they reinforce our dependence on such systems. The dependence, in a sense, draws attention to how increasingly, science is a collaborative sport between humans and computers. This in turn highlights a change in social science itself as we transition from qualitative study of small groups of people to quantitative computer-aided study of big data sets created by human-machine interactions. The interactions indicate a kind of intelligence that is different from humans and in a sense urges us to identify new questions. Questions that direct our scientific enquiries into blind spots that our algorithms find for us, and indicate the levels of diversity the teams need to have to address these questions. The complexity of these interactions can never be fully understood, as they evolve continuously, and in this context, the idea of social computing gains relevance. Given the vast implications of ICTs and the impossibility of considering them all, this discussion is limited to the domain of cybersecurity and the related domain of privacy. The discussions are approached through stories that emphasize an ever-increasing and diverse set of threats of the growing complexity of digital ecosystems, and the concerns that it might lead to violation of fundamental values such as equality, fairness, freedom or privacy. It is becoming increasingly evident that applying cybersecurity mechanisms are essential to the protection of digital assets, that could be personal, industrial or commercial. However, such measures may also encroach on individual privacy while potentially exclude individuals from society. Given the background, this paper proposes to trigger a discussion on how technology and society interact on practical levels, and how the impact such interactions have on society could offer a unique perspective on innovation processes.

Keywords: Information communication technologies · society · socio-technical interactions · social computing · innovation

1 Introduction

"You who enter, abandon all hope!" The Divine Comedy, Hell III, 9 ("Die ihr eintretet, lasst alle Hoffnung fahren!" Die G¨ottliche Kom¨odie, H¨olle III, 9)

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The prevalence of information and communication technologies (ICTs) in all spheres of modern life makes the world a richer, more efficient and interactive place, while also increasing its fragility as they reinforce our dependence on such systems [11]. This has brought cybersecurity and related issues of privacy into direct focus. As technologies of globalization, ICTs are woven into the very fabric of our societal organizational structures. This has consequences, related to the interactions of technological objects as a phenomenon that even though triggered by human action in one context, manifest in ways that are sometimes invisible and at other times unpredictable. Several studies articulate in diverse ways how even as firms are increasingly becoming technically capable and economically efficient through innovation and free market mechanisms, their practices of organizing are intensifying economic inequity, eroding critical environmental systems and inflicting stress on people and communities (see [10, 13, 18, 19, 45, 46, 49–51]. This is not sustainable and calls for a transition. For instance, smartphones are often lauded for their innovative capabilities that lend them enormous processing power without heating up. What gets neglected is the presence of vast server farms where the actual processing is outsourced, and the cooling takes place, thus outsourcing the activity [41]. This captures the idea of externalizing or outsourcing that characterizes globalization, and demands closer attention, as the idea is key to understanding what distinguishes industrial societies from information societies. The distinction is relevant for comprehending computing as a tool that offered industrial systems the means to activate vast innovation ecosystems and in doing so enabled the augmentation of social interactions [15]. This augmentation offers an opportunity for continuous learning and development by leveraging networks that become proficient in managing externalities, thus addressing issues as they emerge. In this context, the design of computing infrastructures could be understood as a socio-technical assemblage of the human and the technical. This socio-technical assemblage has resulted in information infrastructures (II) that are composed of other infrastructures, platforms, application and IT capabilities, where recursion forms the organizing principle implying that such IIs return 'onto' themselves by being composed of similar elements [20, 31]. This is the case socially as well, where IIs are recursively organized in that they are both outcomes and conditions of design action and involve both rule-following and rule-shaping activities [20]. Therefore, the control of such II is distributed and episodic and the result of negotiation and shared agreements. Distributed forms of control depart from traditional approaches with a single entity assuming control, instead, here the forms of control are episodic where groups come together according to capabilities, interests, needs shared across multiple communities in myriad and unexpected ways [20]. The distributed forms exhibit unbounded openness with no clear boundaries between those who may design and those who may not, and where new components can be added and integrated in unexpected ways and contexts [20]. This requires reimagining Computational Social Science (CSS) as Social Computing which goes beyond merely using computational tools to make sense of the contemporary explosion of social data [15]. Social Computing requires recognizing societies as emergent computers of collective intelligence, innovation, and flourishing and proposes that we imagine a socially inspired computer science that takes these insights into account as we build machines. Machines, that are not just meant to substitute human cognition but radically complement it. Evans, (2020) describes social computing as an extreme form of interaction between humans and computers whereby machines and persons recursively combine to augment one another in generating collective intelligence, enhanced knowledge, and other social goods unattainable without each other. Social computing reveals the limits of sociality and computation, and suggests imaginaries for transcending those limits together. In this paper, we propose that issues related to cybersecurity and privacy needs to be understood within the realm of social computing and therefore require a radically different treatment. For instance, stories emphasizing an ever-increasing and diverse set of risks owing to the growing complexity of digital ecosystems, in combination with global risks, inevitably lead to an overemphasis on cybersecurity. This creates a conundrum. An overemphasis leads to concerns that it might violate fundamental values such as equality, fairness, freedom or privacy, on one hand, while neglecting it could undermine citizens' trust and confidence in digital infrastructures, in policymakers and in state authorities [11]. Thus, while supporting the protection of values such as non maleficence, privacy, and trust, cybersecurity brings forth a complex relationship between values [11, 32].

Applying cybersecurity mechanisms is essential to the protection of digital assets, which could be personal, industrial or commercial. However, such measures also include the collection of data from several points to detect, and potentially foresee, anomalies which might encroach on the individual privacy [23]. This calls for an innovative social approach that begins with an imaginative design practice of developing a social imaginary described as 'not a set of ideas; rather it is what enables, through making sense of, the practices of society' [48]. Progressive discussions on socio-technical futures combining techno-scientific potentials and prospects with visions of societal change and new social arrangements bring into focus knowledge objects, as well the practices and processes that contribute to the construction of such futures, and their bearings on innovation and governance processes [28]. Socio-techno imaginaries refer to the shared beliefs and visions that a society has about the role and impact of technology in their lives. These imaginaries shape how individuals and groups understand and relate to technology, as well as how they make decisions about its development and use. They can include ideas about the potential benefits and risks of technology, as well as cultural and social values that are associated with it. Socio-techno imaginaries are shaped by a variety of factors, including historical, economic, political, and cultural contexts.

Examples of socio-techno imaginaries include the "Internet of Things" (IoT), which refers to the belief that everyday objects will be connected to the internet and be able to communicate with each other, leading to a more connected and convenient world. Another example could be the impact of self-driving cars on society. These different imaginaries can shape the way that people approach the development and regulation of self-driving cars, as well as the public's acceptance of the technology.

There are two levels of interactions with these technologies: the existing and emergent, that are both recursive. These interactions also reveal the need for building new network designs for accessing a combination of resources that contribute towards building coping mechanisms to deal with severe disruptions, and survive or even thrive in a context of volatility and uncertainty. Diverse streams of literature define this coping mechanism as antifragility, which goes beyond the traditional ideas of resilience and adaptation and their attendant issues [1, 9, 14, 26, 33, 42, 43, 53, 54]. Seen from this perspective, any innovation is a combination of knowledge, contracting, and collective action governance problems, implying that entrepreneurial discovery can extend to high-order groups, requiring a multilevel selection model of economic evolution [38]. Many of these resources often lie outside of what we define as business networks, but are accessible through commons [38–40]. The transitions ushered in by innovations and the transformations they demand are complex and emergent processes and need diverse resource ecologies for the reconfigurations of the current system. Here the idea of commons offers the means for addressing the issue of radical uncertainty that is inherent in any innovation process. Dispersed knowledge is the central problem in any organizational setup; the pieces of a puzzle are dispersed among various actors and therefore they must interact with others to develop a sense of the whole problem and imagine new ways to address them.

By infusing imaginaries, innovation processes take into consideration what is imaginable and possible within distinct social, political, and historical contexts. In doing so, they offer a thread of continuity and stability by extending existing frames of reference from the past into the future, and mitigating the disruptive quality of innovation processes.

To trigger discussions on these topics, this paper is organized as follows: Section 2 describes the related work and general definition of elements of this research. Followed by Sect. 3, which present examples of technology impacts on society and responses from the different stakeholder groups. In Sect. 4 the suggestions for a model and research program on the deducted topics and stakeholder needs is given. Finally, the relation to the SPI manifesto is provided, and the work is concluded in Sect. 6.

2 Related Work

This research needs to bring together a transdisciplinary knowledge framework, each with a distinct perspective on interactions between information communications technologies and society, with the objective of making sense of and building a consensus on the context. As such, perspectives on sustainable socio-technical transition strategies and innovations systems from economics, business administration, and science and technology studies needs to be considered, and linked to emerging ideas from innovation management, industrial networks and complex collaborations in multi-sectorial platforms and computational science studies and data analysis. In the context of cybersecurity, this diversity of perspectives is a critical contribution to a clear and precise understanding of the context within which resilience and adaptation, as a response, are being put forward. This is because any articulation of future strategy that scaffolds itself within risk to urge for responses of resilience and adaptation with the purpose of protecting the current system configurations and an exclusive focus on preserving organizational success is problematic. However, when these responses or reactions enable creative discovery and enactment of market shaping opportunities [37] they are able to formulate strategy within an understanding of risk that is not limited to organizational success but become entangled with grand challenges [16, 21] and wicked problems [21, 36].

2.1 Sustainability and Transformative Concepts

The implementation of this research is built on an understanding of sustainability that goes beyond resilience and adaptation. Sustainability transitions [24, 27] in this context, serves as an entry point to progress towards 'transformation' or 'transformative knowledge', as the aim is not merely to transition from one state to another, but to fundamentally re-arrange the system as a whole [5, 6, 17].

For such transformation, the ideas of resilience and adaptation as viable responses to crisis are limiting. This is especially evident when responses to crisis are designed to reinforce an existing system. Such responses remain inadequate and become incompatible with the natural world, while consistently deepening inequality, and exacerbating conflicts, leading to fragility that creates conditions for yet another version of the crisis [52]. Here, a deliberate cultivation of emergence, a shaping of the environment, to enable transformation [35] present the potential for building a new level of resilience and adaptability or antifragility [1, 33, 42]. However, such shaping is not possible within single actor domians, as the idea of knowledge as division of knowing is implicit in this continuous and evolutionary process of shaping and becoming. It is evident in Adam Smith's suggestion pointing to the most fundamental division of labour is the division of knowledge and consequently making possible the roundabout and combinatorial ways of producing knowledge [34]. This notion also links to the ideas and writings of the Austrian school of economists in their understanding of the open-ended and evolutionary nature of knowledge based economic activity [34]. The theory of complex adaptive systems underlying the ideas and activities of shaping and becoming [35] forces a confrontation between knowledge and the institution of social understanding. Knowledge is private, at the level of the actor, while understanding is social, thus becoming a phenomenon that emerges through interactions between actors in specific contexts [34]. The concept of social computing that attempts to broker a deeper compact between social interactions and computing offers a more coherent means of imagining and designing new network configurations.

2.2 Social Imaginaries

In this context, social imaginary offers an entry into the exploration of how actors make sense of practices and resource combinations related to ICTs. This can then develop into socio-technical imaginaries, defined as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of social life and social order attainable through, and supportive of, advances in science and technology" [25]. The imaginaries highlight the instrumental and transformative role played by technology in generating imaginaries of social order [25], that addresses issues related to cybersecurity and privacy. Social imaginaries help in dealing with the normative expectations and deeper notions and images that underlie these expectations, while socio-technical imaginaries enable the development of collectively held notions of desirable futures that are inclusive of threats and challenges. Such an innovative social approach could help in identifying what kind of social processes are needed for unlocking society's latent potential for discovery. How could these processes trigger possible imaginaries that could act as catalysts and motivation for contributing towards building anti-fragile safety and security elements at a societal level.

Examples of socio-techno imaginaries include, among many others, “smart city” and the “Internet of Things”, and how people imagine these technologies to impact society and life. Concrete examples of socio-techno imaginaries also include the way that people imagine and talk about the impact of social media on society. Another example could be the way people imagine the impact of self-driving cars on society. These different imaginaries can shape the way that people approach the development and regulation of self-driving cars, as well as the public’s acceptance of the technology.

3 Impact of Technology on Society

The conceptual sophistication of the word technology, and how it had been understood through its relationship with science and industry, over time, has come to represent a combination of ‘science of the arts’ and ‘applied science’ [44]. The combination has led to a fusion of meanings that tend to reduce the entire idea of industrial arts to invention, and invention to applied science, resulting in deterministic discourses that categorize technological change as the inevitable consequence of scientific discovery [44]. Technology, through its ability to intervene between scales, offers the possibility to navigate complexities of planetary science as well as the mundane [2]. This opens up possibilities for it to be extended beyond an actors’ category into an analytical one. It means that while paying attention to the richness of technology as an actor’s category, it is also possible to sharpen thinking with technology as an analytical category [2, 7]. It helps in incorporating the paradox inherent in technological advances as an important element in understanding transitions. A convenient place to start is with Beck’s (1992) ‘world risk society’, an idea that describes how the very technology, science, and industrialism responsible for the progress of late modern society might be putting it at risk as well. Embedded in this idea is the acknowledgement of progress, the risks inherent in such progress, and the realization that we are entangled in this in ways we do not fully understand or control [30]. The first step would be identifying the narratives that highlight such risks because talking about them creates opportunities for new ways of thinking. This is a process of reproblematization of the past through the imagination of a future that is threatening, as well as a reevaluation of norms and imperatives that guided past decisions to develop alternative perspectives on capitalism, law, consumerism, and science [4]. Such a framing enables technology, science, and industrialism to remain relevant during transitions [4]. Retaining relevance is important as they are integral in organizing the complex assemblage of networks of unexpected associations between heterogeneous elements, each of which is an active node that is no longer just a compliant intermediary [30]. The notion of externality that has always been somewhat problematic [8], gets resolved in such assemblages. For instance, A recent report captures how teen users have developed a number of strategies to make themselves seen, heard, and valued online. The users appear to counter the prevalence of ignorance inside social media and gaming companies that abdicate responsibility by strategically choosing what they prefer to not know about their users and thus failing to protect the health and well-being of minors. Progress in modern societies have meant a continuous process of automatization, beginning with skills of manual workers to the current systems of knowledge through digital retention [47]. It is in this current digital transformation where information is stored and retained through an artificial means of automated categorization that the need for human choice gains significance and along with it the opportunity to create innovative organizational forms [47]. The objective is not to depict what these organizational forms are but what they could become. Seen from this perspective, what kind of organizational forms could address different contexts of cybersecurity and privacy transform into innovative arenas.

4 Model and Research Suggestion

In this section, we propose a research model for conceptualizing a new way of problematizing cybersecurity and privacy. The figure below offers a basic framework of ideas for developing the model.

The first phase of the model is to create a frame of reference for the problem setting and to set the agenda for transition by articulating the context. This includes a participative exercise to identify and incorporate issues related to responsible science and incorporate them into the design and planning of further research activities. Which will include clear ethical guidelines related to collection, analysis, and storage of data, and ensuring equal representation of gender and perspectives. The focus shall be on investigating the meaning of transition in the context of the emerging information society, including a mixed-methods approach of interviews, workshops, data scraping and analysis. The aim of the first phase is to create a shared understanding of sustainability transitions and how this is framed within modern social imaginaries of the industrial age, representing a knowledge framework along with its set of related beliefs and practices. These will serve as blueprints for identifying and subsequently proposing a set of imaginaries for transforming towards a sustainable and just information society. While each separate viewpoint will employ its own methodology (qualitative or quantitative, or mixed) to investigate the knowledge framework and the related beliefs and practices. The flexibility in methodology is necessary for accommodating the multidisciplinary perspectives that are at the core of this research agenda. The results will help to present the understanding of sustainability transitions and their framings within modern social imaginaries of the industrial age. This is an important step as it clarifies why challenges continue to persist in European and global contexts (Fig. 1).

In the second phase, the use of socio-technical imaginaries [25, 28] helps to investigate the possible resource combinations that are relevant to the emerging information age. This should involve workshops for generating collective sociotechnical imaginaries for ICTs and required resources for embedding cybersecurity and privacy practices. The objective of this step is to offer insights into unarticulated ideas and other resource combinations relevant to the emerging information age. This is expected to address persistent challenges that businesses and policymakers face, despite all the good intentions [22]. Technology enhancements emerge as solutions driven by new ideas, yet these are unable to adequately match the complex dynamics of these challenges. Therefore, contributions from involved stakeholder groups and result in creating new socio-technical imaginaries of possible resource combinations for engaging with these complexities. It will also highlight which combinations could be scaled and those that cannot. This also

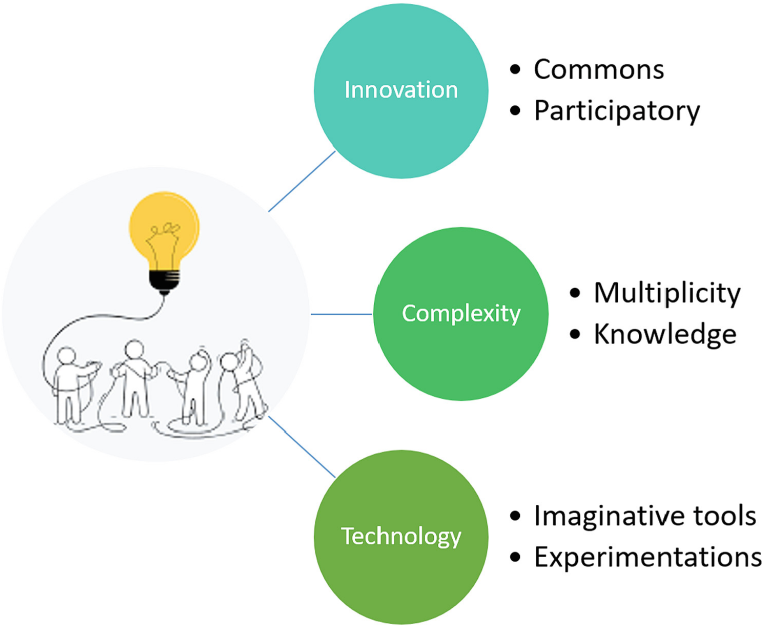

Fig. 1. Cybersecurity and privacy research model

offers insights into areas where individual actors can build resource competencies and areas where collaborative dimensions become necessary.

The third phase will focus on ways of new socio-technical imaginaries of industrial network configurations and related knowledge frameworks and practices. This will focus on the need for a new societal approach to technology, one that does not reduce it to the homogeneity of gigantic industrial technologies. This phase shall investigate the possibility of using technology as imaginative tools for innovative organizing of industrial networks that acknowledge the distributed character of control across multiple heterogeneous actors and resources. Also involving ethnography-inspired field-work and interviews with industrial actors to develop new socio-technical imaginaries of industrial network configurations. The objective is to develop a new way of thinking about technology, one where computational possibilities offer imaginaries that are beyond disruptive technologies and associated short-term profitability to incorporate an evolutionary perspective on contemporary antifragile organising. This approach will use socio-technical imaginaries to bring about transformative change in thinking about industrial networks in the information age and the associated meanings. The result of this is the creation of a new semantic level of understanding of industrial networks for the information age recognizing the distributed character of control.

Phase four will use socio-technical imaginaries to reframe the natural way of life ecological theory and practice. This will draw upon Geoghegan's cybernetic apparatus to explore the connections between technologies and the natural world. Instead of evoking a reaction against civilization through its manifestations in technology, education, and society, this framing will acknowledge the idea of 'world risk society' [3] to draw attention to the idea of progress in technology, science, and industrialism of late modern society, and the risks inherent in such progress. Such a framing enables technology, science, and industrialism to remain relevant during transitions for their ability to affect change through retrospective knowledge [4]. The framing will draw on Stiegler's view that humans affect change by actively modifying the environment with the objective of making things better. The resulting socio-technical imaginaries will offer a radically different means of dealing with the challenges related to cybersecurity and privacy. The result is to offer a model for policy continuity and coherence that is relevant for building antifragile cybersecurity and privacy policies. The central idea that this phase shall deal with is that any activity will throw up challenges, how can we engage with these activities, recursively, using the powerful technologies, in a just, transparent and inclusive manner to solve the challenges.

In the final phase various socio-technical imaginaries from the other phases shall be used to create predictive models for cybersecurity and privacy. These models will incorporate the view that the idea is not to protect society from the corrosive and de-socializing market forces, rather market settings should be seen as ongoing collective experiments in which emerging concerns are continuously articulated and revised [12]. In these simulations, industrial networks transform into 'devices' that form and shape such experiments, and are, in turn, formed and shaped by them. The transactions embrace the incomplete nature of knowledge, and socio-technical devices become tools for a continuous cycle of information gathering, analysing, and coordinating. The models will be designed to turn challenges and issues to opportunities for innovation, and study how in doing so, political and moral elements can be addressed as part of the activities. This phase shall be designed for testing and experimenting with the various ideas that the exercises with socio-technical imaginaries present. The experiments will offer useful indicators for practitioners and policy makers wanting to engage with transitions purposefully, and specifically with issues related to cybersecurity and privacy.

5 Relation to SPI Manifesto

With this paper contributes to certain suggestions of the principles and values described in the SPI manifesto of the EuroSPI community [29]. Specifically, we aim to enhance the involvement of people and extending their awareness of agency they have(A.2). This leads into our explaining changes of businesses and values of businesses (B.2). Further objectives, which are related to change of the context (C.1) and adaptation of vaules (C.2) are also mentioned and thereby also to support the vision of creating learning organisations (4.1) and empower business improvement objectives (8.1).

6 Conclusion

The objective of this research proposal is to offer a pragmatic approach towards understanding and making sense of the emerging information society. The focus is not on accuracy in describing reality, but more on how existing realities can intervene to bring about a change in and expand our existing knowledge frameworks. By turning the focus away from the representational dimension of reality to a pragmatic one, this research approach aims to embrace the socio-technical, socio-economic and larger environmental realities while making transparent the practical implications of such realities. As a continuous process, this cannot be contained within a single frame but can be described, and that is what it offers. Offering a description of reality by weaving together a diversity of knowledge frameworks to offer a narrative of possibilities for addressing complex issues. Interaction with possibilities could enable a transition in the cognitive representation of how we understand transitions, identify the role of interacting networks of actors and information in such transitions. The interactions understood within the realm of social computing could motivate activities for engineering new designs at the interface of humans and computational devices. The idea is to enable us to do what we do, better, through continuous social interactions, and in turn help us build technologies that complement human limitations and compensate for them as well. This would give us the time and abilities to think further, to think bigger, to overcome a range of problems that limit the ways in which we think and biases the ways in which we think.

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Frugal Innovation Approaches Combined with an Agile Organization to Establish an Innovation Value Stream

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Abstract. Today it becomes more and more important to keep the pace of the changing world and its markets by continuous innovation delivery. To establish a continuous innovation capability enterprises search for ways to integrate this needed innovation culture into their organizational DNA. However, not all enterprises can establish for all topics dedicated innovation units like labs or innovation centers. An approach to innovate within an established respective "ordinary" organization and its structures is an innovation network. An innovation network comes with lean structural elements and is more tied to the operational value streams than dedicated innovation units. However, it requires also governance and methodological approaches respectively procedures to innovate continuously to establish an innovation value stream. One challenge is to establish a sustainable innovation value stream which lasts for a long time and delivers continuously with its projects valuable innovations to its enterprise. This work presents the in 2017 established Quality innovation NETwork (QiNET) initiated by the IT Test & Quality Assurance (TQA) of the Volkswagen AG which combines Frugal Innovation approaches with agile approaches within a zero budget frame for establishing an innovation value stream within the Volkswagen Group IT.

Keywords: Frugal Innovation · Agile · Lean · agile transformation · continuous innovation

1 Motivation, Context and Methodology

Many enterprises in different countries and regions are working hard to become more innovative like Google [1]. Not all enterprises can allocate for all relevant topics large amounts of resources – like budgets, topic related skills - or build dedicated organizations to manage these resources – like labs or innovation centers. Also it is a kind of strategy decision to consolidate innovation like in labs or distribute innovation into the entire organization like as part of the culture with a strong innovation DNA. This work focus on a distributed innovation strategy: the innovation network. The approach of innovation networks exists for a long time in different setups [2] and its orchestration is a well analyzed topic [3]. The concept is to have a lean governance and agile management of the innovation process of the innovation network. The innovation projects of the

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innovation network are running in teams formed from different organizational units. One important aspect is that the innovation network itself has not own respectively very limited resources which are not sufficient to run respective finance etc. its innovation projects. The project assigned human resources are spare and the other resources are very limited, too. Mostly all contributing resources are based on a “volunteering” and “donation” to the idea behind the innovation project. Some are contributing with their “brain and hands” others “donate” funding for features or project phases. These kind of setup is not the classic enterprise project environment and more a frugal setup which might be supported by the company culture. It is more oriented on the concept of “by and for users” [4]. One of the challenges with innovation is that it is one thing to “born” one innovation - the hard thing is to innovate continuously. A key idea behind an innovation network could be to bring together “experienced innovators” and “new/fresh innovators” within one innovation project were possible. This fosters to get new areas of innovations with the “determinism” of the experienced innovators. The IT domain is a good place to establish this kind of innovation network because from the fixed expenses view IT is low priced – typically a notebook with internet connection – the most important part is the “brain” of the engineer. This is at least at the beginning of many IT innovations a typical setup. So everybody within an IT organization is potentially ready to innovate – in other words: every IT employee is an existing full equipped “innovation unit” by design. The term “by design” is motivated that currently IT also is a partner respectively facilitator of digitalization in many enterprises. Digitalization itself is the chance to innovate and build a more sustainable business for the future. Therefore, it is important to find ways to innovate in a more and more constraint setup driven by the growing war of talents [5].

The research scope is to evaluate how close Frugal Innovation derived from emerging markets with their constraints fits to the described kind of innovation network.

The research questions about this enterprise IT frugal innovation setup are:

RQ1: Why to combine Frugal Innovation and Agile for continuous innovation delivery?
RQ2: What is needed to establish a setup for Frugal Innovation in Agile organizations?
RQ3: How to manage and perform Frugal Innovation in Agile organizations?

Section 2 elaborates the Literature. Section 3 presents the applied methodology and Sect. 4 presents the Data and its analysis, Sect. 5 makes the synthesis and discussion based on a case as example from the Volkswagen Group IT. Finally, Sect.6 concludes by summarizing the article’s key contributions to research and practice and giving an outlook to the authors’ ongoing research activities.

2 Literature

Agile and Innovation

Existing a lot of different approaches to innovate [6]. Continuous improvement can be seen as a starting point for continuous innovation. Improvement target is operational excellence in innovation [7]. In a next step measures are needed to see the innovation performance for optimization. In [8] innovation capability and capacity performance measures are proposed. As many organizations are using Lean and Agile approaches their inherent innovation capacities of these models is used. In [9] is analyzed how Agile is fostering continuous innovation. Also in product development and innovation processes Agile methods are facilitating innovation [10]. However, typical Agile approaches, like Scrum [11], are development approaches and no innovation approaches. The development approaches can be combined with innovation approaches like Design Thinking [12] – but it comes with additional complexity and skill demand to manage different methodologies.

Frugal Innovation Approach
To keep the innovation projects complexity - including methodological approaches - and required resources low Frugal innovation can be used. Frugal Innovation is “do more with less” [13]. More refined definitions are “Frugal innovation is good-enough, affordable products that suffice the needs of resource constrained consumers” [14], “Frugal innovation refers to products and services that are developed under resource constraints” [15], “Frugal innovation is also an innovation process design in which customers are the key focus to develop accessible, adaptable, affordable and appropriate products” [16], “Frugal innovation has low to medium sophistication, medium sustainability, and medium emerging market orientation” [17], “Frugal innovations are products and services that focus on crucial needs, spare resource use or eliminate non-essential features in the design process” [18]. Over time the definition of Frugal Innovation is evolved and refined as [19] presents with the three evolution stages and summarize as key-areas of Frugal Innovation: cost-effectiveness, ease of use and prescriptive variables. Furthermore, the work suggest to combine Frugal Innovation with Agile for sustainability outcomes.

Agile and Frugal in Combination
The combination of Agile and Frugal Innovation can be used to handle uncertainty [20]. This aspect make it useful in startups [21]. And moving focus from the BoP to emerging market to “un(der)served” customers [22].

To run Frugal Innovation in established organization something is needed. Established organizations have to setup a system which is able to explore (innovate) and exploit (efficient production at scale) [23]. Dual organizations are the way to balance these two aspects [24].

Establishment of Innovation in Organizations and Innovation Network
To align independent innovation projects (e.g., realized with autonomous agile teams) something on a strategic level is needed. First the innovation strategy has to fit to innovation ecosystem to ensure performance [25]. Then a innovation strategy has to be elaborated [26].Furthermore, the innovation strategy has to fit to the organization [27]. Innovation networks with their by design openness can be seen as an additional opportunity space [28]. And an important element of rural innovation setups [29].

3 Methodology

The approach of a post-mortem analysis is an established approach to gather information [30] also in research context [31]. A post mortem also can conducted in a vital setup to look backward to past phases of a project or organization. In this case the post mortem is conducted to assess past phases to learn from them. A post-mortem analysis is applied to the in 2017 established QiNET with the focus to identify what are relevant "performance factors" for continuous innovation. The QiNET as Quality innovation NETwork was founded to enable the Group IT Test and Quality Assurance (TQA) to establish in cooperation with other Volkswagen Group units and entities a way to ship IT quality related innovations. For the post-mortem evidences like the innovation process and strategy in its versions is used. Additionally, the innovation projects "fact sheet" were a resource about the setup and its outcomes. Furthermore, contributors to innovation projects are requested to a survey. All gathered data is used to identify relevant indicators. The identified indicators and factors are analyzed to map them with established the Frugal Innovation approach and Agile approaches.

The questionnaire inspired by [32] and adopted to the IT context of the QiNET asked the following questions:

– In how many QiNET projects did you participate? [number]
– Could you imagine to participate in future QiNET projects again? [yes/no]
– Rate the overall project effectiveness about the realized outcome to the invested resources from 1 (not effective at all) to 10 (highly effective)
– Rate the projects effectiveness in comparison to other projects you have participated in your organization from -5 (significant lower) to + 5 (significant higher)
– Rate the following aspects about relevance related to the QiNET innovation projects you contributed from 1 (lowest) to 10 (highest) or set 0 for not relevant for your project(s)?
  - o Simple: minimalistic requirements and its implementation
  - o Adaptable: levers existing components or products/services
  - o Green: fosters green products/services or based on renewable resources
  - o Affordable: low price to buy (CAPEX) and ops costs (OPEX)
  - o Human-Centric: intuitive and easy to use
  - o Rugged: usable/operates in harsh environments
  - o Last-mile distribution: uses unconventional channels and access
  - o Lightweight: portable (usable) into varying scenarios or environments
  - o Mobile: easy connectivity and integration
  - o Local: operates local by sourcing remote resources and equipment
– Rate the autonomy of the innovation project team about decisions what is to do to reach the best outcome from 1 (no autonomy) to 10 (complete decision autonomy)
– Rate the "agility" of the innovation project from 1 (no continuous learning and delivery at all) to 10 (continuous learning and delivery about the outcome)
– How was your project engagement from 0 (forced by somebody) to 10 (absolutely by choice)?
– What would you change in a potential future innovation project related to the QiNET? [free text]

The survey was sent to project members from past QiNET innovation projects as long as contact data was available. The survey was realized by an anonymous survey system.

4 Data and Its Analysis

The analyzed data shows that the QiNET incubates mostly small innovation projects – the projects to build the innovative idea to a product or service. Small, because they are running typically for months rather than years. Also the team is small – normally 3- 4 persons - and build on part-time assigned project members. The projects are pull- driven. The idea is to have at least one person in the team who will be a "user" or "outcome consumer". Only one project was canceled in the more than 5 years, because no "pull" could be established – the project respectively its topic was placed too early in the "hype-cycle". On average 6-7 individual and independent innovation projects are performed per year. With the agile mindset of the QiNET the projects are sized as small as possible in size and runtime. Sometimes an innovation project version 1.0 leads to a version 2.0 respectively follow-up project – as part of the iterative and incremental innovation project performance on a large scale thinking. The version 2.0 can be established with the same or a change project member setup – depending on factors like skills and "volunteering" interests. Within this setup not all kind of innovations can be realized.

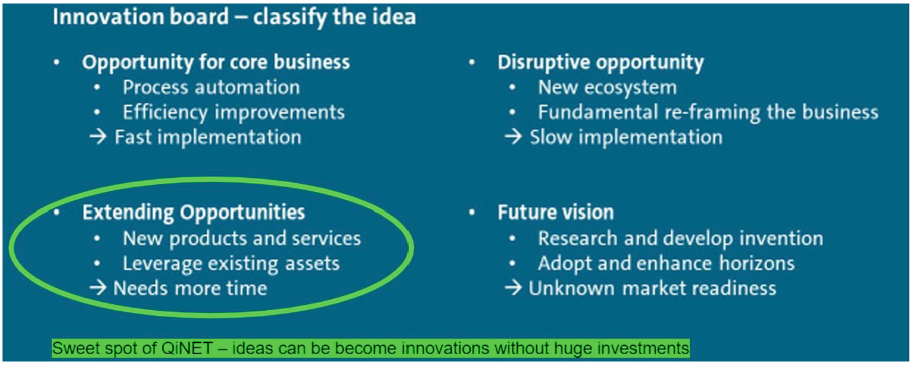

Fig. 1. Classification of innovations within the QiNET.

The QiNET has established the "Innovation Board" to ensure that the projects are feasible and around the defined "sweet spot" innovations which are focused by the QiNET. Figure 1 shows the sweet spot of innovation addressed by the QiNET – however, also some "exception" program exists outside the sweet spot. This is realized by strategic cutting of a larger vision. One example is the over years running efiS® framework [33] (larger vision) with its building blocks (strategic cuts as projects) or the Sustainable Software Engineering initiative combining different relevant aspects of the topic like [34, 35]. This example shows that the outcomes are building on top of each other, too. This kind of reuse helps to perform efficient.

To realize a high outcome rate respectively high success rate the staging approach from Fig. 2 is applied. The state "business confirmed" is realized with the pull-principle applied to the projects. The other stages are passed during the innovation project life-cycle. The life-cycle phases observed by the Innovation Board are addressing specific aspect of an innovation. The first phase address the inherent risks of an innovation, the

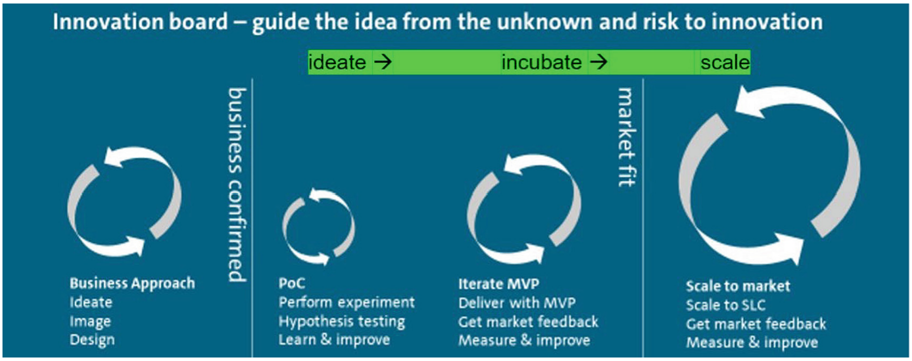

Fig. 2. Innovation project stages within the QiNET.

second phase produces outcomes as evidence that the idea "works" and the third phase focus on impact like rollout the innovation projects outcomes within the Group IT – see Fig. 3. Fast running projects can pass.

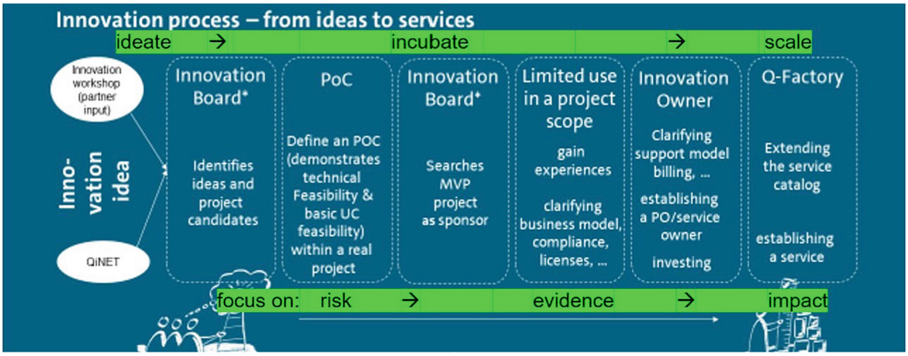

Fig. 3. Innovation Board scope related to the innovation project phase.

Furthermore, the Innovation Board is interested on an organizational view, that also "failed projects" generated added value with the learning gathered during early phases for the organization also if they do not deliver the expected outcomes from the project perspective. Figure 4 shows how the learning focus from the innovation project moves to an outcome centric working style to scale its results in the last phase. The Innovation Board is an facilitator for the innovation projects by helping for example with its management network and experience. Furthermore, it is a decision board about the direction and focus of the QiNET with vision setting and strategic break down of initiatives into small innovation project etc.

The presented innovation process shows that the breakdown of initiatives into small innovation projects is the core to define a resource limited (head-count, time, funding etc.) setup for each innovation project and a high success rate from the outcome perspective. Also relevant is that the Innovation Board in all the years never assigned persons to an

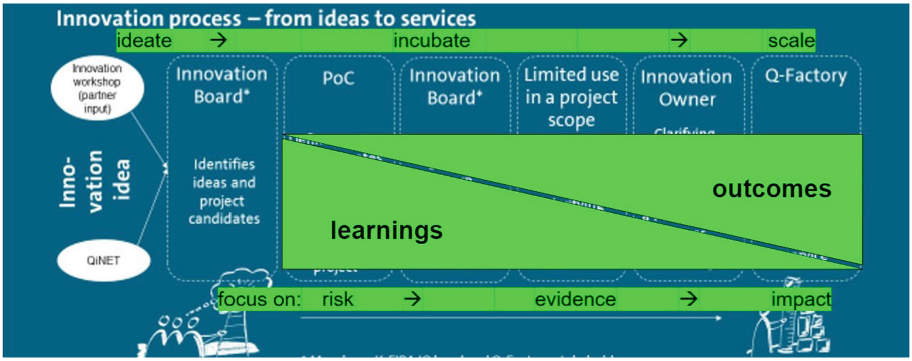

Fig. 4. Innovation Board focus from the organizational view.

innovation project – all project members are "volunteering" to the idea and objectives of the innovation project. Furthermore, the Innovation Board didn't rejected an innovative idea within the scope of the QiNET innovation area – all ideas are welcome as long the outcome pull is established and sufficient volunteering resources forming an innovation project. The Innovation Board is a moderator, facilitator and enabler of IT quality related innovations belonging to its mission: transfer quality ideas into business value to drive quality of life. This open mission fosters a wide range of focus areas like an example of the 2022 innovation portfolio of the QiNET (Fig. 5).

Organization development
- E.g., efiS® framework establish inherent quality in agile organizations

Sustainable Software Engineering (SSE)
- E.g., LoD layer ISO 14001 and cheat-sheet SSE

Technology for software quality
- E.g., Test Case Prioritization (TCP) with ML

Data-driven software quality
- E.g., Open-Source Quality Radar (OSQR): Data-driven FOSS component analysis

Quality for technology
- E.g., Blockchain Service evaluation approach (BSea)

Fig. 5. QiNET focus areas in 2022 with example outcomes.

To foster inspiration and integration the QiNET encourages to build innovation project teams from different legal entities respectively brands and based on different locations. Furthermore, volunteers from outside the Group IT are also welcome. Figure 6 shows some examples about the diverse team setups (with some public referred cooperation partners) and their outcomes – grouped by methods and tools. Last but not least, the QiNET and the managing team – the Innovation Board – does not have an annual budget for distribution to its innovation projects. Each innovation project has to find its needed resources – the Innovation Board helps the projects with this task with its network etc., but can't write a cheque. This leads mostly always to the point that an innovation project is started within a sufficient to setup resource-set.

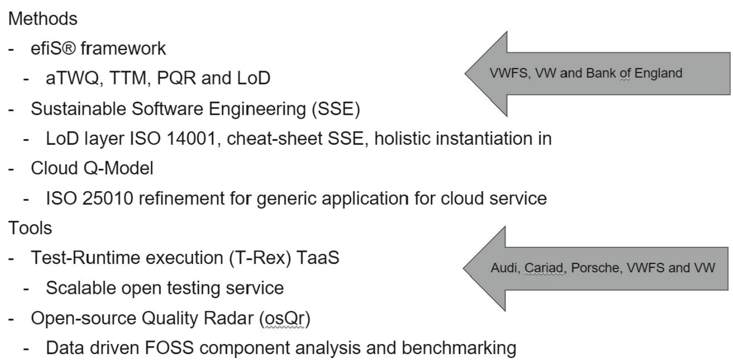

Fig. 6. Selected global cooperations and users of QiNET outcomes.

5 Synthesis and Discussion

Based on the gathered data and its analysis the research questions are answered by synthesis of analyzed data and discussed in the context of the research question.

Why to Combine Frugal Innovation and Agile for Continuous Innovation?
Agile approaches are established over years in organizations. However, to be Agile does not guarantee to become an innovative organization. But Agile helps to establish a continuous value delivery with value streams. The missing element is to ensure that this value stream becomes an innovation pipeline. Innovation cannot be "ordered" by management etc. However, it can be facilitated by management with establishing an innovation fostering environment. Frugal Innovation is operated in a specific environment driven by some typical constraints. Management can decide to emulate for each innovation project a frugal environment. For the case that an organization wants to innovate but does not have resources like large budget or limited knowledge a valid approach is to build respectively emulate a frugal environment. In a next step process respectively an agile value stream is established to build for each innovation project an adequate frugal environment over the project life-cycle. Both together, Frugal Innovation and Agile approaches, can be used to build a continuous innovation pipeline (see Fig. 7). The Fig. 7 shows that the QiNET itself – as a kind of Fugal Innovation platform - uses Scrumban as Agile approach to run its innovation procedure and the QiNET-tasks. The innovation projects can chose how they are "running". However, most are small and based on part-time projects members and it is not effective to run in a structural Scrum or Kanban. Important is that the innovation projects and the QiNET are part of the Group IT. One important aspect is that this setup is used to work as dual organization to explore (innovate) and exploit (produce) – it's a way of ambidexterity.

Furthermore, the amount of running innovation projects differ over time. Each innovation project has its own life-cycle and is independent for others – this fosters project autonomy by design over the innovation project life-cycle. This also makes it easier on the QiNET level without project dependencies.

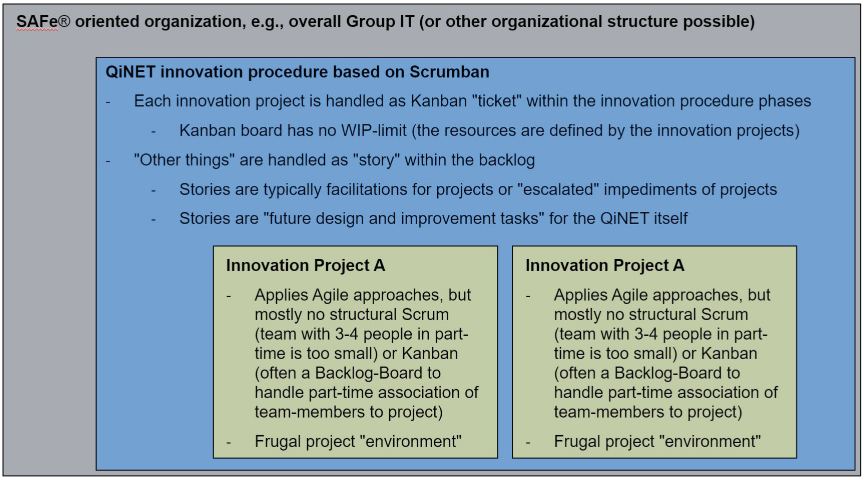

Fig. 7. Integration of innovation projects into QiNET and Group IT.

Discussion: This way to establish an innovation pipeline does not serve for all kind of innovations equally well-suited (Fig. 1). Also other approaches for innovation existing and should be evaluated as alternative options for an organization. The analyzed QiNET as an IT innovation pipeline runs fine with the well-known Agile approaches widely adopted by IT organizations. The new thing for people outside the QiNET is the frugal innovation approach. The "frugal environment" for innovation projects is an innovative approach adoption of the QiNET. The usage of Agile approaches within the frugal environment is a decision made by its project members and not forced by the QiNET. However, an intuitive decision because Agile is a "standard approach" within the Group IT. Important is that this intuitive decision is made again and again independent – this confirms that Frugal and Agile fits together in an innovation project.

Limitations are that this is one possible approach to combine Frugal Innovation and Agile approaches which also comes with its drawbacks to not facilitate all type of innovations (Fig. 1). However, as long the sweet spot of innovation is acceptable as "innovation type" the "intuitive" decision of the innovation projects to combine Frugal and Agile approaches confirms the presented approach. Another limitation is that the QiNET has not to work hard to build a frugal project environment – it has no resources and has not option to give more than "sufficiency" to its innovation projects. In case in which the overall organization spends money to its "innovation unit" it becomes a pressure to allocate it also if it is more than sufficient. This risk can destroy the frugal innovation approach.

What is Needed to Establish a Setup for Frugal Innovation in Agile Organizations? From the post-mortem analysis of the 2-digit number of innovation projects delivered by the continuous innovation pipeline a set of generic parameters are derived. At least the following parameters have to be addressed during the establishment of a Frugal Innovation approach within an Agile organization:

– An environment for the Frugal Innovation project with "objective" (e.g., target picture) and "sufficient" resources. This has to be instantiated for each innovation project.
– A governance and management environment to setup and maintain the frugal project environment during its life-cycle. This has to be established once to "handle" the innovation projects.

These two core ingredients are building the base for establishing a continuous innovation pipeline. Further important ingredients for each innovation project are:

– Keep the teams small and give autonomy (includes necessary freedom, too). A good performance is seen by a team size of 3–4 persons. This fits good with an Agile and Frugal setup.
– Part-time and non-collocation also works fine, if the teams defines clear working slots and "homework" as contribution to the next common working session. A rule of dump: it is better to have skill-demand fitting and self-motivated people in part-time than "others" with higher availability. This observation fits good to the frugal setup.
– Integrate into the team at least one person from a first customer respectively user/adopter of the expected outcome to establish a pull and ensure applicable outcomes. This fits good with the value view of an Agile and Frugal setup.
– Let the team "motivate" its resources for the next increment of the innovation project. This fits good with the Zero Budget setup.

Further ingredients for the continuous innovation pipeline setup and its ongoing procedures are:

– Establish alignment of the innovation teams with the innovation strategy by cyclic reviews and limited resource commitment. At least for each project phase change have a review to commit on a sufficient level the resources. This fits to a Frugal, Zero Budget and partly to an Agile (sprint) setup.
– Establish innovation teams with internal headcount (addresses also German regulations about the separation of internal/external workforce). Minimize contracting of consultants in the small innovation teams; only for clear defined implementation packages contracting boosts delivery performance and can be seen respectively "used" as an additional early external feedback source, too. This fits good to team autonomy and accountability of an Agile and Frugal setup.
– The hosting organization allocates some free time for people who want to contribute or lead an innovation project. This helps to develop internal know-how and collaboration with other organizations. Furthermore, this ensures that all in the innovation

project have always one foot in daily business topics and innovation is not misinterpreted with research without relation to practice. This fits good to the Frugal resource constrained setup and the Agile collaboration mindset. (the free time relation depends on the innovation domain, e.g., the QiNET hosting organization – Test and Quality Assurance of the Group IT - reserves approximately 1/40 of the internal headcount over the past years)
– Have some academic partners to feedback and give ideas from outside into the innovation projects were possible.

Discussion: The learnings results of the post-mortem analysis from over 5 years QiNET shows some common aspects and patterns which lead to successful innovation projects. The identified ingredients working in local organizations like business units and in distributed organizations like cooperation's between legal entities. One risk in the part-time allocation of team members is that the innovation projects sometimes has not the highest priority and this can provoke delayed outcomes. However, real innovation cannot planned with a classical plan and time-line – it depends on many things and the QiNET accepted this kind of "disruption". Better an integrated and inherent innovation than no innovation or not accepted and to slow adopted innovation from outside. Only once a motivated person was not allowed to contribute to a QiNET innovation project by its management – this shows that the approach works fine over years as long as at least the culture of the enterprise is open for the ideas and project contribution wishes of its experts. This can be seen respectively assumed as a hygiene factor for a vital and healthy enterprise which is able to handle the ambidexterity of exploration and exploitation.

Limitations are that the identified parameters are derived from the post-mortem with its case study and survey in the IT domain. It is not proven that this is sufficient in other organizational setups like other companies or cultures. Furthermore, the "management team" of the QiNET has no significant changes since its establishment – it could be that the leading and managing people have a significant impact to the observed long-term results. Never the less the observed patterns are not wrong, but the effects could be smaller if the people factor of the management team respectively an adequate management mindset is not given.

How to Manage and Perform Frugal Innovation in Agile Organizations?
There is no generic standard set of KPIs for continuous innovation which combines Frugal and Agile approaches. However, existing indicators showing that the innovation pipeline is running into the strategic direction. The objective by the definition of these measures was to keep the amount small and cover all phases of an innovation – from the early ideate stage phase to reduce fast and cost-effective the risks of the innovation, to the incubate phase of showing evidences of the working respectively running or usable instantiations of the innovative ideas, and its scale phase with its impact after "releasing" the innovation to the organization. We identified the following indicators – depending on the life-cycle phase of the innovation project not all measures are available but all are leviable until the innovation is scaled:

– alignment of the "innovation projects" with the innovation strategy. Indicates that the allocated resources are working on the right topic; avoids that the objective of continuous innovation end in itself activities. The measure is qualitative and the "common opinion" of the supervising board of the innovation projects.

- resources allocated for "innovation projects" to ensure a frugal setup. Indicates that the focus is the objective of the project; indicates cost/result-effectiveness. The measure is based on the transparent resource allocation; however, what is sufficient is a qualitative "common opinion" of the supervising board.
- contribution of "volunteers" to see engagement and pull for potential user. Indicates that future adaption is given; indicates knowledge transfer into the "network". The measures are: #people engaged, #engagement-days, #engaged organizations.
- contribution of the innovation outcome to the innovation strategy. Indicates short term "success" of the innovation project. The measure is qualitative and the "common opinion" of the supervising board of the innovation projects.
- adoption-rate in the target organization. Indicates long-term "success" of the innovation. The measures are: #adoptions/a, #engaged organizations/a, #users/a.
- research performance based on established research indicators to track that the innovation is not a "enterprise internal" innovation with some internal relevance. Indicates the global impact and relevance; furthermore it indicates novelty and its quality. Selected generic indicators are used: #publications/a, #references/a, h-index and i10-index. Especially the value of the h-index and i10-index in a running time-frame over the last 3 or 5 years to see the continuous innovation delivery

The proposed measures are actively not like classical measures, e.g., an early stop-rate of innovation projects with initially unplanned outcomes. This is because it is not wrong, if during the project learnings are made with this kind of result respectively "outcome impact". The mindset behind is attitude is there was no better known way to get cheaper with less resource allocation the "answer" to the risks belonging to the initial idea to contribute to the strategy. The innovation project team and the QiNET innovation board are accountable that the resources are allocated best based on the current view.

Discussion: These set of measures are fostering the frugal mindset - "do more with less" respectively "do better with less" [13] - by focusing on keep resources limited and pulling the innovation project to the next life-cycle stage if possible. Agile mindset is fostered by transparency and focus on each life-cycle phase and openness for change. The value focus is common in frugal and agile approaches. The key-objective of the measure set is that continuous innovation is delivered in a sustainable performance within the engaged organizations.

Limitations of this measure-set are that not all principles of frugal innovation like [32] or agile like the manifest [36] are measured. However, existing different definitions of frugal innovation or agile working and it is not possible to cover these different options with a actionable measure set by keeping the idea of frugal and agile applicable to the continuous innovation process. The measure set evolves over the last years and demonstrate that is works under real world conditions by "continuous innovation delivery" of methods, tools and frameworks aligned with the QiNET strategy.

6 Conclusion and Outlook

This work shows how an enterprise IT organization enables itself with Frugal Innovation to establish continuous innovation as a value stream aligned with the strategic topics. The established innovation value stream of the QiNET builds on Agile and Frugal Innovation approaches in a Zero Budget setup in which all innovation projects have to "apply" for sufficient resources. Important on the setup is that it was initially not actively intended to establish Frugal approaches – over time the developing innovation process becomes more and more oriented to Frugal concepts which was discovered by an mapping of the innovation approaches. However, a Zero Budget and Agile approaches were part of the initial setup, because both together are not so far away from fugal innovation approaches. Overall, we can suggest to combine sufficiency approaches for sustainable engineering with frugal innovation approaches as a way avoid over-engineering in combination with an agile organization for a sustainable value stream establishment of the continuous innovation pipeline.

The key contributions *to practice* can be summarized by the following aspects:

– It is possible to establish with Frugal Innovation approaches continuous innovation in large enterprises.
– Frugal Innovation can combine aspects of Sustainability Engineering, Agile approaches and Zero Budget – however, it is not complete sustainable by design with the local optimization view instead of an holistic life-cycle view.
– In established enterprises it is active work to establish and maintain a frugal setup respectively environment for the innovation projects over their life-cycle.
– It is possible to run the continuous innovation process "governance and management" itself under Frugal Innovation aspects and agile approaches.

The key contributions *to theory* can be summarized by the following aspects:

– Identification that there is a kind of inherent convergence of Agile and Zero Budget approaches in direction Frugal Innovation.
– Presenting that Lean, Agile and Frugal approaches can combined to establish a sustainable innovation performance.
– Presenting "parameters" to establish a Frugal, Agile and Zero Budget environment for innovation projects within large organization.
– Presenting a measure set to build continuous innovation pipelines.

As summary about business context there are some open questions: Does an Agile and Zero Budget approach for projects intuitively become a Frugal Innovation "touch" over time?

Also keep in mind that currently often Lean is used to optimize costs. And sustainability also often still is reduced to cost-management with the principles like avoid and reduce, too. However, this is only a part of sustainability – Frugal also focus on these aspects of sustainability and does not systematically establish a sustainable life-cycle view. Is there a risk to lost the systematic and holistic view about sustainability?

An additional investigation aspect for the future is how teams can benefit from Frugal Innovation approaches by establishing a real holistic sustainable product or service by design which goes beyond the bycatch of frugality like reduces resource allocation? A further question derived from our observations is do we have with Frugal approaches a succession of Agile approaches? From a historical view [37] it can become a sequence like Lean, Agile, Frugal. It optimizes costs and foster sustainability aspects of Frugal combined with the benefits of Lean and Agile. Using this approach current global trends such as reactions on economic impacts of the crisis's and the global environmental and sustainability can be dealt with.

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Open Innovation Cultures

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Abstract. Multiple sectors are experiencing high uncertainty in terms of disruptive technologies and market changes. Continuous uncertainty in business evolution is triggering the need for concepts that explore distributed and open innovation, networking effects, and ambidexterity approaches. Therefore, open innovation, a term that is used to promote a mindset toward innovation that runs against the silo mentality and closed innovation of traditional corporates, is used frequently in multiple research areas. Nevertheless, these different research areas identify and specify open innovation in different ways.

Therefore, this paper will concentrate on open innovation effects and implications from the different research perspectives of (a) the societal level, (b) the organizational level, (c) the human resource and (informal) leadership level, and (d) the engineering technology level perspective. The work establishes a basic mutual understanding of insights into open innovation from different research focuses.

Keywords: open innovation · socio technology impact · human resource management

1 Introduction

Currently, different sectors are experiencing high uncertainty in terms of disruptive technologies and market changes. Stable approaches, products, or architectures of companies are a risky game [4] and can become barriers to innovation. The uncertainty of business evolution is nevertheless considered to be ongoing [11]. Thus, response scenarios shall imply open innovation approaches and integration of open community or platform networks. Concepts that explore distributed and open innovation, networking effects, and ambidexterity approaches are the most promising. Therefore, open innovation, a term that is used to promote a mindset toward innovation that runs against the silo mentality and closed innovation of traditional corporates, is used frequently in multiple research areas with different attention.

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Open innovation has had various concrete examples of the **impact on the societal level**. One example is related to the medical domain, where open medicine projects have provided a collaborative initiative that brings together healthcare professionals, patients, and researchers to develop innovative healthcare solutions. The European Union is also leveraging open innovation to develop new and sustainable solutions. The striking example, in this case, is the European Union's Horizon 2020 program, which provides funding for research and development. Through this program, researchers, innovators, and industry experts work together to develop new and innovative solutions. Open innovation has also had a significant impact on education. Examples are online educational platforms that provide free access to high-quality educational materials to students around the world. Overall, open innovation has had a significant impact on the societal level by enabling collaboration between various stakeholders and driving innovation that addresses complex social challenges. This topic is also becoming more dominant via multiple Horizon Europe programm and multiple projects, like FLAMENCO. A recent project focusing on Forward Looking Approaches for Green Mobility Ecosystem Network Collaboration (FLAMENCO) [6].

On an organizational level, open innovation has been increasingly adopted to leverage external expertise and resources and foster innovation. However, there are several challenges associated with the research and practice of open innovation practices. One key challenge is the lack of a comprehensive approach that considers the interactions and interdependencies among different factors, such as technology, stakeholders, and society [34]. This can result in a fragmented understanding of open innovation and hinder its potential for generating innovative solutions and value for organizations and society. To address this challenge, more holistic approaches that integrate different perspectives and expertise are needed. On organizational level, such as the combination of open innovation and design thinking, which can provide a framework for generating and evaluating new ideas, prototyping and testing solutions, and integrating feedback from stakeholders, is typically used.

Informal leadership, as an additional viewpoint of the relation of open innovation to **human resources and people management**, can play an essential role in the design and implementation of collaborative projects [19]. Recent publications related to the topic of open innovation and human resources found that HRM work is mainly conducted through informal means, separate from the host corporation's business as usual [37]. Another study found that there is growing interest in the human aspects of open innovation, and that an important challenge for managing open innovation remains the motivation of individuals for knowledge sharing and sourcing [9]. In these implementations, the role of informal leadership can emerge for one or more people in the group. Open innovation can thereby benefit from informal leadership. Cooperation and development between organizations ultimately take place between individuals. In turn, support for development within the organization supports this inter cooperation. The role of informal leadership in such collaboration can be a catalyst and a source of initiative that maintains the collaboration through actually taking leadership actions to meet the goals of the group.

Open innovation from an **engineering perspectiv**e is frequently seen in the context of digitalization and novel technology-based solutions [36]. The value creation in technology focus is supported through innovation focused on accelerated development, validation, and deployment of innovative assets with improved quality. This trend is further supported by the technology push and the market pull [21, 26]. By embracing these changes, organizations become heavily reliant on innovations. That concerns innovation management as a driver of sustainable business models and collective maximization of benefits. While, therefore, research suggests open cooperation and business model innovation as the vital components for success [14, 26].

This paper will concentrate on open innovation effects and implications from different research perspectives. To that aim, the analysis presented in this paper integrated the different research perspectives on (a) the societal level, (b) the organizational level, (c) the human resource and (informal) leadership level, and (d) the engineering technology perspective. Within the scope of this work, we present the different research viewpoints and implications derived from the different views of the analysis of open innovation capabilities. The aim of this analysis is to establish a basic mutual understanding of different insights into open innovation from different research focuses. The paper is organized as follows: Sect. 2 describes the related work and literature review of the different research perspectives. Followed by Sect. 3 highlighting the contribution of open innovation concepts in the individual research fields and describes the outcomes and conclusions that can be drawn from the individual research perspectives. Finally, the relation to the SPI manifesto is provided, and the work is concluded in Sect. 4.

2 View Points and Related Work

In this section, related work on open innovation from different research perspectives is analysed. To that aim the analysis presents perspectives on (a) the societal level, (b) the organizational level, (c) the human resource and (informal) leadership level, and (d) the engineering technology perspectives on open innovation. Since one of the key challenges in open innovation is related to the fact, that it encompasses a very wide range of research streams, innovation activities, and organizational practices. These factors are leading to inconsistencies and ambiguities in how it is operationalized and implemented in organizations [13]. The complexity of open innovation from the perspective of technology, stakeholders, and wider society and environment has also been highlighted as a challenge by Vanhaverbeke et al. [35]. The authors mention the requirement for a more comprehensive and integrated approach that considers these factors when talking about open innovation. A rather scientific analysis of the past, present and future of open innovation is also conducted by Bigliardi et al. [1].

2.1 Societal Level

The work of Lancker [18] shows that also public research organizations need to increasingly engage in open innovation processes besides classic collaboration with industry and public-private partnerships. Their study examines the effectiveness of an open innovation approach by a public research institute, as well as influencing factors, which provides insights towards the applicability of open innovation in a public research environment.

Another example of circular-oriented innovation is provided by Brown et al. [2]. In this paper, implementations of circular economy strategies and empirical investigations on such collaborations are conducted. The research focuses on how practitioners in the Netherlands have conducted collaborative circular-oriented innovation. The authors highlight the need for future research on the assessment of the current modes of collaborative innovation are sufficient to deliver a circular economy transition.

The research of Pedersen [27] identifies five different purposes for using open innovation. It also suggests that public sector organisations primarily use open innovation to pursue one specific purpose, innovation in society. Which means creating value by improving citizens' quality of life and the quality of neighbourhoods. The research also indicates that open innovation, until now, has primarily been used to solve minor problems, and not large-scale problems of society.

Sims et al. [31] conduct an in-depth case study of an open-source software community providing affordable medical record-keeping software in developing nations. The study creates an understanding of open innovation communities and their role in addressing societal challenges.

Also, the works related to the FLAMENCO project [6], focus on piloting forward-looking approaches and methods to enable sustainable collaboration on skills for the automotive domain can be considered in this context.

2.2 Organisational Level

Dahlander and Gann [7] highlight the need for a more comprehensive and integrated approach that considers different factors of open innovation on the organizational level. For instance, open innovation processes can sometimes focus too much on technological capabilities and overlook user needs and preferences. Implementing open innovation can be met with resistance from internal stakeholders, who may be resistant to change. This lack of clarity and integration hinders the potential of open innovation to generate innovation and create value for organizations and the wider society. In this sense, there is a potential to connect this approach with other, similar approaches to explore potential complementariness. One such approach having theoretical and empirical complementarities with open innovation is design thinking (DT), an approach to innovation inspired by how designers think and work, used by many managers, consultants, and other practitioners worldwide [23]. Both approaches emphasize the importance of collaboration and knowledge sharing with external stakeholders, as well as a focus on the user or customer [5]. Design thinking approaches can provide a framework for generating and evaluating new ideas, prototyping and testing solutions, and integrating feedback from stakeholders, which are all essential elements of open innovation [3]. Therefore, integrating DT into open innovation practices can potentially help to bridge the gap between research and practice and enhance the effectiveness of open innovation for generating innovative solutions and creating value for organizations and society. While DT has been extensively related to innovation more generally [30] and to service innovation [8], still more efforts in connecting DT and open innovation are needed.

Sivam et al. [32] examine settings for the Open Innovation Arena. The paper aims at analysis of factors which influence open innovation and how firms can create an effective arena to gain access to external knowledge. The study concludes that culture, leadership and strategy, are the main drivers to an open innovation arena.

2.3 Human Resources Level

Human resource management has major contributions to human aspects in general and therefore to open innovation capacities in special. One of the most important challenges for managing open innovation remains the motivation of individuals for knowledge sharing and sourcing [9].

Therefore, also Jotaba et al. [15] conducted a systematic literature review on innovation and human resource management to evaluate any potential patterns among scientific articles. A growing interest in the role of strategic human resource management (SHRM) in managing employees and supporting their capacity for innovation in high-tech firms could be identified.

Similar findings Engelsberger et al. [10] identified in their paper where the authors also introduced the OI mindset as a new concept that is critical for organizations. Their findings include an emphasis on collaboration incentivizes for employees to participate in knowledge exchange and that managers can influence open innovation by establishing a shared mindset through specific SHRM practices.

Natalicchio et al. [25] investigated open innovation and HR factors in an Italian manufacturing sector. The purpose of their work was to understand how the adoption of open innovation (OI) strategy influences the innovation performance of firms, and how this can be moderated by the recruitment and training of employees.

In the work of Naqshbandi [24], the relationships between empowering leadership style and inbound and outbound open innovation are analysed. The results indicate strong positive effects of empowering leadership on open innovation and the mediating role of employee involvement climate.

The keynote paper of Riel et al. [28] investigates trends in industrial companies with the objective to identify key competencies of Innovation Managers. The work already highlights the importance of innovation management that evolves from product development and manufacturing, and includes the need for designing career paths and management support.

2.4 Technology Level

In the context of technology and engineering, the focus of open innovation is mostly the improvement of development processes and methods, which are the focusing on open innovation [26]. In this work, the author also highlights the engineering focus highly related to product innovation, than rather on market change or customer-base innovation. Such an example is also provided by an open innovation community platform Industry meets Makers (IMM)[1]. Where the focus is to initiate new collaboration models between the industry and the creative maker scene in order to make the resulting innovation and business potential fruitful for the benefit of both sides. The platform also focuses mainly

[1] https://www.industrymeetsmakers.com/

on future technology collaboration support but aims to attract also start-ups, SMEs, freelance developers, designers, students, researchers, and hobbyists.

A study conducted by Harel et al. [12] on open innovation in small businesses in the industry and craft sectors showed that the utilization of open innovation (OI) tools are effective in promoting innovation in small businesses. The authors found out that OIT tools contributed mainly to the level of product innovation, but they also identified the utilization of networking and external collaboration contributes more to levels of innovation.

In their work in the context of digital innovation, Riel et al. [29] focus on how to leverage and push innovation from bottom-up by mobilizing the creativity and diversity of the workforce in engineering. Their attempt on fostering the democratization of innovation is based on the appropriate empowerment of the workforce and making them act as innovation agents on all levels and organizational positions.

How open innovation activities influence the Korean new information and communications technology (ICT) industry is analysed by Kim [16]. Their results indicate that the level and intensity of companies' technological cooperation impact their innovation potential. Therefore, the authors also suggest the construction of technological innovation networks.

Madrid-Guijarro [22] also focus his work on SME and their favouring of open innovation related to promoting product and process innovations, but identifies that the effect on human-centred innovation would be even bigger.

Overall, open innovation shows tremendous potential for positive impact by enabling companies to access new external ideas and expertise, accelerate innovation, and improve quality and competitiveness, but in the technology context, is frequently focused solely on development processes, products, or (less often) service innovation.

3 Contribution of OpenInnovation Concepts in Individual Respective

In this section, possible potentials and opportunities of open innovation for the different research perspectives of (a) the societal level, (b) the organizational level, (c) the human resource and (informal) leadership level, and (d) the engineering technology perspectives are provided. Each field of research focuses and interprets open innovation slightly differently. Therefore, this section shall provide a common view and suggestions on a more holistic way of open innovation.

3.1 Societal Level

As mentioned in the introduction, open innovation can have a huge impact on the societal level. Here the examples of the European Union's Horizon 2020 program or open learning platforms (like DRIVES platform[2] or EuroSPI academy[3]) shall be mentioned. These platforms, in their own context, enable the engagement and interchange of the different

[2] https://www.project-drives.eu/en/home
[3] https://academy.eurospi.net/

stakeholders of open innovation and create potential impact on the societal level. By providing funding for research and development or through providing access to fast up and reskilling for individual competencies [20, 33] and thus enabling agency of social stakeholders and potential of societal change.

Open innovation practices that can be used to tackle societal challenges shall include external knowledge sources and most important paths to market them internally. The imperative shall not be direct business enhancement but rather open access, open source and open-source potentials. Big opportunities are related to motivating the community and connecting with young talents.

Therefore, make social behaviour beneficial in the company (socialization and reward systems – everything should make it difficult to benefit oneself at others' expense).

Build platforms and ecosystems to promote purposeful collaboration, which includes:

– Harvesting of value from knowledge platforms
– Pursue new collaboration opportunities (e.g. R&D project consortia)
– Exploiting available data ecosystems
– Involve synergy networks and circular economy thinking
– Harness the intelligence of employees and empower workforce
– Imply different strategies for keeping employees' competencies up to date

Use crowdsourcing approaches to tighten open innovation at the societal level with feedback from a large group of stakeholders. Crowdsourcing can be used to generate ideas for new products or services, as well as to identify and solve social problems.

Engage with open data initiatives to spur innovation by providing access to data that can be used to develop new products or services, as well as to address social and environmental challenges.

3.2 Organisational Level

For organisational-level open innovation, the design thinking (DT) concept provides an approach that emphasizes empathizing with users, defining problems, ideating potential solutions, prototyping and testing. Due to these characteristics, DT is inherently related to open innovation research areas. The DT approach can therefore be effectively applied to open innovation practices to foster a culture of collaboration and engagement among internal stakeholders. Design thinking can help to create a more collaborative and inclusive environment, which can encourage participation and buy-in from different reluctant stakeholders within the company. Within the organisation, DT helps to diminish blind spots as it aspires to consider both customer and employee needs and perspectives and empowers them to engage in open innovation practices actively. In such a way, open innovation is promoted across the company, and everyone has a sense of ownership of its results, not only leadership. Iteration for innovation is a common DT characteristic and leads to faster development and decreased risk of open innovation solutions.

Open innovation provides a framework for collaborative innovation, enabling organizations to leverage internal and external expertise and resources on specific topics of interest. On the other hand, DT offers a human-centred approach to problem-solving and innovation, placing emphasis on understanding the needs and aspirations of stakeholders. When used in tandem, these two concepts can facilitate more effective and sustainable innovation strategies that are better aligned with the interests and values of stakeholders. Other recommendations include:

– Sharing of common organizational values
– Change the nature of work for employees - establish self-organized teams
– Deepen customer relationships
– Establish strategically significant research cooperation
– Upskilling/Reskilling of staff via educational programs (e.g. Erasmus +)
– Foster different forms of open innovation networks

3.3 Human Resources Level

Human resource management and leadership have been challenged a lot in recent years due to Covid and the shift of values of the employees. Open innovation can bring additional challenges and opportunities to human resources and leadership. Open innovation requires a culture of openness, collaboration, and risk-taking. Therefore, leaders need to be open to fostering this culture by encouraging employees to share ideas, collaborate across departments, and experiment with new approaches. This can be challenging for established structures, but on the other hand, enables informal leadership. Therefore, informal leadership skills and benefits need to be enhanced and supported by organisational structures. Open innovation involves collaborating with external partners as well as fostering a learning culture. Leaders will have to create a learning culture within their organization and participate in external networks and engage in continuous learning.

Rewarding and recognizing employees for their innovative contributions will be of high importance. By creating a culture that values and celebrates innovation, leaders can encourage employees to continue generating new ideas and solutions. Organizations need to be designed to make social behaviour advantageous (socialization and reward systems – everything should make it difficult to benefit oneself at others' expense).

The other people-related practices associated with the workforce shall change the nature of work for employees and boost their brainpower and skills. Informal leadership and a culture of innovation within the organization can also be used to create a more diverse and inclusive workplace, which also helps tap into talent pools and involve staff in the company.

Another idea to foster intrinsically motivated experts and prevent demotivating organisational context factors e.g. via sabbaticals for a few months, performance appraisals, career paths, and job design enabling a balance between research and service. Transfer such intrinsically motivated experts to establish self-organized cross-functional teams to achieve breakthrough innovations. The structure of such a self-managed team with (a) no specific job titles, (b) changing project roles and tasks, (c) freedom to collaborate and change responsibilities, and (d) transparency in task loads, costs, and time budget aims at performance management, individual development, and ownership of the individuals. This procedure favours fast, radical innovation and clear goal orientations of relatively small-sized teams composed of intrinsically motivated team members.

3.4 Technology Level

On an engineering level, technology can play a crucial role in enabling open innovation. Various platforms enable to facilitate collaboration and knowledge-sharing across departments and with external partners. But open innovation should not solely be focused on the development of technologies for process and product development. While open innovation has a significant impact on the engineering and technology of the resulting products and services, the impact in terms of the process of innovation should be focused.

As such, collaboration and knowledge sharing between different organizations and individuals can lead to the development of new technologies and solutions that would not have been possible through closed, in-house innovation processes. Thus, connecting with external expertise (including customers, suppliers, and research institutions) can help to accelerate development and improve quality. Additionally, the flexibility to engage with the external workforce provides more agility with changing market conditions and fast response to customer needs.

All forms of co-creation and collaborating with stakeholders, such as customers, employees, and community members, can be used to create new solutions or products. This can also include cooperation with business partners for technology scouting. By partnering with startups or investing in new technologies, companies can access new markets, build new capabilities, and stay ahead of the competition.

Other technology related open innovation includes hackathons and innovation challenges where diverse groups of people are brought together to work on specific technology or engineering challenges. These events are also usable to engage with external stakeholders, generate new ideas, and test new concepts.

Finally, the most prominent technology focused form of open innovation is related to open source development. For this model software developers make their source code publicly available, allowing anyone to modify and improve the software. By contributing to open source projects, companies can also build their reputation and demonstrate their commitment to innovation.

4 Conclusion

This study highlights the significance of exploring the interplay between open innovation and (a) the societal level, (b) the organizational level, (c) the human resource and (informal) leadership level, and (d) the engineering technology practices. By adopting a more integrated and holistic approach to innovation, individuals, organizations, and society can address some of the challenges associated with open innovation better. Describing this holistic concept highlights overlaps between the silo concepts of open innovation and bridges the gap of understanding between the four research areas. The paper presented the different research viewpoints and implications derived from the different views of the analysis of open innovation capabilities. The presented concept can have far-reaching implications for societal and environmental impact, ultimately driving sustainable growth and creating value for a wider range of stakeholders. Therefore, there is a need for further research to investigate and identify the most effective ways to leverage the potential complementarity between these concepts. Considering the line of argumentation of the paper, a more holistic approach to innovation that incorporates the presented principles will provide organizations with better navigation through the complexities of open innovation and maximize their impact.

5 Relation to SPI Manifesto

This paper contributes to the principles and values described in the SPI manifesto of the EuroSPI community [17], with a specific focus on enhancing the involvement of people through expanding their awareness of the agency they have (A.2). Additionally, the paper aims to promote the creation of learning organizations and environments (4.1) to support the vision of different organizations and empower additional business objectives (5.1). The objectives outlined in this paper are related to changing the context (C.1) and adapting values (C.2) in order to bring about changes in businesses and their values (B.2).

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Virtual Reality and Augmented Reality

Augmented Shopping: Virtual Try-On Applications in Eyewear E-retail

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Abstract. Transformation of trends in online shopping is arising from the changing needs of consumers and expansion in online activity, especially among the tech-savvy generation of Millennials. The biggest disadvantage of e-retailers, especially among those that sell experience goods like eyewear and watches, is the lack of physical apprehension. In eyewear retail, consumers are increasingly being offered to try on items online with Virtual Try-on applications. However, while general online shopping increases during the COVID-19 pandemic, among eyewear retail, online sales do not significantly rise.

Therefore, the goal of this paper is to investigate how Virtual Try-on tools impact the Millennial consumers' shopping behavior regarding eyewear in the DACH region. Moreover, it is also analyzed if Virtual Try-on tools are beneficial for eyewear retailers in the DACH region.

The outcomes of the qualitative research indicate that Virtual Try-on technology in eyewear retail has an impact on the Millennial consumers' shopping behavior in the DACH region, as the technology enhances the shopping experience by being perceived as a tool with great utility. Therefore, individuals shift from buying in-store to also browsing for products and purchasing eyewear online. However, while Virtual Try-on tools can be a beneficial application for large eyewear retailers, small retailers struggle with the large investment volume of implementing the technology. Nevertheless, results indicate that the potential of Virtual Try-on in eyewear retail in the DACH region is perceived as being high.

Keywords: Augmented Reality · Augmented Shopping · Virtual Try-on · Consumer Shopping Behavior

1 Introduction

E-Commerce achieves sustained acceptance among consumers and continues to grow in popularity. Especially post the COVID-19 pandemic, as numerous stores shut down, several retailers go digital. The greater advantages of e-shopping include lower prices, broader product range, flexibility and privacy of information [1]. Recent studies indicate that online shoppers purchase more products during the COVID-19 pandemic than during non-pandemic times [2].

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Transformation of trends in online shopping is arising from the changing needs of consumers and expansion in online activity, especially among the tech-savvy generation of Millennials – individuals born between 1982 and 1996.

The biggest disadvantage of e-retailers, especially among eyewear retailers, is the lack of physical apprehension. Traditional stationery shopping benefits customers in regards of greater social experience, assistance of sales personnel, post-purchase service, certainty about look and fit of the item, no shipping costs and immediate availability. As of now, online-shopping cannot fully compete with the benefits of in-store shopping listed above [3]. This is particularly true for experience goods like optical glasses and sunglasses. While online shopping increases during the COVID-19 pandemic, online sales do not significantly increase in the eyewear industry.

To create an immersive and memorable experience for their customers, retailers are increasingly adding Augmented Reality tools to their websites and marketing strategies. However, especially smaller retailers fear to implement new technologies due to multiple reasons e.g., lack of knowledge and resources. However, according to the SPI Manifesto, change is at the core of Software Process Improvement [4]. Augmented Shopping has the potential to bring online items closer to the reality of the consumer and result in better brand awareness, enhance the entertainment value, increase of sales and a lower return rate [5, 6].

Today, many retailers offer Virtual Try-on applications in their online shops. When it comes to eyewear, leading retailers like e.g., Ray-Ban and Mister Spex offer their potential customers to virtually interact with the offered frames. This technology gives individuals a highly realistic impression of items – similar to the perception of an item in real life. As such, Augmented Shopping in terms of Virtual Try-on applications is revolutionizing the way that online shops are displaying their products.

Therefore, it seems intriguing to examine what impact Virtual Try-on tools have on the consumer buying experience of Millennials shopping for eyewear in the DACH region. Furthermore, this paper is focused on analyzing how far a Virtual Try-on tool in an eyewear retailers' online shop in the DACH region is beneficial.

2 Literature

2.1 Augmented Shopping

The fast advances in technology are changing the ways today's society experiences the environment and how people interact with businesses and experience goods [7]. Virtual experiences simulate product trials in more detail than any other type of showcasing before [8]. Various research investigates the impact and acceptance of AR technology in retail using various types of theories.

Several existing literatures consider the adoption based on the variants of the Technology Acceptance Model (TAM). Research by Huang and Liao [9] explores the technology acceptance and experiential value variables. Findings suggest that usefulness, ease of use, service excellence, aesthetics as well as playfulness are the main variables that strengthen a sustainable relationship behavior regarding AR interactive technology.

In addition, research by Kallweit et al. [10] implies that AR technology closes the information gap at the point of sale, thus, positively impacting consumer satisfaction. However, users' perceived usefulness and enjoyment are decisive in consumer' technology acceptance and reuse of the application [10].

Further, Hyun and Kim [11] suggest that information quality indirectly impacts reuse of AR, while service quality indirectly and directly impacts reuse of the technology.

Further, AR applications can add value throughout various steps of the customer experience [7]. They broaden product knowledge and influence brand attitude and purchases by enhancing online product display. By using AR applications, customers keep being involved, interested and enjoyed. Hence, they are more satisfied and have a superior shopping experience [12–14]. Many AR tools are developed to be entertaining for customers. However, the expectations go beyond that.

In this regard, a recent study by Poushneh et al. [15] needs to be mentioned. The research explores the causes of satisfaction and dissatisfaction of consumers with AR in online shopping. Results suggest that successful applications need to be developed in an informative and interactive way to be more than just entertaining to the end-user. Informativeness and interactivity are therefore inevitable attributes of AR in retail.

According to research by Alimamy et al. [16], another benefit of AR technology in retail is that the perceived risk of making a wrong purchase decision is lower. The findings of this study are consistent with the results of research by Yaoyuneyong et al. [17] and Kim and Forsythe [18]. Both studies indicate that AR applications in the form of VTO reduce perceived risks in consumers regarding purchasing clothing online. Thus, AR tools bridge the gap between the online and in-store apparel shopping experience [18].

In addition, other studies show that interactive technologies lead to increased purchase intentions and trust in comparison with traditional website product display [8, 19–21].

2.2 Virtual Try-On Technology in the DACH Region

In order to go into more depth about the popularity of VTO in the DACH region and the providers of the technology, this paper looks into eyewear retailers who offer VTO in showcasing their products online. Every retailer in Austria, Germany and Switzerland who has at least one physical store located in one of each country as well as a website is being considered in this study.

Extensive study of eyewear retailers in the DACH region shows that besides having a physical store, most retailers also sell their products online. Only seven out of 31 relevant retailers have a website, but do not use this channel for sales.

Regarding AR technology, 17 out of 31 retailers provide applications in form of 3D real-time or image based VTO for fitting frames, 3D face scans for providing measurements or 2D image based VTO for fitting frames.

Regarding the 3D based VTO software, the two main providing companies are Ditto and Fittingbox. Altogether, 15 retailers have one of those two providers' applications embedded on their website. Three retailers provide mobile applications that allow 3D face scans for face-measuring. Only one provider offers a 2D VTO application. Noteworthy, in none of the examined online shops with VTO, all products are available for virtual trial.

While bigger companies usually sell their products online in addition to their physical stores, in most cases, smaller opticians do not have an online store. However, e.g., Austrian retailer United Optics or Swiss retailer Optik2000 offer VTO applications on their websites, but do not sell their products online. When customers want to buy one of their products, they need to visit one of the retailers' stationery stores.

2.3 Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM), developed by Davis [22] is one of the most substantial models of technology acceptance. Numerous studies use the model as a framework – either in its original form by Davis [22], or in the extended version by Venkatesh and Davis [23]. TAM uses the Theory of Reasoned Action as a theoretical fundament for defining the causal relation between the factors Perceived Usefulness (PU) and Perceived Ease of Use (PEU) in regards to users' attitudes, intentions as well as the actual technology usage behavior [22].

PU refers to the extent to which a technology is anticipated to enhance a potential user's performance. PEU refers to the perception of whether the use of a technology can be learned in an easy manner [22]. In addition, there is a relation between these two factors. As such, PU is affected by PE [24].

The following are the variants of the TAM [22, 23]:

- External Variables
- Perceived Usefulness
- Ease of Use
- Attitude Toward Using
- Behavioral Intention to Use
- Actual System Use

The original framework can be further enhanced by more constructs. For instance, Perceived Enjoyment is one of the most analyzed variants in the extended TAM. It describes to which extend the use of the technology is enjoyable – excluding any performance consequences following the use of it [25].

Another frequently added variable is Perceived Risk. Pavlou [26] refers to Perceived Risk as a "subjective belief of suffering a loss in pursuit of a desired outcome".

3 Method

The overall aim of this paper is to explain and understand consumers' shopping behavior in eyewear e-retail. A qualitative study with semi-structured interviews with two sample groups is used to collect data.

3.1 Conceptual Model

The conceptual model of this paper is based on the extended TAM mentioned above and serves as a guideline for the following qualitative research. As such, the significant variants that influence a consumers' use of VTO are explored. Therefore, this research studies the relevance and underlying reasons of Perceived Ease of Use, Perceived Usefulness, Perceived Enjoyment, Perceived Risk and Attitude in relation to using VTO (Fig. 1).

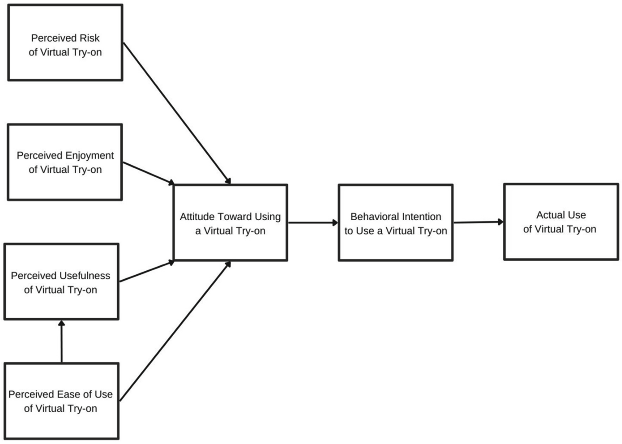

Fig. 1. Conceptual Model

3.2 Data Collection

Semi-structured Interviews. For this research, semi-structured interviews are the chosen method for data collection. Regarding the study population of this paper: qualitative interviews are held with two types of samples – individuals working in eyewear retail (two samples in total) and Millennial consumers (12 samples in total). As for the Millennial consumers, half of the sample has the prerequisite, that there is an underlying visual impairment. The other half has no visual impairment. This is important to work out differences about purchase habits in connection to eyesight measurement requirements.

The research method follows a qualitative design, which is characterized by striving to be as flexible, open and free as possible. As such, the order of interview questions can be changed and new questions can be added according to the content of the individual conversations.

For this papers' study, two different guidelines for the two different sample groups are developed. During the interviews, the Millennial consumers are asked to try the VTO tool of Fittingbox via the website of the retailer Mister Spex. The link is being sent to them by the interviewer. On the website, all respondents are asked to try the same two pairs of glasses and sunglasses. Afterwards, they are further asked about their experience.

Sample Size And Data Collection. All interviews are held mostly in English, only the two interviews with the individuals in retail are held in German. The interviews last around 20 minutes or until no further relevant knowledge is gained from the respondent. Regarding the Millennial consumer sample group, twelve female and twelve male consumers are tested to examine possible gender differences. Due to restrictions because of the travel distance, all interviews are carried out through videocalls with the software Zoom. All samples are found and contacted through social networks. All conversations are video recorded with the consent of the samples. Lastly, the interviews are written down in verbatim transcript.

Data Analysis and Evaluation. The data analysis of the transcriptions follows the qualitative content analysis approach according to Mayring [27], which will aim in identifying categories within the body of content. As such, a deductive-inductive category system is employed. For scientifical structure, the data coding software MAXqda is used.

4 Interpretation of Results

This research does not serve completely new insights, however, the qualitative research method helps to get a deeper knowledge of the primary reasons of VTO use among consumers and retailers. As for that, the research and the design fulfill the purpose.

Prior to getting into the interpretation, it needs to be pointed out, that no grave differences are found among genders and only few differences are found between interviews subjects with a visual impairment and without.

4.1 Millenial Consumers

Among the key findings of the study is that most of the subjects already have prior knowledge about VTO and some subjects are frequent users of the tool, discussing their opinions about it and what they have previously experienced. While for most interview subjects the existing knowledge about the tool appears to not or rather negatively influence their expectations of the VTO performance, many participants seem surprised of how much the technology has developed from their last perception/use of it. Altogether, participants appear to have mixed attitudes towards the tool and its potential utility prior to trying it during the study.

The interview data aims to gain insights into the key TAM factors. The analysis reveals several sub-categories to these factors. In terms of Perceived Ease of Use, all participants agree on the fact that the VTO is very easy to use. Noteworthy, even the participants that experience errors during their trial state that it is user-friendly. Many participants point out that the tool works surprisingly easy – simpler than expected. Moreover, the majority expresses that the Perceived Ease of Use is a decisive factor determining whether they will use a VTO again.

An important finding is that the Perceived Ease of Use influences the Perceived Usefulness of VTO – particularly when it comes to the feature, where the face scan is being saved for trying on different models and for the general overview of products. Not having to redo the scanning process and being able to view several models quickly is user-friendly and coming in handy, according to the interviewees.

From the perspective of Perceived Usefulness, subjects generally express that the VTO helps them to get an impression of which eyewear items suit them or do not suit them. However, in terms of realistic visualization, the opinions of the respondents are ambivalent. One half of subjects thinks that the VTO shows accurate sizing and look of the frames, however, the other half does not feel like the visualization is fully accurate. An important finding is that half of the subjects feel the need to try on glasses in real life before making their final purchase decision – whether in-store or sent to them for trial. Moreover, it is interesting that most of these respondents have a visual impairment. Furthermore, most respondents rather use a VTO for initial browsing, than right before making a purchase. However, for some individuals it is a great tool for decision-making. Therefore, the VTO can be considered helpful for both stages along the customer buying journey. In general, the VTO is perceived as a tool that influences the purchase decision of the Millennial consumer.

In terms of Perceived Enjoyment, all subjects agree that using a VTO is entertaining, enjoyable and that it enhances the shopping experience. While the "fun gadget" has an influence on the Millennial customer to use the technology again, other factors, e.g., usefulness, have more impact.

The Perceived Risk of using VTO is quite low among Millennial consumers. While some respondents have minor fears, like using the mobile- or webcam and poor look and fit of the glasses in real life, they do not keep them from using the VTO. The Perceived Risk does not influence the re-use of VTO, as even the individuals with concerns intend to re-use the application.

After the Millennial consumers try the VTO, all express a positive attitude toward the technology. Another important finding of the study is that most respondents remark that it makes a difference to them if an eyewear e-retailer offers a VTO or not. Especially because it is timesaving when browsing for products and for those who do not want to visit a physical store for trying on glasses in real life.

Lastly, almost every Millennial consumer asked will use the VTO again. Moreover, most of them intend to buy glasses online more now that they can try on glasses virtually. On top of that, the majority is likely to recommend using the VTO to others.

Based on these findings, the conceptual model guiding this research is adapted (Fig. 2).

Although this research does not provide quantitative proof the influence of the TAM factors on the actual use of VTO, the results can be explained from a theoretical point of view.

4.2 Individuals in Retail

Referring to the individuals in retail, it is clearly shown that they have different opinions about VTO. However, both interview subjects share the same future outlook for VTO. As competition grows, especially for larger retailers, it is important to improve the technology and offer VTO. Furthermore, they mention that it is important to keep the technology simple.

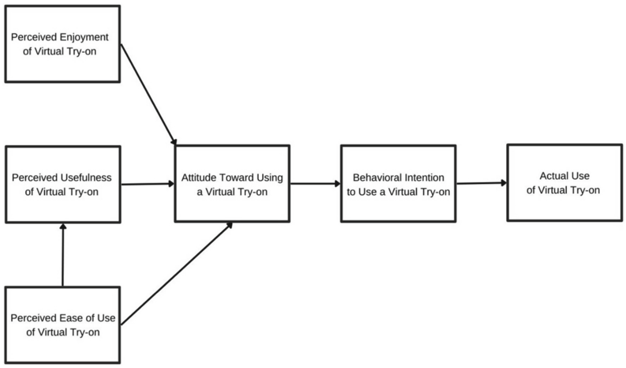

Fig. 2. Revised Conceptual Model

One expert expresses that it is crucial for the customer to get the right customization in-store and to physically try on the product – for the respondent, the issue is that there is no defined sizing for glasses. The other respondent only sees minor hurdles with that, as the individual experiences the VTO to be very true to size and realistic.

Another important remark by one retailer is that the simpler the VTO works, the more likely it is to be used. This matches the findings of the Millennial consumer sample group.

Furthermore, an important finding is that customers tend to order only one pair of optical glasses but multiple pairs of sunglasses for home trial. The customer pushback for that is the doubt about the sizing of the frames.

According to one respondent, the deficit of trying on sunglasses virtually is that the user cannot see his or her eyes well. However, with buying optical glasses online the hurdle is that they come at a higher price-point because of the customized lenses. This matches the findings of the Millennial customer sample group, whereas those interviewees who make the remark that they want to try glasses in real-life prior to the purchase, have visual impairments.

Both individuals in retail believe that VTO has an impact on the customers' shopping behavior. One of them remarks that it is especially important to fulfill the needs of a younger customer segment, that tends to have less time for shopping, as well as for foreign customers. Moreover, the respondent mentions that customers tend to use multiple sales channels before making their final purchase, now that VTO is offered. Customers try glasses virtually and buy them in-store and vice versa.

5 Discussion and Conclusion

In summary, this study investigates, from a TAM perspective, the impact of VTO applications on eyewear retailers' websites on Millennial consumers in Germany, Austria and Switzerland. Valuable insights are also gained into potential value for retailers, when implementing a VTO in an eyewear online shop.

VTO applications can significantly and positively influence the shopping experience of Millennial consumers. Notably, participants perceive VTO to be easy to use, useful, entertaining and low risk. The technology provides the user with enriched product information gained from a stationery shop as well as an online shop – e.g., by allowing consumers to view glasses from the side of their heads.

The interviews show that VTO influences the users' engagement and therefore impacts the shopping behavior of Millennial consumers. For all Millennial test subjects, the VTO is being positively received after trial. In the past, almost all the respondents used to prefer buying eyewear in-store. Now, they intend to use the VTO application in the future. Several individuals even intend to buy more eyewear online now that they can virtually try on the glasses.

However, the study shows that there is a trust deficit in the accurate visualization of look and fit of the glasses. Therefore, multiple respondents prefer to try on glasses in real-life, prior to making the final purchase decision – especially individuals with visual impairments. Thus, when it comes to visiting different sales channels, it can be observed that Millennial consumers like to browse online and purchase in-store and vice versa.

There is no particular phase along the customer shopping journey, where the application is rather used. It aids respondents in browsing for models and making their final purchase decision alike. Concluding, one key finding is that the majority of respondents is likely to recommend the VTO application to others.

It is crucial to note that the individuals working in retail have different opinions about VTO technology. However, the sample group agrees that particularly for large and international retailers it is necessary to offer novel applications that enhance the shopping experience of their potential customers. For one retailer VTO applications aid in fulfilling the needs of a younger customer segment and have an impact on their shopping behavior.

There is common ground about the future potential of VTO in the DACH region, which the retail individuals estimate as being high. Nevertheless, for small retailers there is a great financial and organizational hurdle that comes with implementing the technology. This must be considered if a retailer wants to implement a VTO application in the future.

5.1 Recommendation for Action

Three main points are identified, which need to be taken into consideration as VTO will be an inevitable technology for eyewear retailers to keep their online shop competitive and to provide potential customers with the best possible shopping experience.

First, retailers should consider implementing a VTO on their website, whether it is for showcasing the products or for integrating the application in the online shop. Results show that the Millennial consumer intends to rather buy from a retailer who offers this technology.

Second, a well-designed VTO is of importance. The tool needs to be novel, easy to use, useful, enjoyable as well as accurate in look and sizing. These are attributes that impact if the Millennial consumer will use VTO technology when shopping for eyewear online.

Third, retailers need to consider having their online and in-store stock in sync, as the Millennial customer likes to try virtually and buy in-store and vice versa. In addition, flexible trial and return policy is required, in order to make VTO and online orders more attractive to the consumer.

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On the Service Quality of Cooperative VR Applications in 5G Cellular Networks

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Abstract. With the improvement of virtual reality (VR) technology and the spread of VR equipment, attention to VR services has increased, and a variety of new VR services have appeared. Among them VR services with interaction require real time synchronization of the user's position in the space, actions taken, and other information, so it is important to increase the speed of communication to maintain the quality of the user experience. However, when synchronizing information between users using a cellular network, it is difficult to speed up communication for all terminals because multiple terminals share the same network and the cellular resources allocated to each terminal are limited. Therefore, it is necessary to clarify the characteristics of applications that should be prioritized for communication among VR applications that involve interaction and the extent to which communication delay affects the quality of user experience in order to do appropriate cellular resources allocation that do not impair the quality of user experience. In this study, VR services that involve information processing of user interaction are implemented on actual devices, and the user experience quality is measured in an environment with multiple different communication delays. The results provide data on the characteristics of VR applications with interaction that should reduce the amount of delay, as well as data related to the quality of the experience when running in own 5G environment.

Keywords: VirtualReality · 5G · Quality of Experience · Metaverse · Multiuser virtual environments

1 Introduction

With the improvement of virtual reality (VR) technology and the spread of VR equipment, attention to VR services has increased, and a variety of new VR services have appeared. Among them, VR is used for a wide range of services, from Employee training programs [1] to human interaction in a metaverse space and has the potential to significantly change our daily lives. Applications that include interaction in such VR spaces require real time synchronization of information, so it is important to speed up the synchronization of information to improve the quality of the user experience.

Motion-to-photon latency, an important indicator for comfortable use of VR applications, indicates that the delay required from the user's motion to the screen switching

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should be kept to about 20 ms as a threshold for the user to experience VR with a sense of immersion [2]. [3] points out that the jitter as well as the delay affects the quality of user experience. Wired communication, such as Ethernet, has a potential to achieve the short delay less than 20 ms. However, its cabling limits the VR applications; there are some VR services that are hindered when the user's range of movement is limited by cables [4]. An example is a service that generates a VR space linked to the direction and speed of the car's movement during the ride [5].

Such problems will be solved with the introduction of the 5th generation cellular network (5G) [6]. In 5G, resources are allocated in a frequency domain and a time domain. The time domain is slotted; for example, there are 20 slots with in 10 ms at 30 kHz subcarrier spacing (SCS). The low-latency communications are achieved by utilizing the bandwidth available in the 5G standard and shortening the slots [7]. However, when synchronizing information between users using a cellular network, it is difficult to speed up the communication of all terminals because the cellular resources allocated to each terminal are limited. Thus, it is required to allocate an adequate amount of cellular resources, by e.g., RIC (RAN Intelligent Controller) [8], to terminals such that users can enjoy VR services. For this purpose, we need to clarify the characteristics of applications that should be given priority in communication among VR applications, and the extent to which communication delay affects the user's experience quality.

In this study, we investigate the impact of communication delays associated with information synchronization between users on the quality of user experience for VR applications that involve interaction. The effect of the amount of delay on users in shooting games [9] and certain VR applications [10] has been studied, but there is still a few of study on VR applications with interaction. In addition, Ref. [7] deals with an experimental scenario involving user interaction similar to the VR application addressed in this paper. The authors shows that the average delay can be reduced by using mmWave and MEC in a 5G environment, but jitter is not mentioned. Thus, while there have been studies on average delay reduction in 5G environments, less studies have discussed on jitter of VR applications with interaction. For this purpose, this study conducts experiments in which participants experience VR applications in our own 5G environment and measure the quality of the experience based on subjective evaluations. Two simple VR applications with different characteristics are created for our experiments. In addition, since the wireless signals in the 5G environment is affected by unrecognized signal reflection/absorption, experiments are also conducted in a wired environment, not for achieve lowest latency, but for comparing the quality of user experience with arbitrary amounts of latency.

The remainder of this paper is as follows. Section 2 describes the details of the experiment. Section 3 presents the experimental results. Section 4 presents the results of the experiment in a 5G environment. Section 5 presents the conclusions.

2 Experiment Setup

In this study, two simple VR applications is tested in wired network and wireless cellular network. We evaluate the quality of user experience, through questionnaires following a Likert scale obtained from the users.

2.1 Application Scenarios

Two application scenarios are investigated to clarify the delay requirements in VR. Scenario 1 models the act of users cooperating with each other to place objects. Specific example of this is users cooperating to determine the layout of a room in a VR space. Scenario 2 models a monotonous task, in which the user repeatedly receives the other user's object. Specific example of this is a game in which the user performs a directed action. They have different characteristics as shown in the Table 1.

Table 1. Characteristics of application scenarios

	Characteristics
Scenario1	Users rarely focus on moving objects Users are difficult to predict the other user's behavior
Scenario2	Users often focus on moving objects Users are easy to predict the other user's behavior

Scenario 1. Application scenario is a cooperative task in which two users work together to place multiple components and assemble a specified product. Figure 1 shows when each user enters the VR space. Two users enter the room across the central table, with components and blueprint of the specified product placed on the table near the users. In this scenario, the components are cube objects that can be distinguished by their different colors, and the blueprint shows a picture of stacked blocks. The users cooperate with each other to place the components on the central table in the VR space to create the specified product described in the blueprint of the product. As shown in the figure 2, the task ends when an object identical to the blueprint is completed on the central table.

Scenario 2. In application scenario 2, two users enter the VR space and one user indirectly passes cans to the other user. There is a table that flow at a constant speed when objects are placed across the user in the central space. The two users are divided into two groups: the user who places the cans on the table and the user who receives them flowing on the table. The user passes the can one at a time to the other user by placing it on the central table and confirming that the other user has received it. When the user confirms that the other user has received the can, the user repeats the task of handing the next can. Figure 3 shows each user's perspective in scenario 2.

2.2 Experimental Environment

This study uses the experimental environment shown in the Fig. 4. OculusQuest is used as the head-mounted display (HMD). By using this device and a dedicated controller, tracking of the user's hand and 6DoF movement. The VR application used in this study adopts a local rendering method as well as the major metaverse platforms, including user interactions in VR. [11]. VR applications are run on a PC connected to the HMD, and

Fig. 1. Scenario1 (application start)

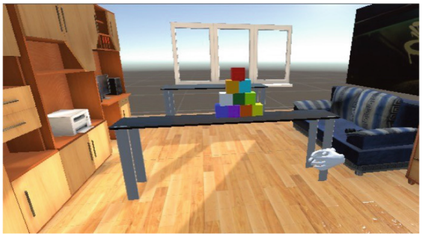

Fig. 2. Scenario1 (application end)

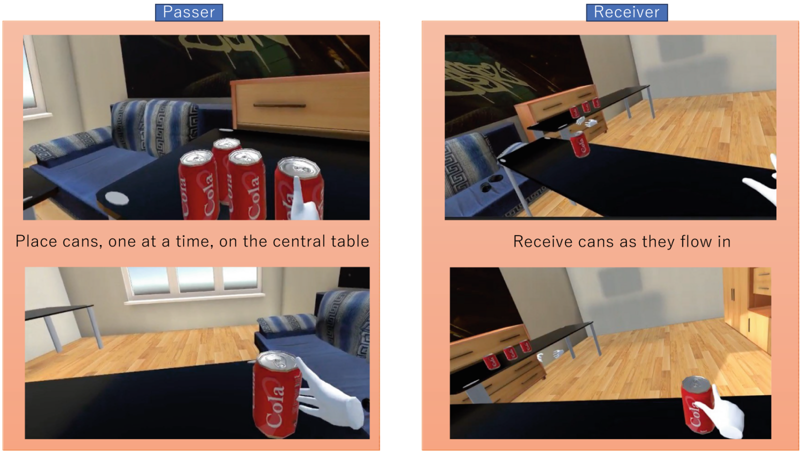

Fig. 3. Scenario2

images are transmitted to the HMD using a Link cable. The VR application running on each PC synchronizes information through the application server, which relays a delay server that waits for packets along the way to generate arbitrary delays between PCs.

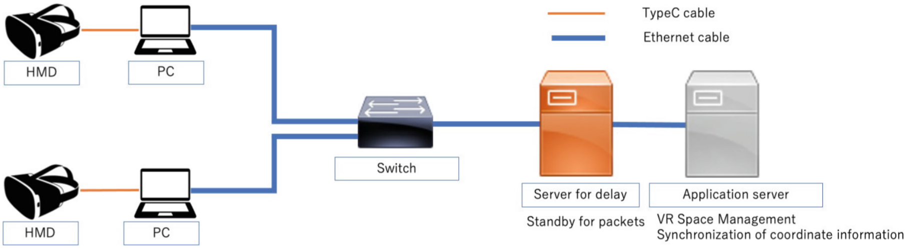

Fig. 4. Experimental environment (Wired)

2.3 Delay Settings

In the application scenario described in Sect. 2.1, we set up the delay patterns shown in the Table 2 using a delay server to measure the effect of changes in communication delay on the quality of the user experience. Experiments were conducted using four different delay patterns with different average delay and jitter.

Table 2. Delay Pattern

Environment	Min (ms)	Max (ms)	Average (ms)
Delay pattern A-1	22	22	22
Delay pattern A-2	40	120	80
Delay pattern A-3	40	360	200
Delay pattern A-4	200	1000	600

2.4 Experimental Procedure

This section provides a detailed procedure for conducting the experiment. Firstly, participants are given an explanation of how to operate the VR application. They are instructed to wear a head-mounted display (HMD) and hold a controller to manipulate objects within the VR space. The explanation covers various aspects such as viewpoint rotation, movement within the VR environment, and methods for interacting with objects. Following the operational instructions, the application scenario is presented to the participants. The roles assigned to the users within the scenario are explained, and a practice session of approximately 5 min is allotted for each role. Subsequently, the questionnaires are introduced. Prior to experiencing the VR application, participants are briefed on the questionnaire items and the evaluation method for these items. Any questions or uncertainties regarding the questionnaire are addressed at this stage. Once the participants have a clear understanding of the questionnaire, the VR application is initiated. The experiment involves experiencing the VR application under four different delay patterns. After completing each session of the VR application with a specific delay pattern, participants are provided with a time to respond to the questionnaires. This process is repeated four times to cover all four delay patterns.

The questionnaire for the participants consisted of the following items. In the application scenario 1, it is considered necessary to accurately grasp the current behavior of the other user in order to avoid interfering with the other user's operations. Therefore, the following items are surveyed in the application scenario 1. 1: Did you grasp the position of the opponent's hand (5-point scale 1: could not grasp, 5: could grasp). 2: Did you feel any discomfort in the opponent's hand movements (5-point scale 1: felt discomfort, 5: did not feel discomfort). 3: Did you ever grasp the same object (5-point scale 1: frequently, 5: not at all). 4: Did you assemble the objects smoothly (5-point scale 1: not smoothly, 5: smoothly).

In the application scenario 2, it is considered important for the user to know the exact position of the other user's hand and to know the object's position. For this reason, about the user who passes the cans following items are investigated. 1: Did you grasp the position of the opponent's hand? (5-point scale: 1: did not grasp, 5: grasped). 2: Did you feel any discomfort in the opponent's hand movement (5-point scale 1: felt discomfort, 5: did not feel discomfort). 3: Did you grasp the position of the object (5-point scale: 1: not grasped, 5: grasped). 4: Did you feel any discomfort in the object's movement (5-point scale: 1: felt discomfort, 5: did not feel discomfort). 5: Did you know when the opponent grabbed the object? (5-point scale 1: couldn't tell, 5: could tell). About Object receiver, only the fifth item differs as follow. 5: Did you know when the opponent released the object? (5-point scale, where 1: didn't know, 5: knew).

3 Experiments with Wired Network

3.1 Experimental Results (Scenario 1)

In the application scenario 1, the following four evaluation items exist. They are Position (Discomfort with the opponent's position), Movement (Discomfort with opponent's movement), Error (Failure in the task), and Smoothness (Discomfort in the task).

Figure 5 shows the average value of the questionnaire items. The results of the experiment show that there is no significant difference in each evaluation item depending on the delay pattern. This indicates that the amount of delay does not significantly affect the quality of the user's experience in application scenario 1. The reason for this is that the user is focused on the already assembled object or blueprint and does not pay attention to the moving object, making it difficult to notice that the object is affected by the delay.

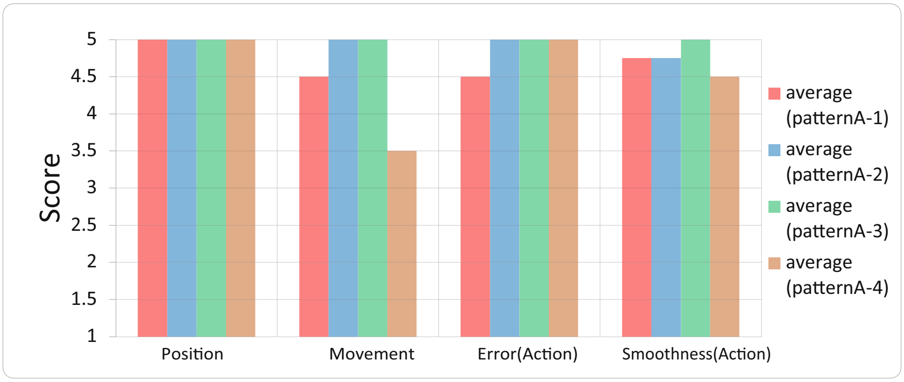

Fig. 5. Results: scenario 1

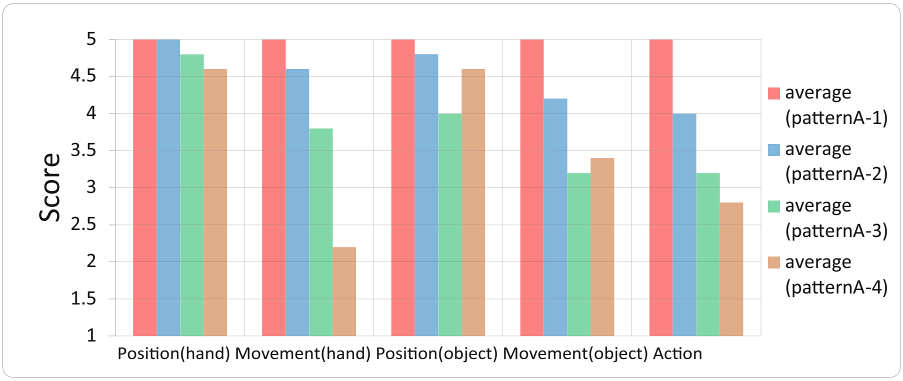

Fig. 6. Results: scenario 2 (passer)

3.2 Experimental Results (Scenario 2)

In the application scenario 2, the following five evaluation items exist. They are Position (hand) (Discomfort with opponent's hand position), Movement (hand) (Discomfort with opponent's hand movement), Position (object) (Discomfort with object position), Movement (object) (Discomfort with object's movement), and Action (Discomfort in the task).

Evaluation of the Object Passer. Figure 6 shows the average value of the questionnaire items. From the results of Fig. 6, we can see that the users' evaluations decrease as the delay pattern increases, indicating that the increase in network delay and jitter leads to a decrease in the perceived quality of the experience.

However, there are some areas where the evaluation improved despite the increase in delay. In the Position (object) and Movement (object), the evaluation improves for delay pattern A-4, which has a larger delay amount, compared to delay pattern A-3. This may be due to the success rate of object receiving. Because the coordinates of the object are determined by the user who most recently owned the object, according to the specifications of this application, so the passer does not realize any delay regarding the object if the receiving fails. In delay pattern A-4, the success rate of the transfer is lower, so the user has less chance to feel the effect of the delay, and the evaluation is improved. On the other hand, the hand is affected by the delay because the ownership of the hand is owned by the other user from the beginning, and the evaluation decreases in proportion to the amount of delay.

Evaluation of the Object Receiver. Figure 7 shows the average value of the questionnaire items. Figure 7 also shows that as the delay pattern increases, the user's evaluation decreases, indicating that the increase in network delay and jitter leads to a decrease in the perceived quality of the experience. Figure 7 shows that the decrease in the perceived quality of hand is slow when the amount of delay and jitter increase, while the decrease in the perceived quality of object is rapid. This discrepancy is attributed to the user's increased attention towards the object as the delay amount increases. In delay patterns A-3 and A-4, the object's displacement due to the delay becomes larger, prompting the

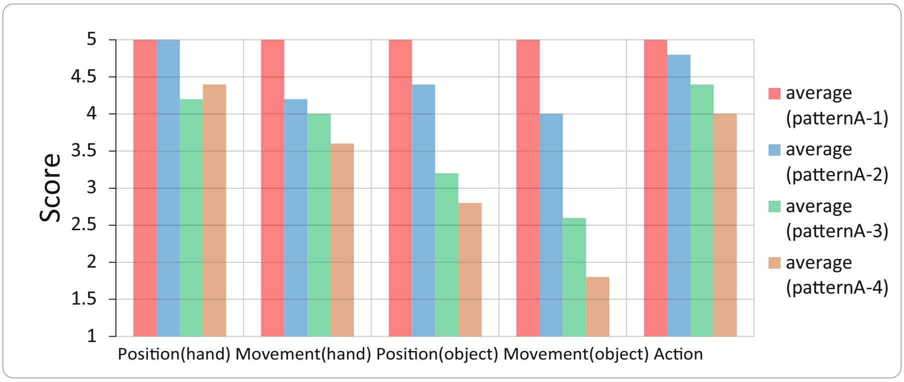

Fig. 7. Results: scenario 2 (receiver)

user to pay closer attention to the object's movement in order to receive it accurately. Consequently, although users provide a more critical evaluation regarding the object's coordinates, they are more tolerant in assessing the opponent's movement. Figure 8 that compare the Movement (hand) and Movement (object) items of the passer and receiver of the object indicates that in delay patterns A-3 and A-4, the evaluation of hand, which is more tolerant on the side of the object receiver, is higher than that of the object passer, and the evaluation of object, which is more severe on the side of the object receiver, is lower than that of the object passer. This indicates that there are differences in the items for which the amount of delay should be suppressed depending on their own role in the application, and that the user's focus of attention affects the quality of the experience.

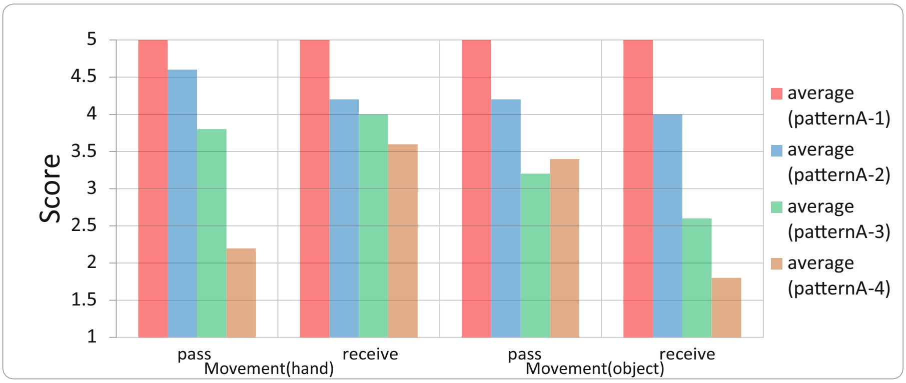

Fig. 8. Comparison of ratings for hand, object motion

3.3 Discussions

In application scenario 1, there is little change in experience quality regardless of the increase in delay, whereas in application scenario 2, there is a downward trend in experience quality as the delay increased. This suggests that in VR applications involving the characteristics that the user's attention often focus on the moving object and that the other user and object's moving can be predicted, the amount of delay should be reduced as a priority. The results of application scenario 2 show that even in VR applications with the same interaction, there is a difference in the decrease in the quality of the experience due to the increase in the amount of delay, depending on the role each user has and the point of the attention. Therefore, it is also conceivable that the type of information that should be accelerated differs depending on the role of the user even in VR applications with the same characteristics.

4 Experiments with 5G Cellular Environment

Figure 9 shows that our 5G environment to measure the effectiveness of using a 5G environment in application scenario 2, which has strict latency requirements. Our 5G environment is licensed and is operated at 4.85GHz center frequency width 100MHz bandwidth. The number of terminals connected to the base station is set to two. The same experiment is also conducted with two delay patterns (pattern B-1 and pattern B-2) to measure the change in experience quality as the delay and jitter increase compared to own 5G environment. Delay pattern B-1 is an environment with larger jitter, and delay pattern B-2 is an environment lower jitter and higher average latency.

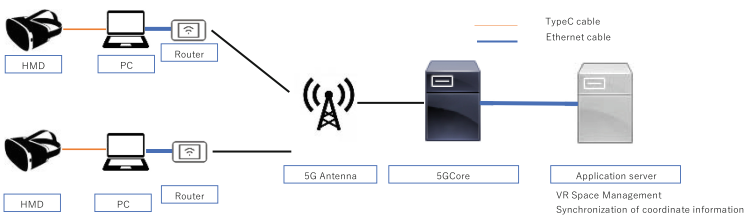

Fig. 9. Experimental environment (5G)

4.1 Experimental Results

The results of the Fig. 10 and Fig. 11 show that the perceived quality is high in an uncongested 5G environment. Next, the experience quality related to delay patterns B-1 and B-2 showed comparable ratings. In delay pattern B-2, the average value of delay increased compared to delay pattern B-1, but the jitter was suppressed (Table 3).

Fig. 10. Results: object passing side

Table 3. Delay pattern

Environment	Min (ms)	Max (ms)	Average (ms)	Variance
5G (number of terminals 2)	10.8	43.6	19.9	24.7
Delay pattern B-1	5.6	55	22	61
Delay pattern B-2	37	45	41	4.1

Fig. 11. Results: object receiving side

4.2 Discussions

The research [12] shows that jitter affects cybersickness. Additionally, the absence of a difference in user experience quality between delay patterns B-1 and B-2 suggests that suppressing jitter is just as effective as suppressing average delay, and effective to not only cybersickness but also interaction in VR applications. In an environment where the average delay is low, but when the jitter is high, objects move instantaneously or otherwise move erratically, increasing the chance that phenomena contrary to the user's expectations. Therefore, it is also important to suppress the jitter in environments When the average delay is below a certain level. This indicates that even in a situation where it is difficult to speed up the communication speed of all terminals, if cellular resources are allocated appropriately and the jitter is suppressed, the VR application can be used without lowering the user experience quality.

5 Conclusion

In this study, we clarified the characteristics of VR applications that should accelerate information synchronization in VR applications with interaction, and evaluated the quality of the user experience when the application is operated in own 5G environment. Among VR applications with interaction, VR applications involving the characteristics that the user's attention often focus on the moving object and that the other user and object's moving can be predicted, user's experience quality drops significantly as the latency increases for applications. In addition, when experiments were conducted in an ideal 5G environment with a small number of connections, the user experience quality was evaluated to be high, and the evaluation was equivalent to that of suppressing the average delay by suppressing the jitter. This result shows the effectiveness of using VR applications with interaction in a 5G environment and reducing the jitter through appropriate resource control.

As future work, we will study the actual amount of average delay and jitter that should be suppressed in a 5G environment and resource control methods to achieve this.

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