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Solutions in global software engineering: A systematic literature review

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ABSTRACT

Global software engineering (GSE) has received increased attention, as globalization enables and encourages increased distribution of product development. Many empirical studies and systematic literature reviews (SLRs) focus on the identification of challenges, this paper however presents the first SLR collecting and analyzing solutions associated with GSE, while also evaluating the level of empirical validation of said solutions. As a starting point the paper presents a GSE model, designed to categorize solutions into process areas, useful for the analysis of the research community's contributions to state-of-the-art and identifying fundamental gaps in research. In addition, the model categorizing the solutions is populated with references and good-examples, useful for practitioners, which can use the model to find solutions to overall challenges in various process areas. The overall results of the systematic review revealed more than 330 papers containing 127 solutions that were then identified and mapped to the model. The process areas of project management are highly populated, while other areas like product integration have received surprisingly little attention. In addition, selected process area is elaborated upon in terms of contents and deficiencies.

1. Introduction

As globalization is a fact that industry has to face, software engineering has been affected by offshoring and outsourcing (Clear, 2009; Damian, 2007; Purvis, Purvis, & Cranefield, 2004). The GSE research community has produced many studies focusing on challenges and needs of distributed development environments (Huda, Nahar, Tepandi, & Deo, 2009; Smite, 2007), and case studies are pre-dominant in relation to how these challenges can be met (Šmite, Wohlin, Gorschek, & Feldt, 2010). Several systematic literature reviews also exist focusing on everything from applying agile in a GSE environment (see, e.g. Hossain, Babar, & Paik, 2009), to subcontractor management issues (Khan, Niazi, & Ahmad, 2009), while some studies are wider and on a macro level look at rigor and level of empirical validation of solutions in GSE (Šmite et al., 2010).

For industry, problem descriptions and identifying challenges is relevant, but so is offering information on possible solutions to tackle the complexities. This paper presents a systematic literature review (SLR) (Kitchenham, 2007) focusing on identifying and collecting as many solutions for GSE as possible by extracting them from peer-reviewed literature. Solution in this context means any process, tool, technique, model and so on, that claims to tackle specific GSE challenges. As the found solutions are extracted, they are put in a Process Area Map (PAM), which structures the solutions into main- and sub-process areas. Each of the solutions are further evaluated against different criteria, for example, level of trust a potential industry practitioner can accredit a specific solution based on the level of validation the solution has undergone.

This paper thus presents the results of an extensive systematic review, extracting solutions in a GSE context, gauging their level of validation, and mapping them into a structure creating the process area model (PAM). The use of PAM, populated by the extracted solutions, can be seen from two main perspectives. First, researchers can use this first version of PAM to build upon, and to see which process areas are well researched, and which areas require extensive study in the future. Second, industry practitioners can use PAM as a reference framework to evaluate and improve their development environment by finding solutions in a structured way.

The paper is structured as follows. In Section 2, related work is presented along with the context of this study at Daimler AG, the main partner in the study presented in this paper. In Section 3, the design of this study is presented. In Section 4, results, and in Section 5 a solution characterization is offered. Section 6 concludes the paper.

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2. Related work and background

This section discusses related work, elaborates on the industrial collaborating partner and the work context in relation to GSE. Background and motivation to the study and the creation of PAM is also described.

2.1. Related work

Several systematic literature reviews (SLR) have been performed previously in the area of GSE.

Hossain et al. (2009) studied the use of SCRUM in GSE, as agile practices seem to be extremely popular in GSE projects. They identified approximately 400 papers and extracted results from about 20 of them. The main conclusion was that it is hard to provide solutions for GSE problems as the type of development distribution differs from project to project. Yet, there were some findings that the authors believed could improve GSE projects in general, e.g. the importance of synchronous communication.

Khan et al. (2009) focused on the outsourcing part of GSE and studied success factors for, e.g. supplier selection. The SLR ends by stating some similarities and differences between cultures of offshore outsourcing.

A more general study of GSE can be found in the SLR of Šmite et al. (2010). Focusing on empirical studies in GSE, this SLR provides a deep insight into the field of GSE presenting useful practices and techniques. For practitioners, in particular, the SLR provides the seven most frequently discussed practices in literature.

The SLR by Huda et al. (2009) focuses on finding the key barriers for global software projects. As many problems arise during the transition from local to global organizations, the authors identify challenges to guide companies to implement appropriate organizations for GSE.

The risks of GSE in requirements engineering have been studied by Lopez, Nicolas, and Toval (2009). The authors identified risks regarding the requirements process especially with inexperienced teams. These risks are related to the shift towards globally distributed development. The SLR also provides some safeguards that help overcome these risks; however, the safeguards have not been tested in practice.

In general, it can be seen, that SLRs in relation to GSE often focus on specific aspects of GSE, or general challenges and problems associated with GSE. So far, as we can tell, no SLR has been conducted focusing on the investigation of solutions associated with GSE. This paper focuses on the solution perspective, i.e. mining peer-reviewed research for solutions used to address challenges. Furthermore, the level of industrial validation and use of these solutions are also evaluated.

2.2. Study context

The work presented in this paper, the solution-focused literature review, and the creation of PAM was inspired by a gap in literature, but also directly by the needs of Daimler AG, which is the main research partner of this project. Daimler faces many challenges related to GSE. This section gives a brief motivation to the work and the context characterization of Daimler AG.

2.2.1. Daimler AG

Daimler AG is a German premium car, van, bus and truck manufacturer. Group Research within Daimler AG closely works together with well-known brands like Mercedes Benz Cars and Mercedes Benz Trucks, among others.

In a modern automobile, software is a fundamental part of the product. An estimated 90% of the innovation in a car is related to software, and about 80% of a car's features are based on electronic systems (Grimm, 2003). To implement these functions, about 10,000,000 lines of code distributed over about 70 control units have to be written. Up to 40% of the costs of a car lie in software and electronics (Broy, 2006). Software projects in the automotive domain are very extensive, which is evident at Daimler AG. Therefore, problems and complexity pertaining to variants are part of daily work in software engineering at Daimler AG, which is also complicated in a distributed environment (Stupperich & Schneider, 2011).

2.2.2. Daimler AG and GSE

Mercedes Benz Trucks is an internationally oriented department within Daimler AG. Working at different sites in Germany, USA and Japan, they are developing software for various markets.

Daimler employs about 10,000 people in Research and Development at 20 sites in nine countries. The locations reach from Palo Alto, CA, USA, to Bangalore, India, to Beijing, China and Tokyo, Japan, to mention some. The number of people employed on these sites is mostly around 50–200.

As car manufacturing is a very complex and time-intensive process covering many areas of expertise (such as electrical and electronical engineering, software engineering, technical engineering, etc.), the model that needed to be developed was supposed to be relatively abstract. This means, that the model can be used in a wide range of problem areas. However, the model needed to be based on the processes already used at the Daimler AG, which means, that especially CMMI and the V Cycle was the basis for the software part of this model. Other process frameworks and models have been used to broaden the focus of the model, though.

2.2.3. Process area map (PAM)

As a response to the GSE challenges at Daimler AG, a research project consisting of collaboration and co-production between industry and academia initiated the work of creating the process area map (PAM) aimed at structuring available solutions to tackle global product development. PAM can be seen as a framework with process areas sorted in a tree structure, e.g. Requirements Engineering (a main process area) has leaves like Elicitation (sub-process area), and at the end node existing solutions are mapped into PAM. In this example, workshops or interviews can be used for actual elicitation and is thus seen as a solution (end nodes in PAM).

PAM has two purposes: First, PAM and the SLR provide an overview of which fields in GSE are most researched, where the gaps are, and what it avenues for future research. Second, PAM can be used by Daimler AG as a reference model for finding solutions to GSE-based challenges based on process area, and as new solutions are offered they can be mapped and structured into PAM.

PAM will be covered in more detail in Section 4.1.

3. Study design

In this section, a number of research questions (RQs) are presented. In addition PAM will be introduced, as the structure of PAM is a part of the research formulation. The SLR will be introduced in Section 3.3.

3.1. Research questions

The RQs that drive this study are specified and explained in Table 1. The overall idea is to perform an SLR to identify as many solutions in GSE research as possible, then map these solutions to PAM. PAM in turn is based on an empirical study conducted at Daimler AG, and the consolidation of several process models. It should be observed that the main purpose of this paper is not

Table 1
Research questions.

	Research question	Description
RQ1	**What are the main Process Areas identified at Daimler AG in relation to GSE?**	PAM is designed based on state-of-the-art process models and also in addition extended and populated based on the needs of Daimler AG. By being able to map the needs of Daimler to the structure of PAM an indirect validation of the PAM structure is achieved.
RQ2	**Studying state-of-the-art, to what level is it possible to map solutions to PAM?**	There is a need to identify how good the solutions found in state-of-the-art match into the structure of PAM, but also indirectly to the needs of Daimler AG. This RQ is divided into two subquestions.
RQ2.1	What parts of PAM do not have solutions associated to it?	The identification of blank spots within PAM is of great interest as this would mean that there are areas which do not yet have solutions, and thus are areas of future research.
RQ2.2	Is there a need to create new Process Areas in PAM based on the solutions found in state-of-the-art?	Are there process areas (PAs) missing in PAM? That is, are there solutions in state-of-the-art that fall outside the structure offered by PAM. If so, how can PAM be extended? This is also an indirect validation of PAM.
RQ3	**To what extent have the solutions in state-of-the-art been described and tested?**	The solutions found need to be rated for quality. This is as it is important to identify the right solution fast and accurately in an industrial environment. The ratings set up for this purpose are described in the sub-questions in this section.
RQ3.1	How well is the context of the solutions' use and validation described?	To what extent is the case context of the solutions' validation described? This is important to decide whether a solution can be applied to another context.
RQ3.2	How well is the research design of the solutions described?	The description of the design of a study presented in a paper is of fundamental importance to the reader in order to judge whether the results presented are reasonable and reproducible.
RQ3.3	How well validated are the solutions?	The validation of the solutions presented in the paper is also very important to the reader. Very well validated solutions might be implemented right away whereas unvalidated solutions can require additional work to assure, e.g. scalability in a real industry environment.

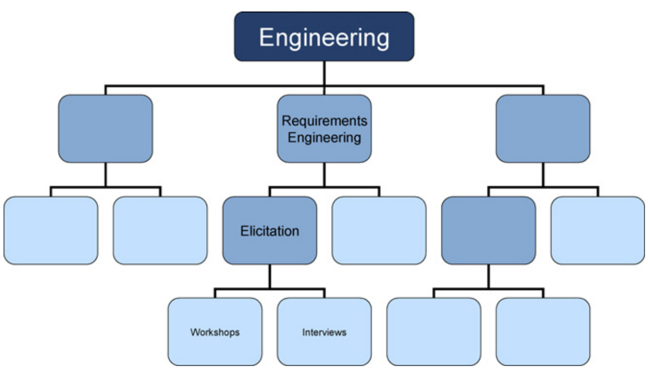

Fig. 1. Generic structure of PAM with example.

to present PAM itself, but rather use it as a structure to sort and categorize the solutions found during the SLR.

3.2. PAM – structure and details

A draft version of PAM was constructed prior to the execution of the SLR. This draft version acted as an initial structure for mapping the solutions. The initial version of PAM was constructed using several sources, CMMI (Chrissis, Konrad, & Shrum, 2003), ISO 12207 and 26262, but also with input from Daimler AG. As a second step, PAM was extended and changed, in an iterative way, as the solutions themselves, caught in the SLR, evolved PAM.

PAM consists of several Process Areas (PAs). Each PA contains one or more child PAs, thus indirectly refining the parent PA. Each of the child PAs might, additionally, contain one or more PAs, if further refinement is needed. The structure can be seen in Fig. 1. Three simple rules govern the creation and subsequent refinement of PAM:

Rule 4. When splitting a PA to two or more child PAs. The original PA must have a ranking above average. A structural change to PAM should always be based on well-ranked PAs. (The ranking will be covered in detail in Section 3.3.3.)

As the draft version of PAM was designed to match the GSE context within Daimler AG, there might be some PAs missing that might be relevant for other domains. For example, as the automotive industry mainly produces embedded software, there might be differences to, e.g. non-embedded domains.

To exemplify the generic structure an example has been incorporated into Fig. 1. The example has been taken from the PA of Engineering and shows a PA structure containing Requirements Engineering as a first level child PA. This is refined by the PA Elicitation, which is then refined into Workshops and Interviews, which are end leaves and considered as explicit solutions. Examples for this specific PA can be found in the qualitative analysis in Section 5.3.1. A list of all solutions for every PA can be found online due to space limitations within this paper.[1]

The idea behind PAM is to offer a practitioner several choices, that is, several solutions can, and preferably should, be offered. It is up to the practitioner and the individual needs, dictated by the domain and context, which of the solutions to choose.

3.3. Systematic literature review (SLR)

State of the art had to be studied to fill PAM. An SLR was designed and executed for this purpose using the procedures set up by Kitchenham (2007), and inspiration was also obtained by Unterkalmsteiner et al. (2011).

Fig. 2 provides an overview of the SLR design, which consists of three major steps. First, the research question was formulated and the need for the SLR was examined. Second, the SLR needed to be planned. That is, developing search terms, pilot searches, test extraction of data, and subsequent refinement of all steps. Third, the SLR inclusion, exclusion and extraction rules and procedures were established and refined.

3.3.1. Search

The following five databases were selected as primary targets because of their relevance in this research area: Scopus, INSPEC, IEEE Xplore, ACM Digital Library and SpringerLink. By using these databases, important conferences for GSE, like the ICGSE or ICSE have been included in the search.

The search string was developed through a cycle of test and refinement. That is, the search string was tested, modified, tested

[1] http://www.mathematik.uni-ulm.de/sai/schneider/SLR_papers.pdf, http://www.mathematik.uni-ulm.de/sai/schneider/mapping2processarea.pdf.

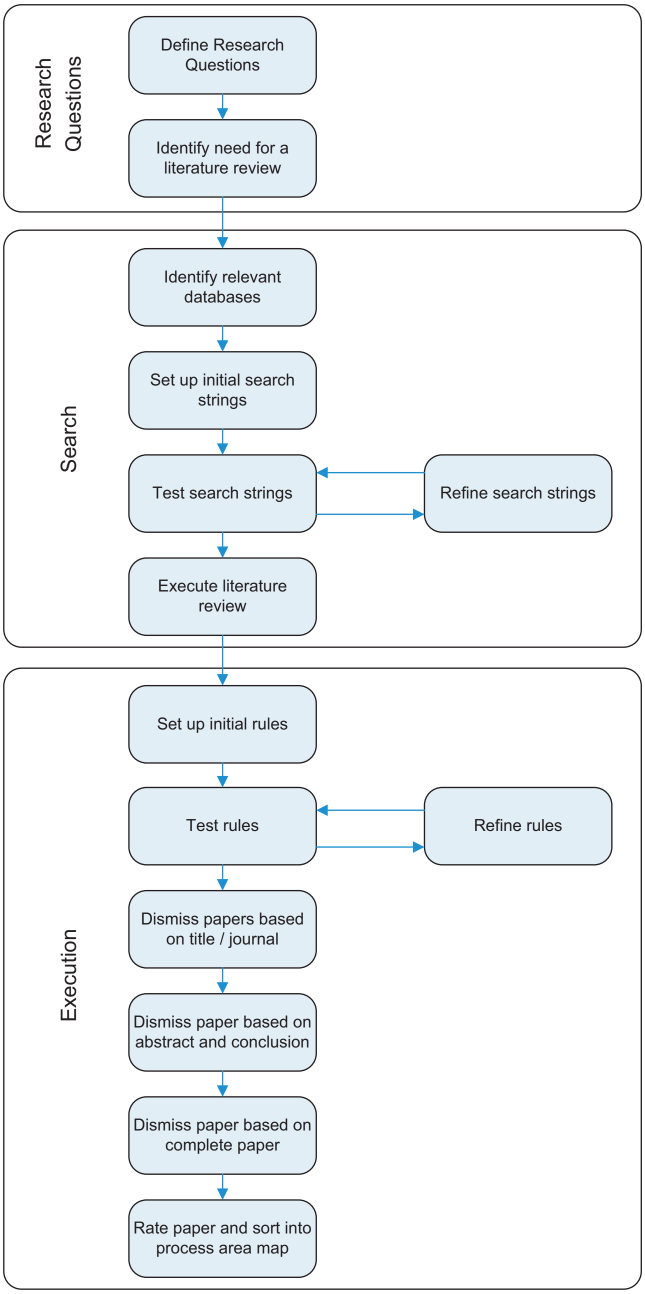

Fig. 2. systematic review process.

again and the results were compared over iterations until adequate results were obtained. The search results were screened for solutions that could be relevant in a GSE context. (This does not mean that solutions relevant for non-GSE context were dismissed.)

The stop criterion for search string refinement was when at least 10% of the top-20 results in a search were relevant for the SLR. This procedure was replicated for all databases using the search strings seen in Table 2. The search string with the best results was composed of two groups of search terms. The first group is related to the GSE part of the problem:

Virtual teams, Distributed development, Offshoring, Outsourcing, GSE/Global Software Engineering

The second group of search terms consists of keywords with the purpose of finding particular solutions in GSE:

Table 2
Search strings.

Database	Search string	Results
IEEE eXplore	((((solution or best practice or lessons learned or 'process improvement' or 'process enhancement' or 'process innovation' or 'spi')) < in > ab) <and> (((virtual team or distributed development or offshor* or outsourc* or gse or global software engineering)) < in > ab))	260
INSPEC	(solution OR "best practice" OR "lessons learned" OR "process improvement" OR "process enhancement" OR "process innovation" OR SPI) AND ("virtual team" OR "distributed development" OR offshor* OR outsourc* OR GSE OR "global software engineering")	931
SCOPUS	TITLE-ABS-KEY((solution OR "best practice" OR "lessons learned" OR "process improvement" OR "process enhancement" OR "process innovation" OR spi OR support) AND ("virtual team" OR "distributed development" OR offshor* OR outsourc* OR gse OR "global software engineering"))	167
ACM Digital Library	(gse or "global software engineering" or "virtual team" or "distributed development")	619
Springer Link	(gse or "global software engineering" or "virtual team" or "distributed development") and (solution or "lessons learned" or "best practice" or spi or "process improvement")	884

Solution, Best practice, Lessons learned, Process improvement, Process enhancement, Process innovation, SPI

The search string combinations, as well as the number of results, can be seen in Table 2. In total, 2861 papers were found in the search. The search covered all papers in the databases until March 2009.

3.3.2. *Data extraction*

After dismissal of duplicates using Citavi (www.citavi.com), rules for the inclusion and exclusion of papers were set up. These criteria can be seen in column one of Table 3. The criteria are exemplified in column two mostly as questions that need to be answered. If a paper did not meet all criteria it was excluded. In the last column the data used to make this decision is given.

The inclusion/exclusion criteria were further tested to ensure the reproducibility of the SLR, by selecting 15 random papers. Three reviewers took part in the test. The test was performed on a sample set of the results of the search, containing papers from every database in approximately the share that each database had in the complete result. For example, INSPEC provided about one third of the total papers included in the SLR, so INSPEC also provided a third of the papers used for the sample set.

The test was separated into four steps:

Step 1. Set up the criteria and a sample set.
Step 2. Perform a classification on the sample set.
Step 3. Compare the results of the classification.
Step 4. If agreement level not met; refine the criteria and go to Step 1, else exit.

This test was then conducted until the agreement level between the three reviewers was not more than one paper out of all in the sample. Furthermore, the final classification rules have been tested and reviewed by two senior researchers with a long practical and theoretical experience in Software Engineering and research.

Table 3
Data extraction form.

Criteria	Description	Information used
Area of interest	Does the paper belong to the area of interest studied in this SLR?	Title, Journal/Conference Information, Authors
GSE context	Does the paper belong to GSE context? Does the Conclusion promise a solution in the paper?	Abstract, Conclusion
Solution	Is there a solution presented in the paper? Is there a technology in the paper that can be used as a solution in GSE? Is there any input in the paper that can help Software Engineers to do their daily work in a GSE environment?	Whole paper
Rating	Is the solution presented in the paper validated and is the validation itself presented in the paper? Is the context of the solution described in the paper? That is, does the paper give an insight into the project and organization that developed this solution? Is the design of the study that led to this solution described in the paper? That is, is it easy to understand how that solution has been developed?	
Populate	Sort the rated solutions into PAM.	

Table 4
Scale for validation ratings.

Done in	Done by	
	Researchers in academia	Researchers in industry
Academia	1	2
Industry	2	3

Table 5
Scale for context ratings.

Scale	Description context
0	There is no description of the context at all.
1	The context is described shortly or the industry is mentioned (e.g. automotive). This gives an idea of the context but leaves many questions unanswered like typical project type, development method, size, length, etc.
2	The reader can find information on the context of the solution but questions remain unanswered.
3	It is easy for the reader to understand the context of the solution. This includes, e.g. the type of distribution (e.g. temporal, geographical, cultural) or the type of organizational distribution (e.g. number of suppliers, work distribution between the suppliers).

Table 6
Scale for design ratings.

Scale	Description design
0	There is no description of the Design at all.
1	There is a short description of the study design (e.g. the steps taken in the study), but many questions remain unanswered.
2	The study design is described (e.g. the steps taken in the study) but some questions remain unanswered.
3	The reader can understand the study because they are given the variables measured, the control used, the treatments etc.

3.3.3. *Rating and transformation*

The rating part presented in Table 3 used a grading scheme (scale) were the value 0 meant that there was no recognizable effort described in the area. That means, that there was no way to tell whether the method had been validated or not, in which context it had been developed or how the study had been designed. The scale from one to three is explained separately for each dimension below. The perspectives and the scales were developed by Ivarsson and Gorschek (2009).

Validation, being the most important measure for industry relevant solutions (Gorschek, Garre, Larsson, & Wohlin, 2006, 2007; Ivarsson & Gorschek, 2009, 2010), is being ranked according to a scale from zero to three as can be seen in Table 4. In this scale, there is a strong focus on validation in industry. Therefore, a validation that is done by a researcher in academia is rated with 1, whereas a validation done by a practitioner in industry can be said to be the most realistic setting for a validation, thus considered to be highly relevant for industry, is ranked with 3. Mixtures of both are ranked 2 as this is not necessarily validated in industry. It should be observed that this rating is primarily adapted to grade the level of industrial validation. Certain solutions might be validated in academic settings, and be *potentially* valid in an industry setting. These types of studies were however not the main focus of this research, as industrial usability and usefulness was in focus.

The scales for Design and Context, however, are described on a linear scale with more general characterizations, as can be seen in Table 5 (cf.). To receive a good rating, information on the context in which the evaluation is performed (e.g. experience of the staff, development process) is needed. It should be observed that the rating is rather forgiving, i.e. providing some contextual information gives a rating of two (2) on a scale from zero to three.

The scale for Design is quite similar, as can be seen in Table 6. To receive a good rating, the products, resources and the process used in the evaluation should be explained. However, here also, the rating is forgiving, and, hence, providing a minimum level of design description would result in a two (2).

This rating has been carried out by five researchers. Two of them have been intensively part of the review process, together conducting more than 70% of the total review. Two others were integrated for about 20–30% of the total review. One senior researcher has been involved into the review for quality assurance reasons checking samples of ratings from the rated solutions.

4. Results and quantitative analysis

This section presents the results for each of the research questions as stated in Section 3.1. Additional results, in terms of a characterization of the actual content of each area/PA are presented in Section 5.

The bases for the results are the papers found in the SLR. The amount of papers that have been kept in each step described in Table 3 can be found in Table 7. It can be seen, that in the end 330 papers have been kept to be incorporated into PAM, i.e. 11.5% of

Table 7
Number of primary studies.

Database	Results	Area of interest	GSE context	Rating and sorting step
IEEE Xplore	260	116	66	65
INSPEC	931	484	88	55
SCOPUS	167	104	29	14
ACM Digital Library	619	165	82	81
Springer Link	884	311	132	115
Total	2861	1180	397	330

Table 8
Top ranked papers.

Paper	Context	Design	Validation
Carver, Kendall, Squires, and Post (2007)	3	3	3
Fricker, Gorschek, and Myllyperkiö, 2007a	3	3	3
He, Li, Wang, Yang, and Ye (2008)	3	3	3

Table 9
Top ranked papers in validation.

Paper	Context	Design	Validation
Begel (2008)	2	1	3
Berner, Weber, and Keller (2005)	3	2	3
Carver et al. (2007)	3	3	3
Cordes and Spine (2007)	0	1	3
Cusumano (2008)	0	0	3
Hogan (2006)	2	1	3
Xu and Lippert (2007)	1	1	3
Seybold and Keller (2008)	2	1	3
Sureshchandra and Shrinivasavadhani (2008)	1	1	3
Cichocki and Maccari (2008)	2	2	3
Anonymous (2007)	1	1	3
Fricker et al. (2007a)	3	3	3
Fricker et al. (2007a)	3	2	3
He et al. (2008)	3	3	3
Hole and Moe (2008)	2	2	3
Kommeren and Parviainen (2011)	2	1	3
Lings et al. (2006)	1	2	3
Rice et al. (2007)	2	3	3
Jain (2006)	2	2	3

all papers that have been reviewed in the SLR. A complete list of papers included in the SLR can be found online.[2]

The solutions presented in the paper have also been sorted into solution groups. These groups cluster closely related solutions together and makes it easier for the reader to identify the right solution. There are 127 solution groups in PAM.

In Table 8 one can find a list of top ranked papers. As can be seen, there were only three papers that received the highest rating in all the categories of Context, Design and Validation, i.e. only about 1% of all the primary studies from the SLR. As these papers are rated exactly the same, the order does not imply any differences between the papers. These papers can be taken as a measurement that other papers have to live up to in this rating. However, the complexity of the solutions described as well as the area of research that this solution was developed in is not taken into account for the rating. Solutions that can be used in GSE are integrated into the SLR. So, solutions in this SLR do not have to be specifically designed for GSE. A detailed list of papers and their detailed ratings can be found online.[3]

In Table 9 the "best validated" papers from the SLR can be found. These are the papers that industry should be looking for as these are the papers that many times contain relevant information for practitioners. The solutions introduced in these papers have proven to be successful in particular contexts and, hence, provide valuable insight into solutions that are used by industry already.

Detailed results of the SLR can be found online[2] and in Section 5.

4.1. RQ1: process areas in PAM

For RQ1, PAM needs to be populated with PAs relevant to Daimler AG. The model structure enables Daimler AG to efficiently store and use the solutions as they can easily be found within the model.

Looking at the structure, PAM consists of four top level PAs (*PA 1 Process Management*, *PA 2 Project Management*, *PA 3 Engineering*, *PA 4 Support*), each containing several child PAs. This structure is shown in Fig. 3. As can be seen, all top level PAs are taken from CMMI. In fact, most of the PAs are taken from CMMI as this is the basis for the structure. In some areas, though, PAs from different standards have been more appropriate. For example, *PA 2.3 Management Process* has been incorporated (see Section 4.2.2).

Another reason to replace PAs from CMMI, by PAs from other standards, is the different view that an area might have. For example, Supplier Agreement Management in CMMI was replaced by *PA 4.4 Acquisition Process*. The reason for this was the meaning of the word supplier. In contrary to acquisition, supplier is interpreted much more narrowly, e.g. acquisition might mean the acquisition of products from a supplier, but it could also mean the acquisition of a complete company. This wider level of possible definitions was used to interpret this PA in a way that fits the context GSE much better.

Due to space limitations in this paper, there is no complete overview of PAM here. The complete model can be found online.[4]

4.2. RQ2: map solutions against PAM

In this section, we describe how the solutions found in the systematic literature review are mapped to the process areas (PAs) in the process area map (PAM). The purpose of this was to identify if there are parts of the PAM that had few or no solutions in current state of the art (Section 4.3). Additionally, the SLR was then used to validate PAM by investigating if PAM needed to be extended based on the findings from the SLR (Section 4.2.2). A complete mapping of the solutions found in the SLR and PAM can be found online.[5]

4.2.1. RQ2.1: white spots in PAM

One goal, when creating a map, can be to find blank spots where nobody has been and then figure out if nobody has thought of the problem yet or if there are no significant problems to expect in this area. In Fig. 4, a histogram of the Process Areas of PAM is shown. The total number of papers within one PA is displayed on the *x*-axis with the corresponding number of PAs on the *y*-axis, e.g. the first bar

[2] http://www.mathematik.uni-ulm.de/sai/schneider/SLR_papers.pdf.
[3] http://www.mathematik.uni-ulm.de/sai/schneider/rating_SLR.pdf.
[4] http://www.mathematik.uni-ulm.de/sai/schneider/PAM.pdf.
[5] http://www.mathematik.uni-ulm.de/sai/schneider/mapping2processarea.pdf.

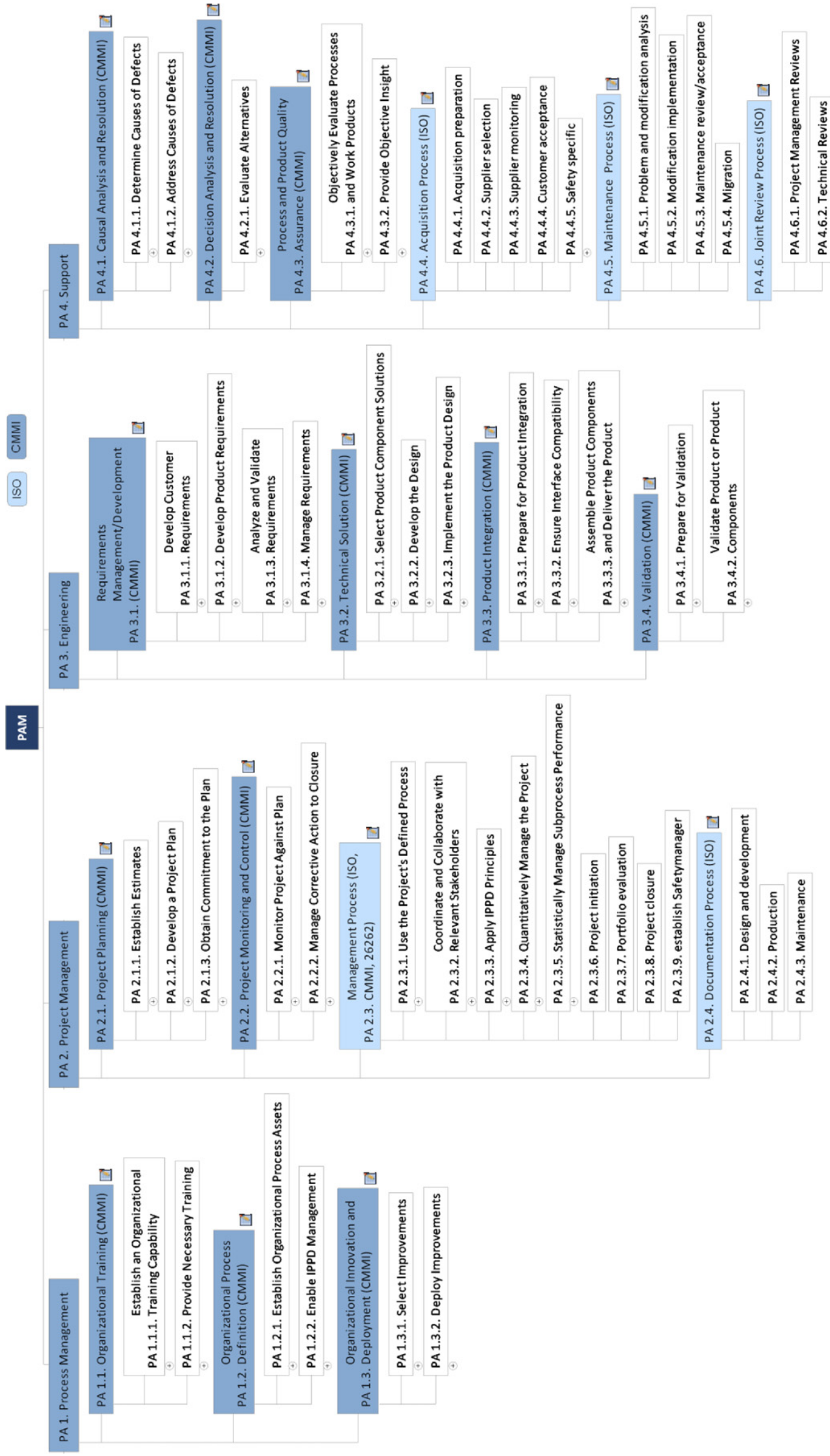

Fig. 3. Structure of PAM.

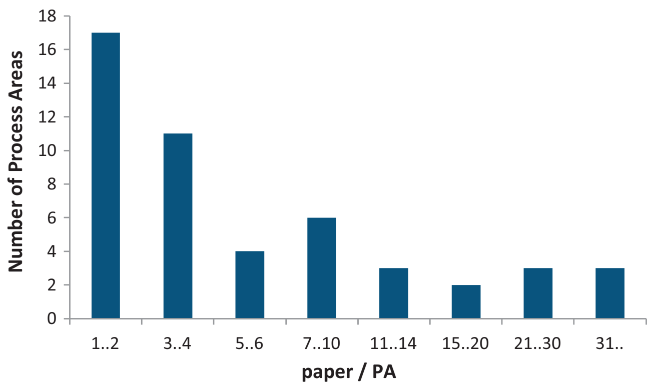

Fig. 4. Histogram of all PAs.

gives the amount of PAs that have only one or two papers. That is, the PAs are categorized into groups, where every group contains the same number of papers. In Table 8 one can see, that there are 17 PAs that contain one or two papers only and 11 PAs that contain three or four papers. So, there are 28 PAs with less than five papers, which means that more than 68% of all PAs in the PAM have four or less papers. Having less than five papers, however, leaves little choice when selecting different solutions. For example, context-specific tailoring of these PAs would probably result in many empty areas. So, in short, one would like to see a larger variety concerning the offered solutions, i.e. surely more than five papers per PA is needed.

While the results shown in Fig. 4 have been gathered from the leaves of the PAM, the results have also been assembled to the PA level. There are four top level PAs as shown in Fig. 5. Three of these PAs seem to be fairly neglected (*PA 3 Engineering*, *PA 4 Support* and *PA 1 Process Management*) compared to *PA 2 Project Management* which is quite populous. The first three will be examined next while the last one will be examined in Section 4.2.2.

In Fig. 6, *PA 1 Process Management* is displayed in further detail. As is evident, there is one larger part (*PA 1.2 Organizational Process Definition*) and two parts containing fairly few papers. In Fig. 7, *PA 3 Engineering* is presented in more detail. As can be seen, there is one larger part (*PA* 3.1 *Requirements Management/Development*). As *PA 3.1 Requirements Management/Development* is a very intense area of research within GSE this is also one of the larger PAs. In Section 4.3 it will be shown that this PA is also of high quality concerning the maturity of proposed solutions. The other three parts (*PA 3.2 Technical Solution, PA 3.3 Product Integration* and *PA 3.4 Validation*), on the other hand, are quite small and might be in need of some additional attention.

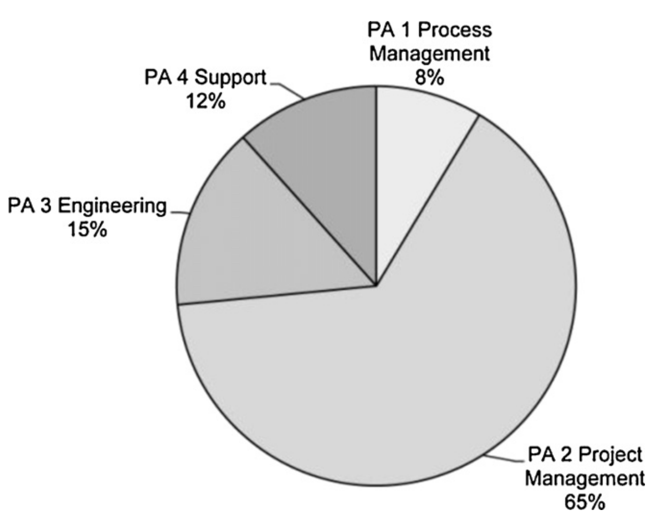

Fig. 5. Overview over the PAs.

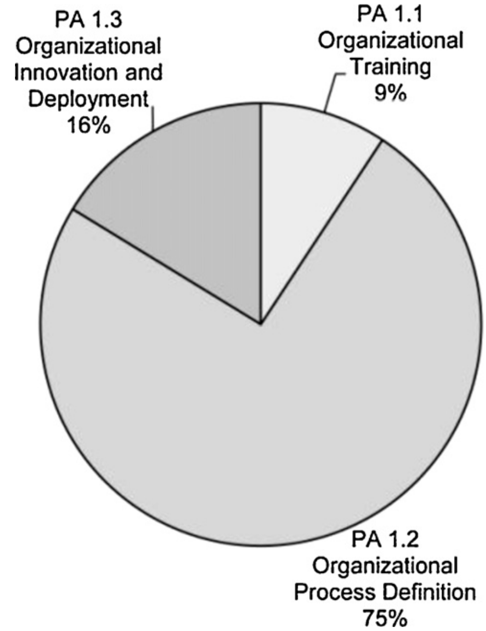

Fig. 6. *PA 1 Process Management.*

In Fig. 8, *PA 4 Support* is described in further detail. It can be seen, that there is one large part (*PA 4.4 Acquisition Process*), whereas the other parts are rather small. Especially *PA 4.1 Causal Analysis and Resolution*, as well as *PA 4.3 Process and Product Quality Assurance*, might be in need of some more attention.

4.2.2. RQ2.2: new PAs

The second important question to be asked is if PAM is complete. Complete in this context means to provide solutions for Daimler AG within the GSE context. This is important to note as it may not be complete for other contexts and companies. However, looking at the distribution of papers in Table 8, it can be seen that some PAs contain a lot of papers. As in Fig. 4, the total number of papers within a single PA is shown as ranges on the *y*-axis with the corresponding number of PAs on the *x*-axis. These crowded PAs are, by large, located in PA 2 Project Management. In Fig. 10, it can be seen that there is especially one very populated area (*PA 2.5 Distributed Team & Project Management*). The other areas fade in comparison.

The next step now is to analyze if there is a PA missing or if a PA needs to be refined and, thus, the large amount of papers should be distributed across two, or more, new PAs.

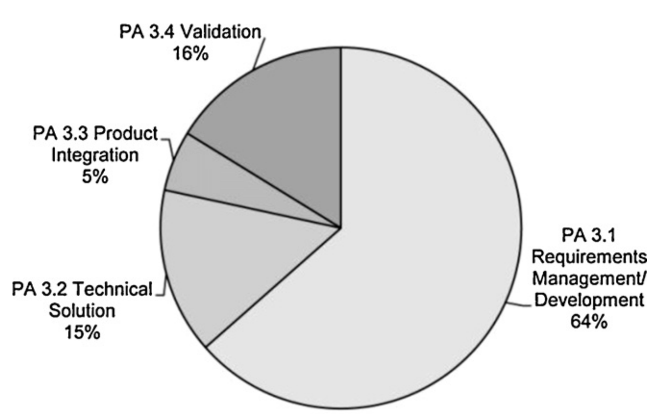

Fig. 7. *PA 3 Engineering.*

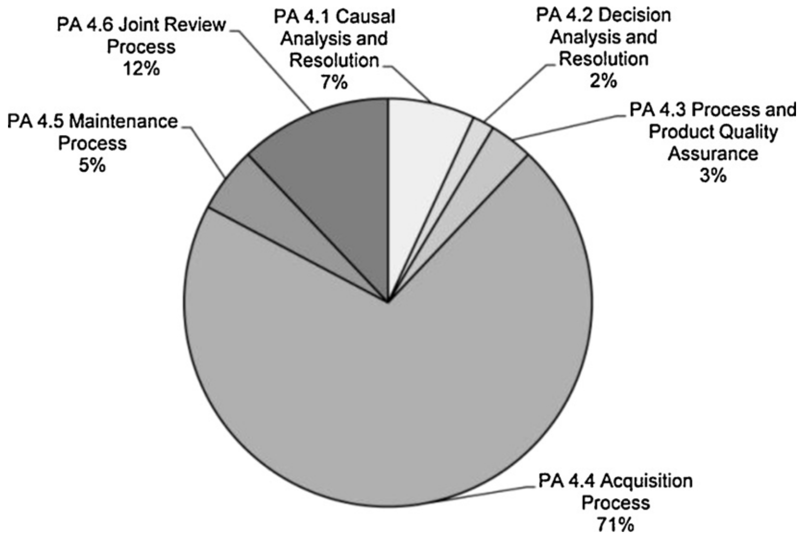

Fig. 8. *PA 4 Support.*

By analyzing the papers in the populated areas of PAM, one could see that there was an obvious need to refine *PA 2 Project Management*, by adding *PA 2.5 Distributed Team & Project Management* as can be seen in Fig. 9. The PA in the lower part of the figure is newly added, combining papers with a clear connection to distributed team management as well as distributed project management, and consists of five PAs:

PA 2.5.1 Team Building/Management contains every paper that deals with how to set up a virtual team and how to manage it.
As *PA 2.5.2 Coordination/Communication* are considered to be two major problems in GSE; there was a need to create a special PA to summarize everything related to communication within a team and coordinating a virtual team into a specific PA.

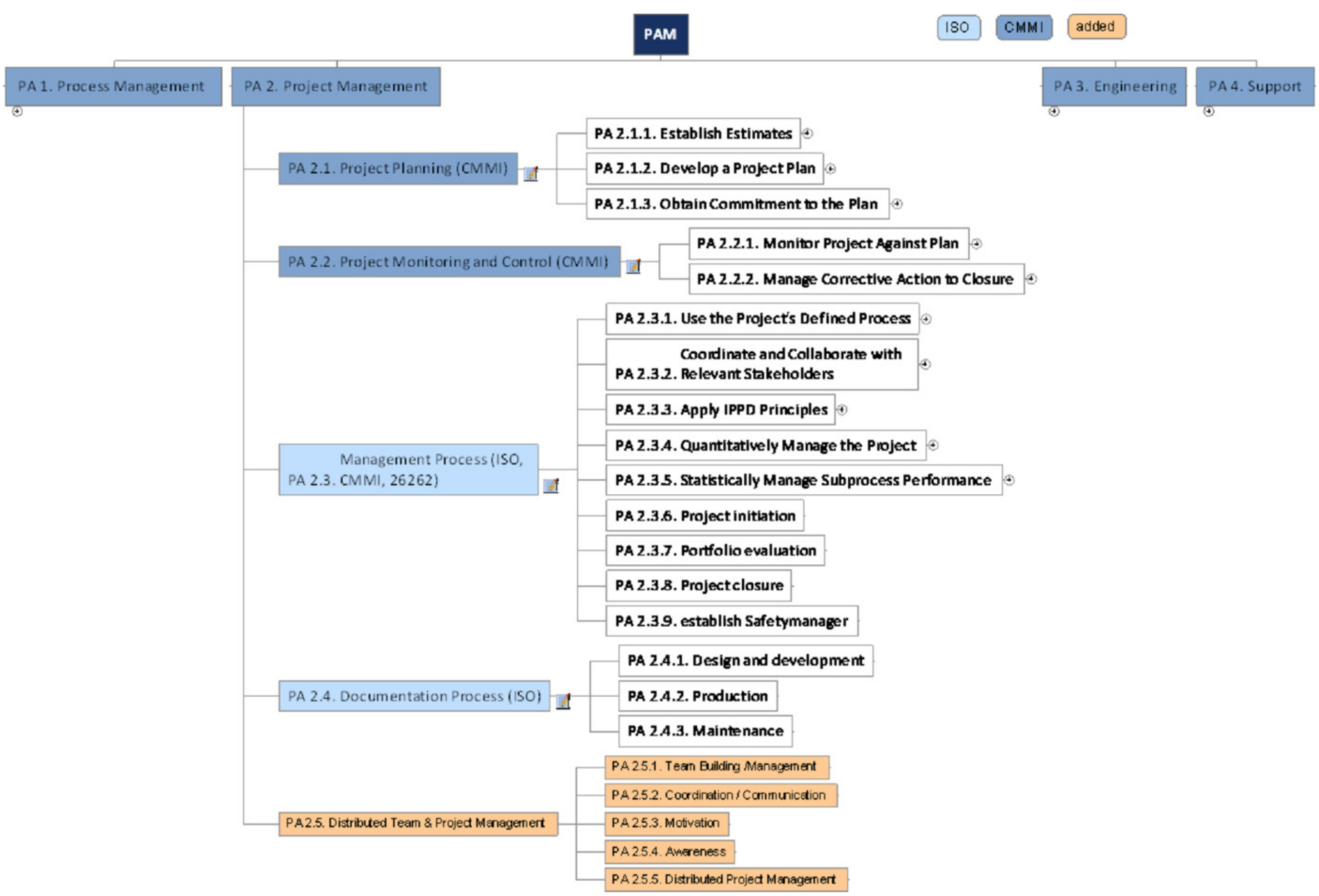

Fig. 9. PAM with added PA.

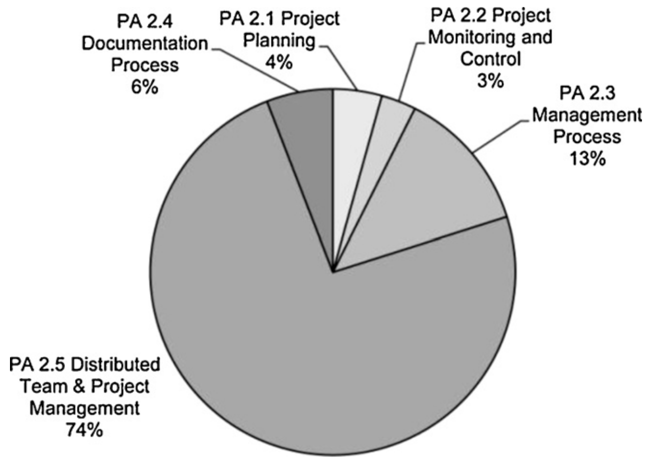

Fig. 10. *PA 2 Project Management.*

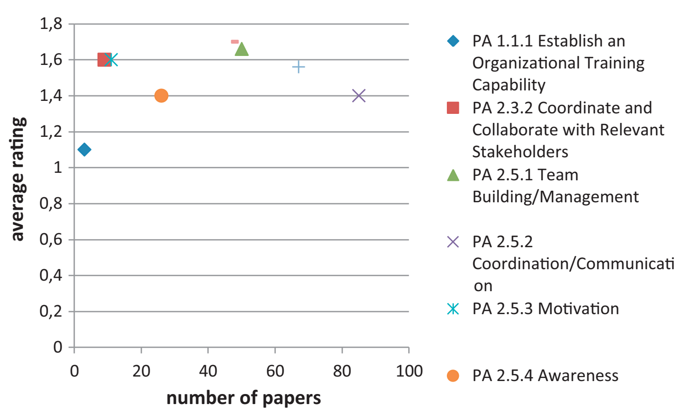

Fig. 11. Average ratings and number of papers in selected PAs.

Virtual teams are not necessarily motivated in the same way as traditional teams. Therefore, *PA 2.5.3 Motivation* contains everything related to motivational solutions.

If parts of a team are distributed all over the world, the team has to be aware that there are other people involved in their project beyond the team members they regularly meet. *PA 2.5.4 Awareness* contains solutions on how to accomplish that.

As there were many papers that summarized several rules on how to manage a distributed project, there was a need to collect these papers not only in the PAs they have solutions in but also in a PA that contains only "solution collections". *PA 2.5.5 Distributed Project Management* is this new PA.

As these PAs are collecting a lot of papers, there might be a need to refine them in even more detail. As *PA 2.5 Distributed Team & Project Management* contains more than 100 papers in the new setting, it might also qualify as a new top level PA, especially as this might be considered the main focus of GSE.

At the moment, the empty areas are more interesting to analyze as compared to the overly populated areas, but during an evaluation of the model at Daimler AG there might be some additional refinements to PAM.

4.3. RQ3: maturity of the solutions

In RQ3, the average maturity of the solutions in a PA is used to describe the maturity of the PA. This average maturity can then be used to compare PAs. To demonstrate the results, the ratings for the selected PAs will now be shown. In Fig. 11, the number of papers in a PA is given along the *x*-axis and the average rating of the papers in this PA is given along the *y*-axis. The average rating of a PA gives an idea of the maturity of the PA. The higher the value, the better. This means, that PAs in the top-right corner have a lot of good quality papers available while PAs on the lower-left corner have neither. A list of all papers rated can be found online.[6]

As described in Section 4.2.2, there are some PAs containing many papers. These PAs have been split up to make the model usable in practice. Five new PAs have been added in *PA 2 Project Management*. The average ratings and number of papers for these five new PAs are shown in Fig. 11. *PA 2.5.1 Team Building/Management*, for example, is rated quite high and has also many papers whereas in *PA 2.5.3 Motivation* has significantly less papers in total. It can also be seen, that *PA 2.5.5 Distributed Project Management* and especially *PA 2.5.2 Coordination/Communication* seems to be a research hot spot with 67 and 85 papers.

The location of the newly added PAs in the upper-right corner is important when adding a new PA to PAM because a structural change to PAM should always be based on well rated PAs. This way it is ensured that the changes made to PAM are of good quality and based on information that is ranked above average compared to all papers in PAM.

PA 3.1 Requirements Management/Development, as can be seen in Fig. 11, is also an example of a very well rated PA. Also, the number of papers available is very high. It can also be seen that *PA 2.3.2 Coordinate and Collaborate with Relevant Stakeholders* is ranked quite good while the number of solutions available in this PA is lower than in the newly added PAs. Finally, *PA 1.1.1 Establish an Organizational Training Capability* is an example of a PA that is ranked very low and contains a small number of papers. This indicates, that there is some work left to do in this PA to improve the rating as well as number of solutions available.

5. Qualitative analysis with solution characterization

Having finished the quantitative analysis of the SLR, this section will now describe and characterize the PAs through the solutions found. This section gives an overview of the contents of PAM to provide insight into the quality of the solutions.

Since the SLR found 127 solutions in total it would of course be impractical to cover each solution in detail. We have instead chosen to select clusters of solutions that we believe might be of certain interest. Nevertheless, all solutions (with reference number, title of paper, abstract, and the ranking they received in our classification) can be found online.[7]

Table 10 gives an overview of the PAs in PAM at the second level of abstraction (the sub-PAs chosen for the qualitative analysis are in bold). Each PA is rated in relation to Amount (of solutions within the area) and Quality (of the solutions in the area).

The amount is rated as *high*, *medium* or *low*. A PA is said to have a low amount of solutions if there are less than 10 solutions, medium if there are less than 25 solutions and high if there are more than 25 solutions.

The quality is also rated in three steps, *high*, *medium* and *low*. This measure is deducted from the average rating of the solutions in this area as described in Section 3.3.3. An area is said to have low quality if the average rating is below 50, medium quality if the rating is 50–100 and of high quality if the average rating is above 100.

As is evident from Table 10 we have chosen to further analyze PAs that have either (according to our classification):

[6] http://www.mathematik.uni-ulm.de/sai/schneider/SLR_papers.pdf, http://www.mathematik.uni-ulm.de/sai/schneider/rating_SLR.pdf.

[7] http://www.mathematik.uni-ulm.de/sai/schneider/PAM_Soloutions.pdf.

Table 10
Overview PAs in relation to amount of solutions and their quality.

Name	Amount	Quality
PA 1.1 Organizational Training	**Low**	**Low**
PA 1.2 Organizational Process Definition	High	Medium
PA 1.3 Organizational Innovation and Deployment	Low	High
PA 2.1 Project Planning	Medium	Low
PA 2.2 Project Monitoring and Control	Low	Medium
PA 2.3 Management Process	High	Medium
PA 2.4 Documentation Process	Medium	Medium
PA 2.5 Distributed Team & Project Management	**High**	**High**
PA 3.1 Requirements Management/Development	**High**	**High**
PA 3.2 Technical Solution	Medium	High
PA 3.3 Product Integration	**Low**	**Low**
PA 3.4 Validation	Medium	Medium
PA 4.1 Causal Analysis and Resolution	Low	Medium
PA 4.2 Decision Analysis and Resolution	Low	Medium
PA 4.3 Process and Product Quality Assurance	Low	Medium
PA 4.4 Acquisition Process	High	Medium
PA 4.5 Maintenance Process	Low	Medium
PA 4.6 Joint Review Process	**Low**	**Low**

(i) Low amount *and* low quality of solutions.
(ii) High amount *and* high quality of solutions.

The reason for this selection is that we believe that, regarding the first category (low–low), these are sub-PAs that might be interesting to further analyze because of the possibility of finding future research topics, or to simply investigate their relevance in a GSE context. That is, these sub-PAs are candidates for removal from PAM based on the solutions found in literature.

With respect to the second category (high–high) we believe this analysis should be interesting for practitioners since being able to choose between several solutions of high quality would be a comfortable situation to be in for many practitioners. (This section also ties back to the results and analysis in Section 4.)

Nevertheless, all PAs are shortly summarized and introduced.

5.1. PA 1 Process Management

Looking at Fig. 5 it can be seen that *PA 1 Process Management* is the smallest of the four PAs when it comes to the amount of solutions. Fig. 6 further shows that *PA 1.2 Organizational Process Definition* is the area with the most solutions within PA 1. In addition, Fig. 11 shows that PA 1.1.1 is ranked quite low with the validation ranking being the worst.

5.1.1. PA 1.1 Organizational Training

PA 1.1 has been characterized low on quality as well as quantity of solutions (Table 10). The reason for the lack of validated solutions might be that companies have started to create solutions for GSE in the recent years. These solutions might not yet be mature enough and thus be included in training for a distributed context. Therefore, this area might get additional attention in relation to validation in future work (and thus increase PA quality). As one of the most important PAs in this area, *PA 1.1.2.1 Deliver Training* focuses on how to train teams that are not co-located, e.g. how to build a global test team through training (Hackett, 2007). The main goal is to understand the ineffectiveness of globally distributed test teams and get the best out of them.

5.2. PA 2 project management

In Fig. 5 it can be seen that *PA 2 Project Management* is the biggest PA of all in PAM. Fig. 11 further shows that especially *PA 2.3.2 Coordinate and Collaborate with relevant Stakeholders* as well as *PA 2.5.3 Motivation* are very well ranked. This indicates a very high quality of papers in that area given the small number of papers in these areas. Also, in Fig. 11 there is a broad overview of the rankings in this PA and it can be observed that they are all quite high. This PA is one of the better ranked, in total, within PAM.

5.2.1. PA 2.5 Distributed Team & Project Management

This PA has been identified to have a high amount and high quality. So, this area seems to be very mature in GSE. Therefore, several examples are given to demonstrate state of the art in this area.

PA 2.5.1 Team Building (see Fig. 11) is one of the best ranked PAs in the newly created *PA 2.5 Distributed Team Management*, from all three perspectives of context, design and validation.

To build a distributed team, some hurdles have to be overcome. Language skills and terminology differences are just two examples of problems that arise in this PA (Smite, 2007). The solutions covered in *PA 2 Project Management* try to take care of the problems arising in globally distributed teams in several ways. One focus is the setup of virtual teams, with multi-culturalism and its implications on the creativity of virtual teams, as one of the major bonuses (Draghici, 2008; Fricker, Gorschek, & Myllyperkiö, 2007b).

Diversity-focused solutions can however lead to effort increase in team unification. Group dynamics and cohesion in virtual teams (Nicolopoulou, Koštomaj, & Campos, 2006) are also a challenge addressed by many of the solutions (see, e.g. Bos, Shami, Olson, Cheshin, & Nan, 2004; van der Duim, Andersson, & Sinnema, 2007).

Another focus area is the leadership in distributed teams and the differentiation from traditional leadership (Heckman, Crowston, & Misiolek, 2007). Setamanit and Raffo (2008) or Oshri, Kotlarsky, and Willcocks (2008) present solutions focusing on the importance of social ties within virtual teams as a key factor of project success. Ungerleider (2008) extends this with solutions for conflict resolution.

Fig. 11 illustrates *PA 2.5.2 Coordination/Communication*, which is ranked below the other PAs in this area; however, it is still above average as can be seen in Fig. 11. This PA addresses the dominant use of asynchronous communication which is a central challenge in coordinating virtual teams (Smite, 2007). Knowledge sharing solutions for this is a pre-dominant measure (see, e.g. Mathrani & Parsons, 2007; Wei, 2007). Further, the extension can be seen in solutions for decision understanding commonality (Fang & Paul, 2007; Rice, Davidson, Dannenhoffer, & Gay, 2007), and tool support for these activities presented by Ferscha and Scheiner (1999).

It is also important to the know rules and constraints in distributed communication. The solutions range from practical lessons learned, as described by Smite and Borzovs (2006), to the more theoretical challenges of virtual partnerships (Ratcheva & Vyakarnam, 2001).

The third example under *PA 2 Project Management* is *PA 2.5.3 Motivation*. Fig. 11 shows a high rank in Context, while Validation seems to be a little low, but still above average.

Motivation of virtual teams is reported to be harder than co-located teams. One reason for this could be the lack of common goals among the distributed team members (Smite, 2007). Lings, Lundell, Ågerfalk, and Fitzgerald (2006) and Lindqvist, Lundell, and Lings (2006) present solutions focusing on defining clear and transparent project priorities and goals. In addition, another important factor in distributed teams is to send out a shared vision of the project to all team members. This shared vision enables the team to accomplish the work together (Adya, Nath, Malik, & Sridhar, 2007; Sangwan & Ros, 2008).

The last example to demonstrate the maturity of this area is *PA 2.5.4 Awareness* (Fig. 11). Having remote team members, it is important to make all the people in the team aware of all the other members of the team (Casey & Richardson, 2008). If a team is separated between different sites, it is often hard to get a team feeling (Smite, 2007). This feeling can be strengthened by building trust between the team members (Alexander, 2002; Babar & Niazi, 2008;

Nakayama, Binotto, & Pilla, 2006). Awareness can also be created by a technique that is best described as virtual co-location, presented by Herbsleb and others (Boyer, Handel, & Herbsleb, 1998; Herbsleb, 2007) as a way to address the issues of motivation lack of and team feeling.

5.3. PA 3 Engineering

In Fig. 5 it can be seen that *PA 3 Engineering* is only about a quarter of the size of *PA 2 Project Management*. Yet, it is double the size of *PA 1 Process Management* and offers double the amount of solutions. In Table 10, further shows the level of quality in this area which can be seen as relatively high.

5.3.1. PA 3.1 requirements management/development

Looking at Fig. 7, *PA 3.1 Requirements Management/Development* is one of two areas that have a large amount of solutions (and high quality solutions according to our ranking).

To produce a product that is of high value for the customer, it is very important to know what the customer wants (*PA 3.1.1.1 Elicit Needs*). In a distributed team, problems might occur related to the limited transparency of decisions especially in the early stages of development (Ebert, 2006). The area of elicitation in a distributed environment has gotten a lot of attention from researchers as it presents a unique GSE twist to the overall challenge of requirements elicitation.

Some of these solutions focus on the techniques used to elicit customer's requirements in a distributed environment (Aranda, Vizcaíno, Cechich, & Piattini, 2005; Geisser & Hildenbrand, 2006), while others focus on the organization of virtual requirements meetings themselves (Aranda, Vizcaíno, Cechich, & Piattini, 2007; Fricker et al., 2007b). Thus both the actual "catching" of requirements, and the subsequent handling and understanding of them are critical to enable a common understanding between the stakeholders.

PA 3.1 Requirements Management/Development (see Fig. 7) is one of the biggest and also best ranked PAs in PAM. This is true for all three aspects (validation, context and design). Due to the lack of synchronous communication and increased "virtualness", changes to requirements can lead to problems if not all team members get instant notification, as well as a rationale for the changes (Ebert, 2006). The continuous tracking of changes in requirements is a challenging task in distributed teams. Heindl and Biffl (2006) present a solution that helps project managers to ensure the correctness and traceability of the requirements documents. Välimäki and Kääriäinen (2008) extend this and present a possibility to transfer requirements management practices into patterns especially tailored for distributed project management.

5.3.2. PA 3.3 product integration

The amount of solutions in this area is low (Table 10) and the quality seems to be lacking. One explanation for this could be that there are few problems in this area that are GSE-specific. For example, the lack of solutions (and quality) might be due to that the actual product integration is not often done in distributed teams (Nguyen, 2008). The parts might get delivered from all over the world, but the integration itself is not done in a distributed way.

However, for example Paulish, Pichler, and Kuhn (2004) and Edgar (2006) identified product integration as a central research area for distributed software engineering. Possible solutions in this area quote the product line approach as a feasible solution for product integration through a tight control of core assets and their use, especially for multi-site projects and large-scale requirements sets.

We feel that the process area of product integration should not be excluded from PAM based on the low amount of solutions, rather the area should be investigated further.

5.4. PA 4 Support

As can be seen in Fig. 5, *PA 4 Support* is one of the three small PAs in PAM. Yet, especially in *PA 4.4 Acquisition Process*, important solutions can be found as can be seen in Fig. 9.

5.4.1. PA 4.6 Joint Review Process

This PA has been identified to have a low amount of low quality solutions. There are different possible reasons for this. One reason might be that this area is of minor interest in a GSE context, and the area is well covered (mature) in SE literature and that the methodology is easily transferred to a global context. However, Duarte et al. (2010), Zu, Taira, Makino, Kano, and Matsumoto (2007) and Meyer (2008) identified this area as important and they claim there still exist several additional challenges with reviews and inspections in a distributed environment.

6. Discussion and conclusions

6.1. Validity threats

The limitations of a SLR can mainly be found in three factors:

- Selected databases
- Design of the review
- Human judgment in data extraction

To mitigate these limitations several actions have been taken. First, the most popular databases in the field of software engineering have been chosen to broadly cover this research area. The search strategy was tested and reviewed to ensure the quality of the results.

Also, the design of the review was developed very strictly to guarantee repeatability of the SLR. The rules set-up for the SLR have been tested, developed and reviewed. The tests have been carried out in several steps and finally been reviewed by senior researchers with several years of research experience.

After these steps, the SLR has been carried out and to ensure the validity of the data generated by the review, the five researchers conducting the review have been assigned parts of the SLR that had overlapping areas. In the areas that have been reviewed by more than one researcher (about 15% of the total review) 89% accordance of the inclusion rate could be found.

Last, it had to be guaranteed that the SLR was not too limited focusing on the industrial Daimler AG context. This has been ensured by integrating senior researchers from universities performing reviews and quality assurance tasks during the SLR. This procedure was used to uncover results relevant for practice while using and generating data relevant for research.

6.2. Conclusion

An extensive SLR was performed to identify and map solutions to software engineering challenges in a GSE context. Further, to sort the solutions, and identify what areas were well populated a process area map (PAM) was created taking inspiration from established frameworks and standards like CMMI. Further the "quality" of the solutions identified were rated in relation to context, design and level of validation. This is central as any solution identified (and the map as a whole) should be a resource for practitioners. Thus it is important to be able to judge the level of validation, as well as in which context, and how the empirical data related to the solutions was collected, speaking the credibility of the validation.

127 solutions were identified in the review, which were subsequently rated.[8] It turned out that these ratings were correlated. However, the correlation was not high enough to combine these three ratings into a single rating. Additionally, the ratings were clearly normally distributed, having no fat tails, which is a good sign for the rating – too many extremely good and extremely bad papers and no papers in-between would have been a sign for an ill-constructed scale.

The map of the different process areas also showed to be a good approximation to reality as it needed little tweaking. Only one PA had to be added post SLR in order to fit the solutions, however this was mainly due to the focus of the review, i.e. some areas were simply overpopulated. Also, in the related work section it can be seen that the problems in GSE are well understood. It is important to see that the problems mentioned there are reflected in the well populated areas in PAM (Šmite et al., 2010). Seeing these results affirming each other is a strong sign for the relevance of the research done in these studies.

Some areas such as *PA 3.1 Requirements Management/Development* and *PA 2.5 Distributed Team and Project Management* are very well populated, that is, a lot of research and subsequent solutions have been presented to tackle GSE-related problems. There are however several areas, most pre-dominantly *PA 3.3 Product Integration* and *PA 2.2 Project Monitoring and Control*, that are very scarcely populated. Researchers can use this as a clear indication for future research efforts, or at least we need to confirm that the solutions for co-located development also apply in a GSE context. To our knowledge little empirical evidence exists clarifying this.

In terms of quality, the rating system of Context, Design and Validation presented in the paper can also be used to preemptively improve research quality in the field of GSE research, and the well rated papers can be used as good examples by researchers.

The actual process model, PAM presented in this paper, and initially populated by GSE solutions, will be given as an open-access resource. Enabling expansion and refinement of the model continuously as new solutions arise. In addition to this PAM will also be validated and further refined and adapted in collaboration with Daimler AG, which will be used as a case.

[8] http://www.mathematik.uni-ulm.de/sai/schneider/PAM_Soloutions.pdf.

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