Association for Information Systems
AIS Electronic Library (AISeL)

Research Papers

ECIS 2019 Proceedings

5-15-2019

BUSINESS PROCESS MODEL ANTI-PATTERNS: A BIBLIOGRAPHY AND TAXONOMY OF PUBLISHED WORK

Agnes Koschmider
Karlsruhe Institute of Technology, agnes.koschmider@kit.edu

Ralf Laue
Westsächsische Hochschule Zwickau, ralf.laue@fh-zwickau.de

Michael Fellmann
University of Rostock, michael.fellmann@uni-rostock.de

Follow this and additional works at: https://aisel.aisnet.org/ecis2019_rp

BUSINESS PROCESS MODEL ANTI-PATTERNS:
A BIBLIOGRAPHY AND TAXONOMY OF PUBLISHED WORK

Koschmider, Agnes, Karlsruhe Institute of Technology, Institute AIFB, Building 05.20, 76128 Karlsruhe, agnes.koschmider@kit.edu

Laue, Ralf, Department of Computer Science, Westsächsische Hochschule Zwickau, Zwickau, ralf.laue@fh-zwickau.de

Fellmann, Michael, Institute of Computer Science, University of Rostock, Rostock, michael.fellmann@uni-rostock.de

Abstract

Patterns have been proven to be useful for documenting reusable solutions to common problems. A recently published bibliography of business process model patterns shed light into the various types of patterns by providing a systematic categorization of these patterns. In this way, such classification improves the understanding of business process model patterns. Anti-patterns document a counterproductive solution to a commonly occurring problem. While a classification for the large body of literature on business process model patterns is available, a structured bibliography of anti-patterns is missing. Related work on anti-patterns discusses patterns for common modeling errors, problems in business process models as well as in the business processes. Modeling experts should be aware of all these types of anti-patterns. To fill this gap, this paper presents a bibliography of business process model anti-patterns and a taxonomy of anti-patterns that has been developed using an established approach for taxonomy development. Both are based on an literature review and are valuable for people during the design and analysis phases of business processes since knowledge about anti-patterns in business process models helps for increasing their quality. Our overview should also be useful for developers of modeling tools who wish to make the modeler aware of potential modeling problems.

Keywords: business process models, patterns, anti-patterns, taxonomy.

1   Introduction

According to Fellmann et al. (2018), *a business process model pattern is the description of a proven solution to a recurring problem that is related to the creation or modification of business process models in a specific context. This description is typically organized in a structured document supporting the reader in understanding under which circumstances the proposed solution will be useful.* For business process model patterns, a taxonomy and research classification exist (Fellmann et al., 2018). Modelers and researchers benefit from them by using the research classification and taxonomy in order to understand and compare existing literature on patterns, to apply patterns, and to have a collection of examples on how to publish new patterns.

The use of patterns in the field of software engineering goes back to the seminal work of Gamma et al. (1993). In this work, a pattern is a structured description of a reusable solution for software design. It is an important property of a pattern that its description follows a certain structure, which includes the pattern name, a description of the problem and a solution and consequences.

Anti-patterns, coined in 1995 by Andrew Koenig (Koenig, 1995), are solutions that are known to have deficiencies. In the domain of business processes, such patterns are also known as *weakness patterns* (Becker et al., 2010). They document commonly reinvented bad solutions to recurring problems (Israilidis et al., 2015). Anti-patterns are often recognized by the appearance of failures, which are identified during execution or system implementation (Long, 2001). Although it is known that the use of anti-patterns has disadvantages, they can frequently be found in practice as long as modelers are not trained to avoid them (Roa et al., 2012). Time pressure, failed design decisions and unforeseen changes might be reasons for the (unintentional) use of anti-patterns (Ouni et al., 2017). In the traditional sense of the word, an anti-pattern "*should not only be a bad solution, but also explains why this solution appears problem-solving and why it actually turns out to be a bad practice*" (Persson and Stirna, 2006, p. 46). For the purpose of this work, we use the term "anti-pattern" less strictly, which is in line with the use of this term by Koehler and Vanhatalo (2007). In order to get a broad overview on the topic, we also include patterns that should rather be called "error patterns". Those are patterns describing frequent errors and violations in business process models.

Some authors already suggested taxonomies for business process model anti-patterns (Döhring and Heublein, 2012; Mroczek & Ligeza, 2014; Vidacic & Strahonja, 2014, Suchenia et al., 2017). (Döhring and Heublein, 2012) is restricted to the special case of potential anomalies, which can occur when mixing graph- and rule-based business logic. (Mroczek and Ligeza, 2014, Suchenia et al., 2017) lists only the most basic BPMN modeling problems: syntactic errors and four kinds of control-flow problems (deadlock, lack of synchronization, dead activity and infinite loop). Both papers provide a narrower view on errors of business process modeling. (Vidacic and Strahonja, 2014) is the most concise work on categorizing problems in business process models. In addition to syntax erorrs and control flow issues, this work also discusses problems with decision rules, data flow anomalies and violations of naming conventions. However, these taxonomies were not grounded on a comprehensive literature review and did not contain a comprehensive list of references. Also, our taxonomy includes the categories discussed by (Vidacic and Strahonja, 2014) and discusses additional categories such as layout deficits and anti-patterns that suggests improvements in the process (not just into the process model), which have not been addressed previously.

Therefore, our paper presents a broader analysis of existing work on anti-patterns for business process models. It does not only contain a more comprehensive taxonomy of business process model anti-patterns but also (other than the papers mentioned before) an exhaustive reference of related work which is backed by methodological considerations and a structured literature review. The literature review was guided by the following two research questions:

1. **RQ1**: Which aspects are described and explained in business process model anti-pattern descriptions?

2. **RQ2**: Which types of anti-patterns seem to be common and which are underrepresented in the BPM domain?

To answer these research questions, we elaborated a structured bibliography and pattern taxonomy backed by methodological considerations with the following benefits:

- *Anti-pattern bibliography:* We provide the results of a literature review on business process model (BPM) anti-patterns. Currently, such an overview is lacking. Instead, publications are scattered in various journals and other publication types, and it can be difficult to find related work on anti-patterns that apply for a given context. Thus, this paper helps to compare and evaluate a pattern publication with existing ones.

- *Anti-pattern description*: There is no guideline for describing anti-patterns. Recommendations exist how to describe anti-patterns in general (Dodani, 2006). They, however, might require revision in order to fulfill properties related to BPM anti-patterns. Therefore, this paper aims supporting the understanding on how to best describe patterns in order to increase their dissemination. For this, the taxonomy served as a template for an online pattern repository pointing to ongoing and underrepresented topics: http://www.bpmpatterns.org

To answer both research questions, the rest of the paper is structured as follows. Section 2 describes the process and result of the structured literature review. A bibliography and classification of the literature is presented in Section 3 and the taxonomy of anti-patterns is explained in Section 4. Both sections give answers to **RQ1** and **RQ2**. Section 5 discusses implications and limitations of our findings. Finally, we summarize our work and give an outlook in Section 6.

2 Process and Results of the Literature Review

This section describes how the literature search, selection and classification for our bibliography presented in Section 3 was conducted. A preceding step of the literature search was the definition of inclusion and exclusion criteria:

- We considered publications between 1996 and November 2018, which is predefined by the first introduction of anti-patterns in 1996 and time of this literature review.

- We included only publications in English language. We were aware of a few sources in German language, but we realized that the authors of those papers published similar work in English as well.

- We considered anti-patterns related to business processes and business process modeling. Anti-patterns related to other domains such as software programming were excluded.

- If anti-patterns have been published in more than one version (e.g., in a revised version), we only considered the latest publication and excluded earlier versions.

In June 2018 and in November 2018[1] we searched the databases SpringerLink, IEEE Xplorer Digital Library, ScienceDirect and ACM Digital Library for related literature according to the recommendations by Webster & Watson, 2002. Additionally, we used Google Scholar to find appropriate literature by browsing the citations of related publications already found through scientific databases. Second, we conducted a backward search to find more appropriate publications cited in papers of the first search round. From our own previous work on the subject, we were already in possession of several papers that actually describe anti-patterns. From these papers, we realized that a great variety of phrases has been used to name what we are referring to as "anti-pattern": Design Flaw, Violation, BPEL Code Smell, Business Process Anomaly, Error Pattern, Quality Issue, Inconsistency, Structural

---

[1] The literature search was conducted in June 2018. In November 2018 we repeated the literature search in order to identify changes in the related literature.

Conflict, Correctness Issue, Structural Flaw, Weakness Pattern, Deadlock Pattern, Process Weakness, Heuristics for Detecting Problem, Modeling Mistake, Problems, Bad Smell and Business Bug Pattern. We considered all those phrases in our query. In addition, our search query included the phrases "attack pattern", "misuse pattern" and "vulnerability pattern" that are frequently used for security-related patterns. All phrases are subsumed in the search query below as "SynonymAntiPattern" (which also includes the terms anti-pattern and antipattern). We used the following query to identify related publications in English language:

("business process" OR "process" OR "BPMN" OR "workflow") AND (SynonymAntiPattern)

Two authors searched for related literature. Afterwards, the search results were collected and duplicate entries removed. The same two authors that performed the search defined characteristics and sub-characteristics for the publications. A publication that was characterized differently by the authors was discussed until a consensus on the characteristics was achieved. We always checked the first 100 hits for the query in each database. When there were more hits, we checked them as long as no matching publication could be found on three consecutive result pages. For the execution of the above query against a database, we applied a full-text search whenever possible to increase the recall. If this was not possible, we used title, abstract, and keywords as search fields. The search results were ranked according to the relevance criterion calculated by each search engine. The result list was cross-checked with two commonly known publications on BPM anti-patterns by (Pittke et al., 2015) and (Höhenberger and Delfmann, 2015) and publications suggesting anti-pattern taxonomies (Döhring and Heublein, 2012; Mroczek and Ligeza, 2014; Vidacic and Strahonja, 2014, Suchenia et al., 2017). We added 13 papers which were not found in the literature search, but were a priori known to the authors as explained above. Eventually, we ended up with 48 relevant publications.

The found literature was evaluated according to the process depicted in Figure 1. First, we classified the literature according to the basic bibliographic data:

- In which literature databases the paper can be found?
- In which year the paper has been published?
- In which type of publication (e.g., conference proceedings, journal) it has been published?

Second, we carefully read all papers and classified them in the three dimensions naming of patterns, type of definition and description schema as described in Sect. 3.
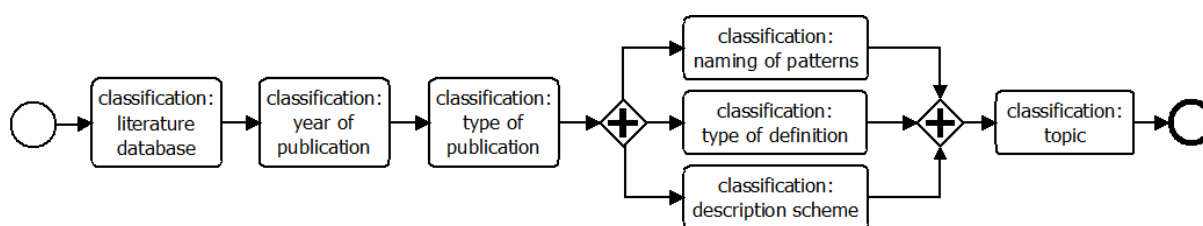

Figure 1. Process of analyzing the results of the structured literature search.

Finally, the last dimension in the classification refers to the topic the papers deal with (i.e. the type of problems the anti-patterns discuss). Following the guidelines of Nickerson et al. (2013), we created a taxonomy for those topics. In this paper we followed the same methodological consideration as described in Fellmann et al., 2018. The results for the basic bibliographic data were as follows: Related publications were found in the following databases: SpringerLink (40%), IEEE Digital Library (24%), ScienceDirect (10%) and ACM Digital Library (26%). The 48 publications were published in the following years: 2018 (4.2%), 2017 (6.3%), 2016 (16.7%), 2015 (12.5%), 2014 (8.3%), 2013 (4.2%), 2012 (4.2%), 2011 (2.1%), 2010 (10.4%), 2009 (10.4%), 2008 (8.3%), 2007 (4.2%), 2005 (2.1%), 2004 (2.1%), 2002 (2.1%), 1999 (2.1%). 77.1% of the papers on anti-patterns were published in workshop or conference proceeding, 18.8% in journals and 4.2% as technical reports.

3   Anti-Pattern Bibliography

To understand how anti-patterns are represented, we further analyzed the set of 48 publications with respect to the dimensions naming of patterns *Naming* (naming of patterns), *Definition* (type of definition) and *Description* (description scheme) (cf. Table 1).

Naming: This dimension refers to the names of the anti-patterns, being *descriptive* or *non-descriptive*. An example for non-descriptive names are pattern publications that simply number the anti-patterns.

Definition: This dimension refers to the way how the anti-patterns are made explicit. We differentiate between *textually, graphically* and *formal*. For some papers, more than one way of definition applies (e.g., textually and formally).

Description: This dimension reflects whether a *problem* and *improvement* is described in the anti-pattern text. Both are inspired by properties of patterns suggested by Gamma et al. (1993) which are problem, solution and consequences. However, in the case of anti-patterns, the problem and its consequence are heavily intertwined. In some cases, the (negative) consequence of an anti-pattern even seems to be more descriptive and recognizable than a detailed description of the problem source (e.g., in the case of the *Infinite loop error*-pattern, the pattern is named after the consequence rather than according to the source problem, which would be "no proper ending condition specified"). So we have opted to combine "problem" and "consequence" to a single column *problem*. The column *improvement* refers to a description how to gain improvements from the avoidance of the anti-pattern or how the application of an anti-pattern could be fixed.

Naming		Definition			Description includes		
descriptive	non-descriptive	textual	graphically	formal	problem	improvements	
X		X	X		X		Awad and Puhlmann (2008)
X		X		X	X	X	Awad et al. (2010)
X		X	X		X		Becker et al. (2010)
	X				X		Becker et al. (2011b)
X					X	X	Becker et al. (2012)
X			X		X		Bergener et al. (2015)
X		X	X		X		Borgert and Mühlhäuser (2014)
X		X	X		X	X	Corradini et al. (2017)
	X	X	X		X		Delfmann and Hübers (2015)
X		X	X	X	X		Eid-Sabbagh et al. (2012)
X		X	X		X		Eleftheriou et al. (2016)
X		X	X		X	X	Gruhn and Laue (2007)
	X	X	X		X		Gruhn and Laue (2009a)
	X	X	X		X	X	Gruhn and Laue (2009b)
	X	X	X		X	X	Gruhn and Laue (2010a)
X		X	X		X	X	Gruhn and Laue (2010b)
X			X	X	X		Han et al. (2013)
	X	X		X	X		Held and Blochinger (2008)
X		X	X		X		Höhenberger and Delfmann (2015)
X		X	X		X		Kim et al. (2009)
X		X	X		X	X	Koehler and Vanhatalo (2007)

							Reference
	X			X	X	X	Kurniawan et al. (2013)
X					X		Laue (2016)
X		X	X		X	X	Laue and Awad (2009)
X		X			X		Laue et al. (2016)
X					X		Leopold et al. (2016)
X					X	X	Leopold et al. (2017)
X		X	X	X	X	X	Lin et al. (2002)
X		X	X		X	X	Liu and Kumar (2005)
	X	X			X	X	Lübbecke et al. (2016)
	X	X			X	X	Lübbecke et al. (2018)
X		X	X		X		Mroczek and Ligeza (2014)
X		X	X	X	X		Onoda et al. (1999)
X		X	X		X		Palma et al. (2015)
X		X	X		X		Pittke et al. (2015)
X		X	X	X	X	X	Pfeiffer (2008)
	X		X		X		Ramadan et al. (2018)
X		X	X	X	X		Roa et al. (2015)
X		X	X	X	X	X	Roa et al. (2016a)
X		X	X		X		Roa et al. (2016b)
X		X	X		X		Roa et al. (2016c)
X		X	X	X	X		Roy et al. (2014)
X			X		X	X	Rozman et al. (2008)
X		X	X		X		Sadiq et al. (2004)
X		X	X		X	X	Silingas and Mileviviene (2011)
X		X	X		X		Suchenia et al. (2017)
X		X		X	X		Trčka et al. (2009)
X		X	X	X	X		von Stackelberg et al. (2014)

Table 1: Analysis of the anti-pattern literature.

4   Anti-Pattern Taxonomy

In this section we will present the taxonomy of business process model anti-patterns. It refers to the dimension that included the largest number of distinct values (or "characteristics" in the terminology of Nickerson et al., 2010). This was the dimension describing the type of problem that is discussed in the anti-pattern. It is the most useful dimension when one is looking for anti-patterns that apply to a certain kind of problem. To make it easier to search for and to compare publications on anti-patterns, we derived a taxonomy that classifies anti-patterns into 7 characteristics, some of which containing additional sub-characteristics. These characteristics (listed below) have been derived within 6 iterations and by review of three persons. Particularly, we merged characteristics in order to be compliant to Nickerson et al., 2013. Also, we renamed characteristics for the sake of its rigor description. Finally, the following characteristics of problem types were derived:

1. Syntax errors: This describes anti-patterns where the syntax of the process modeling language has been used wrongly and therefore the models are invalid (Rozman et al., 2008).

2. Control-flow problems: This describes anti-patterns with flaws related to the control-flow of the process model. In technical terms, this kind of problems can be subsumed as a violation of the soundness property (van der Aalst et al., 2011). This characteristic includes the following sub-characteristics:

2.1. Deadlock: These anti-patterns describe the attempt to synchronize two flows of the control of which at least one has not been activated before (Lin et al., 2002).

2.2. *Dead Activity*: These anti-patterns represent activities that can never be reached by the flow of control (Kim et al., 2009).

2.3. Infinite loop error: This describes anti-patterns which represent infinite loops, i.e. set of activities is executed infinitely often as no abort condition exists or the condition never becomes true.

2.4. Lack of synchronization error: These anti-patterns describe the unintentional multiple activation of activities (Lin et al., 2002).

2.5. Improper completion error: This describes an anti-pattern forcing the process to terminate prematurely (Koehler and Vanhatalo, 2007).

3. Understandability problems: This characteristic describes anti-patterns related to problems that make business process models difficult to understand and includes the following sub-characteristics:

3.1. Language deficit: This addresses incomplete, improper or ambiguous textual labels or labels that do not follow naming conventions.

3.2. Layout deficit: This relates to anti-patterns addressing the spatial layout of a model. This considers things such as the reading direction or the placing of model elements (spacing, overlapping, etc.).

3.3. Complexity: This addresses overly complex modeling by means of too large diagrams, too many elements of a certain kind or a missed chance to reuse frequently occurring sub-fragments of a model.

4. Composition defects: This characteristic describes anti-patterns relating to the collaboration between actors, e.g., the cooperation of human actors in groups, departments and institutions.

5. Data-flow-related defect: This characteristic describes anti-patterns related to data that can be created, edited, deleted, or stored wrongly. It includes violations of security and privacy requirements.

6. Rule-related defect: This characteristic contains anti-patterns related to business rules that are missing, redundant or conflicting or the input for the decision is missing (Döhring and Heublein, 2012).

7. Process-related defect: This describes anti-patterns that describe negative properties of the actual process (other than problems in the process *model*). Included are the following sub-characteristics:

7.1. Need for process improvements: This relates to weaknesses in the process that can lead to higher costs, longer processing time, lower quality or more errors. Examples for such problems are media disruption, inefficient or double work, and problems related to the organizational structure.

7.2. Compliance: This subsumes anti-patterns that describe the violation of rules established by law, organizational rules, or rules defined by standards.

7.3. Ecological impact: This describes anti-patterns that have a negative impact on the ecology. Examples are the negative impact on nature or the climate due to increased energy consumption or a waste of resources.

7.4. Communication defect: This describes anti-patterns that address the communication within the process model. For instance, the quality and structure of the transmitted information can be adversely affected if the communication channels are not standardized.

Table 2 shows the matching of the 48 papers describing anti-patterns on the taxonomy. Please note that some papers are mentioned more than once because they contain patterns belonging to more than one (sub)category. We can see from Table 2 that a large number of publications address the avoidance of control-flow flaws. This is in line with the high number of literature on verification techniques for business process models currently reported by (Fellmann, 2018). Also several anti-patterns have been identified related to the use of natural language in business process models and data-flow flaws. Less work has been published on avoiding composition flaws and the sub-characteristics related to ecological impacts. We expect that the latter will attract higher attention in the future (e.g., due to the increased interest on sustainability).

1.	***1. Syntax errors (7 papers):*** Kim et al. (2009), Leopold et al. (2016), Mroczek and Ligeza, (2014), Roy et al. (2014), Rozman et al. (2008), Silingas and Mileviciene (2011), Suchenia et al. (2017)
2.	***2.1. Deadlocks (17 papers):*** Awad and Puhlmann (2009), Borgert and Mühlhäuser (2014), Gruhn and Laue (2010a), Han et al. (2013), Kim et al. (2009), Koehler and Vanhatalo (2007), Laue and Awad (2009), Leopold et al. (2016), Lin et al. (2002), Liu and Kumar (2005), Mroczek and Ligeza, (2014), Onoda et al. (1999), Palma et al. (2015), Roa et al. (2016a), Roa et al. (2016b), Roy et al. (2014), Suchenia et al. (2017)
	2.2. Dead Activity (1 paper): Kim et al., 2009
	2.3. Infinite loop error (7 papers): Corradini et al. (2017), Gruhn and Laue (2010a), Eid-Sabbagh, (2012), Han et al. (2013), Kim et al. (2009), Koehler and Vanhatalo (2007), Laue and Awad (2009)
	2.4. Lack of synchronization error (16 papers): Corradini et al. (2017), Borgert and Mühlhäuser (2014), Gruhn and Laue (2010a), Han et al. (2013), Kim et al. (2009), Koehler and Vanhatalo (2007), Laue and Awad (2009), Lin et al. (2002), Liu and Kumar (2005), Mroczek and Ligeza, (2014), Palma et al. (2015), Roa et al. (2016a), Roa et al. (2016b), Roy et al. (2014), Silingas and Mileviciene (2011), Suchenia et al. (2017)
	2.5. Incorrect termination error (2 papers): Koehler and Vanhatalo (2007), Roa et al. (2016c)
3.	***3.1. Language deficit (12 papers):*** Delfmann et al. (2015), Höhenberger and Delfmann (2015), Gruhn and Laue (2009a), Gruhn et al. (2010b), Laue et al. (2015), Laue (2016), Pfeiffer (2008), Laue (2016), Leopold et al. (2016), Leopold et al. (2017), Pittke et al. (2015), Silingas and Mileviciene (2011)
	3.2. Layout deficit (2 papers): Leopold et al. (2016), Silingas and Mileviciene (2011)
	3.3. Complexity (11 papers): Becker et al. (2011), Gruhn and Laue (2007), Gruhn and Laue (2009b), Held and Blochinger (2008), Leopold et al. (2016), Silingas and Mileviciene (2011), Winkelmann and Weiß (2011), Rozman et al. (2008), Gruhn et al. (2009), Koehler and Vanhatalo (2007), Palma et al. (2015)
4.	***4.1. Collaboration defect (4 papers):*** Borgert and Mühlhäuser (2014), Eid-Sabbagh et al. (2012), Roa et al. (2015), Roa et al. (2016b)
5.	***5. Data-flow-related defects (9 papers):*** Avad et al. (2010), Eleftheriou et al. (2016), Höhenberger and Delfmann (2015), Koehler and Vanhatalo (2007), Palma et al. (2015), Ramadan et al. (2018), Sadiq et al. (2004), Trčka (2009), von Stackelberg (2014)
6.	***6. Rule-related defects (3 papers):*** Döhring and Heublein (2012), Koehler and Vanhatalo (2007), Laue et al. (2016)
7.	***7.1. Need for process improvements (11 papers):*** Becker et al. (2010), Becker et al. (2012), Bergener et al. (2014), Delfmann et al. (2015), Eleftheriou et al. (2016), Gruhn and Laue (2007), Held and Blochinger (2008), Höhenberger and Delfmann (2015), Laue et al. (2015), Kurniawan et al. (2013), Ramadan et al. (2018)
	7.2. Compliance (2 papers): Delfmann and Hübers (2015), Becker et al. (2011b)
	7.3. Ecological impacts (2 papers): Lübbecke (2016), Lübbecke (2018)
	7.4. Communication defects (2 papers):

Eleftheriou et al. (2016), Höhenberger and Delfmann (2015)

Table 2: Characteristics and sub-characteristics of anti-patterns' scope of application

5 Implications and Limitations

As a result of studying the numerous bibliographies on anti-pattern, we recommend to specify and document anti-patterns with the following characteristics. We believe that these characteristics improve the dissemination of an anti-pattern publication:

- A descriptive and precise name should be selected that points to the problem described by the anti-pattern and thus improves the discussions of the anti-pattern.

- A formal or graphical definition in addition to a textual one should be provided to support a consistent understanding and to restrict room for interpretation compared to a text-only definition.

- A problem should be formulated in order to understand the "suboptimal" (bad) solution of the anti-pattern. The problem should be enriched with a description of the consequences that are associated with the use of the anti-pattern and thus prevent from its use.

- The anti-pattern should not only present the questionable solutions but should also show a better solution that avoids the problems.

A limitation of our research is that − like most literature-based analyses − we cannot guarantee its completeness. However, since we have varied the search query and have used multiple databases, we are quite optimistic to not have overlooked major anti-patterns works. In some cases when the authors of identified papers did not explicitly use the term *anti-pattern*, we had to decide if the work under consideration qualifies as an anti-pattern work or not thus introducing a level of subjectivity (e.g., we omitted Kurniawan et al. (2013) for consideration). Such cases were discussed within the author team (all of them with 10+ years of research experience in BPM) until consensus was reached.

6 Conclusion

While numerous works on business process model patterns are available, a structured overview on anti-patterns is missing so far. Anti-patterns document a counterproductive solution to a commonly occurring problem. Based on an extensive literature review, we devised a bibliography of existing work on business process model anti-patterns and arranged the published anti-patterns in a taxonomy.

We are convinced that our paper is on the one hand useful for business process modeling practitioners during the design and analysis phases of business processes since the knowledge of anti-patterns helps to improve the understandability of business process modeling and to increase their quality. On the other hand, it is useful for researchers who have to acquire an overview on the current state of anti-pattern research and who are in need for sound literature references. In addition, it should be helpful for developers of modeling tools. Those tools can help the modeler by alerting if a potential use of an anti-pattern has been detected. Currently, there is no overview on existing literature on the subject. Instead, publications are spread in various journals and other types of publications. The terminology used in these publications differs. Hence, it is difficult to get an overview on the current literature on the subject even by searching scientific literature databases. To the best of our knowledge, our work is the first attempt to condense all related literature on the subject of anti-patterns for business process models.

For providing sound literature references for researchers as well as information for practitioners who want to learn about model anti-patterns, we provide a searchable online bibliography. It is available at www.bpmpatterns.org and contains both a comprehensive overview on literature on business process modeling patterns (our previous work) and the work on anti-patterns discussed here. Interested users can search for full paper names, papers that belong to one of the categories introduced in this paper,

183 additional manually added keywords and all 336 anti-pattern names mentioned in the literature. This should make it possible to find references to anti-patterns quickly.

For the future, relying on the classification and taxonomy of anti-patterns, possible directions are (1) to develop a procedure model aiming to avoid anti-patterns and thus to improve the business process model quality and (2) to discuss the development of techniques which automatically identify anti-patterns during business process modeling.

7 References

Awad, A. and F. Puhlmann (2008). "Structural Detection of Deadlocks in Business Process Models." *International Conference on Business Information Systems.* LNBIP, vol, 7, Springer, pp. 239–250.

Awad, A., G. Decker and N. Lohmann (2010): "Diagnosing and Repairing Data Anomalies in Process Models", *BPM Workshops 2009*, LNBIP 43, pp. 5-16, Springer.

Becker, J., P. Bergener, M. Räckers, B, Weiß, B. and A. Winkelmann (2010). "A Pattern-Based Semi-Automatic Analysis of Weaknesses in Semantic Business Process Models in the Banking Sector." *European Conference on Information Systems*

Becker, J., B. Weiß and A. Winkelmann (2011b) "Automatic Identification of Structural Process Weaknesses – Experiences with Semantic Business Process Modeling in the Financial Sector" *Wirtschaftsinformatik Proceedings 2011*.

Becker, J., P. Bergener, D. Breuker and M. Raeckers (2012). "An empirical assessment of the usefulness of weakness patterns in the business process redesign". *Europ. Conf. on IS*. 203.

Bergener, F., P. Delfmann, B. Weiss and A. Winkelmann (2015). "Detecting potential weaknesses in business processes: An exploration of semantic pattern matching in process models", Business Process Management Journal, 21(1): 25-54.

Borgert, S. and M. Mühlhäuser (2014). "Formal Based Correctness Check for ePASS- IoS 1.1 Process Models with Integrated User Support for Error Correcting." *6th International Conference on S-BPM ONE 2014*, Eichstätt, Germany, April 22-23, 2014.

Corradini F., F. Fornari, C. Muzi, A. Polini , B. Re and F. Tiezzi (2017). "On Avoiding Erroneous Synchronization in BPMN Processes." *Int. Conf. on BIS*. LNBIP, vol 288. Springer.

Delfmann, P., M. Steinhorst, H.-A. Dietrich and J. Becker (2015). "The generic model query language GMQL - Conceptual specification, implementation, and runtime evaluation." *Inf. Syst.* 47: 129-177

Delfmann, P. and M. Hübers (2015). "Towards Supporting Business Process Compliance Checking with Compliance Pattern Catalogues - A Financial Industry Case Study." *Enterprise Modelling and Information Systems Architectures*. 10(1): 67-88.

Dodani, M. (2006). "Patterns of Anti-Patterns". *J. of Object Technology*, vol. 5, no. 6, 2006, pp. 29-33

Döhring, M. and S. Heublein (2012). „Anomalies in Rule-Adapted Workflows - A Taxonomy and Solutions for vBPMN" *16th Europ. Conf. on Software Maintenance and Reeng.*, pp. 117-126

Eid-Sabbagh, R.-H., R. Dijkman and M. Weske (2012). "Business Process Architecture: Use and Correctness." *10th Int. Conf. on BPM*. LNCS: vol. 7481, Springer, pp. 65–81.

Eleftheriou, I., S. M. Embury and A. Brass (2016). "Data Journey Modelling: Predicting Risk for IT Developments" *The Practice of Enterprise Modeling Conference* 2016

Fellmann, M., A. Koschmider, R. Laue, A. Schoknecht and A. Vetter (2018). "Business Process Model Patterns: State-of-the art, Research Classification and Taxonomy." *Business Process Management Journal*, https://doi.org/10.1108/BPMJ-01-2018-0021

Gamma, E., R. Helm, R. Johnson and J. Vlissides (1993). "Design Patterns: Abstraction and Reuse of Object-Oriented Design." *7th European Conference on Object-Oriented Programming*.

Gruhn, V. and R. Laue (2007) Good and Bad Excuses for Unstructured Business Process Models, *12th European Conference on Pattern Languages of Programs*, Irsee Monastery.

Gruhn, V. and R. Laue (2009) Reducing the Cognitive Complexity of Business Process Models. *International Conference on Cognitive Informatics 2009.*

Gruhn, V., and R. Laue (2010a). "A Heuristic Method for Detecting Problems in Business Process Models". *Business Process Management Journal*, 16(5). 806–821.

Gruhn, V., and R. Laue (2010b). Detecting Common Errors in Event-Driven Process Chains by Label Analysis. *Enterprise Modelling and Information Systems Architectures*, Vol. 6, No. 1

Han, Z., P. Gong, L. Zhang, J. Ling and W. Huang (2013) Definition and Detection of Control-flow Anti-Patterns in Process Models. *IEEE 37th Annual Computer Software and Applications Conference Workshops 2013*. pp. 433-438

Held, M. and W. Blochinger (2008). "Structured Collaborative Workflow Design". Future Generation Comp. Syst. 25(6). pp. 638-653

Höhenberger, S. and P. Delfmann (2015) "Supporting Business Process Improvement through Business Process Weakness Pattern Collections". *Wirtschaftsinformatik* 2015: 378-392.

ISO 15910 (2013). "International Standard ISO/IEC 15910: Information technology - Object Management Group Business Process Model and Notation", Int. Organization for Standardization.

Israilidis, J., R. Lock and L. Cooke (2015). "Anti-patterns in knowledge management." *International Journal of Applied Systemic Studies*, 6(1): 26-41

Kim, G.-W., J. H. Lee and J. H. Son (2009). "Classification and Analyses of Business Process Anomalies." *International Conference on Communication Software and Networks*, pp. 433– 437.

Koehler, J., and J. Vanhatalo (2007). "Research Report - Process Anti-Patterns: How to Avoid the Common Traps of Business Process Modeling." *WebSphere Developer Technical*.

Koenig, A. (1995) "Patterns and Antipatterns." *J. of Object-Oriented Progr.*, vol. 8, no. 1, pp. 46-48.

Kurniawan, T. A., A. K. Ghose and L.-S. Le (2013). "Resolving Violations in Inter-process Relationships in Business Process Ecosystems". International Conference on Service Oriented Computing Workshops ICSOC 2012, LNCS 7759, pp. 332–343, 2013.

Long, J. (2001). "Software Reuse Antipatterns". ACM SIGSOFT Software Eng. Notes, 26(4), 68.

Laue R. and A. Awad (2009). "Visualization of Business Process Modeling Anti Patterns." *Proceedings of the Workshop Visual Formalisms for Patterns at VL/HCC 2009*, Electronic Communications of the EASST, vol. 25

Laue, R., W. Koop, and V. Gruhn (2016) "Indicators for Open Issues in Business Process Models." *22nd Int. Working Conf. on Req. Eng.: Foundation for Software Quality*. Springer LNCS vol. 9619

Leopold, H., J. Mendling and O. Günther (2016) "Learning from Quality Issues of BPMN Models from Industry." *IEEE Software* 33(4). pp. 26-33

Leopold, H., F. Pittke and J. Mendling (2017). "Ensuring the canonicity of process models". *Data & Knowledge Engineering* 111: 22–38.

Lin, H., Z. Zaho, H. Li and Z. Chen (2002) "A Novel Graph Reduction Algorithm to Identify Structural Conflicts." Proceedings of the 35th Hawaii International Conference on System Sciences

Liu, R. and A. Kumar (2005) "An Analysis and Taxonomy of Unstructured Workflows.". *International Conference on Business Process Management 2005*, pp. 268-284

Lübbecke, P., P. Fettke and P. Loos (2016) "Sustainability Patterns for the Improvement of IT-Related Business Processes with Regard to Ecological Goals." *BPM Workshops 2016*. pp. 428-439

Lübbecke, P., A. Goswami and P. Fettke (2018). "A method for Ecological Process Optimization based on Compliance Checking." *2018 IEEE 20th Conf. on Business Informatics*, IEEE press.

Mroczek, A. and A. Ligeza (2014). "A Note on BPMN Analysis. Towards a Taxonomy of Selected Potential Anomalies." *2014 Federated Conf. on Comp. Science and IS*, pp. 1097–1102.
.
Nickerson, R. C., U. Varshney and J. Muntermann (2013). "A method for taxonomy development and its application in information systems." *European Journal of Information Systems* 22, 3: 336–359.

Onoda, S., Y. Ikkai, T. Kobayashi and N. Komoda (1999) "Definition of Deadlock Patterns for Business Processes Workflow Models." *32nd Annual Hawaii Int. Conference on System Sciences*

Ouni, A., M. Kessentini, K. Inoue. and M. Ó. Cinnéide (2017). "Search-Based Web Service Antipatterns Detection." *IEEE Transactions on Services Computing*, 10(4): 603-617.

Palma, F., N. Moha and Y. G. Guéhéneuc (2015) "Specification and Detection of Business Process

Antipatterns." *E-Technologies - 6th International Conference* pp. 37-52

Persson A. and J. Stirna (2006). "How to Transfer a Knowledge Management Approach to an Organization – A Set of Patterns and Anti-patterns." *Practical Aspects of Knowledge Management*. LNCS, vol 4333. Springer.

Pittke F., H. Leopold and J. Mendling (2015). "When Language Meets Language: Anti Patterns Resulting from Mixing Natural and Modeling Language". *BPM Workshops*. LNBIP, vol. 202. Springer.

Pfeiffer, D. (2008) "Semantic Business Process Analysis - Building Block-based Construction of Automatically Analyzable Business Process Models." Doctoral Thesis, University of Munster.

Ramadan, Q., D. Strüber, M. Salnitri, V. Riediger and J. Jürjens (2018). "Detecting Conflicts Between Data-Minimization and Security Requirements in Business Process Models". *European Conference on Modelling Foundations and Applications 2018*, LNCS 10890, pp. 179–198, Springer.

Roa, J., O. Chiotti and P. Villarreal (2012). "A Verification Method for Collaborative Business Processes." *Business Process Management Workshops*. LNBIP, vol. 99, Springer.

Roa, J., O. Chiotti and P. Villarreal (2015). "Detection of Anti-Patterns in the Control Flow of Collaborative Business Processes." *Simposio Argentino de Ingeniería de Software*, pp. 100-114.

Roa, J., O. Chiotti and P. Villarreal (2016a). "Specification of behavioral anti-patterns for the verification of block-structured collaborative business processes." *Inf. and Software Techn.*, 75: 148-170

Roa, J., E. Reynares, L. M. Caliusco and P. D. Villarreal (2016b). "Ontology-Based Heuristics for Process Behavior: Formalizing False Positive Scenarios." *Business Process Management Workshops 2016*. LNBIP, pp. 106-117, Springer

Roa, J., E. Reynares, L. M. Caliusco and P. D. Villarreal (2016c). "Towards Ontology-Based Anti-patterns for the Verification of Business Process Behavior." *New Advances in Information Systems and Technologies - WorldCIST* (2):665-673

Roy, S., A. S. M. Sajeev, S. Bihary and A. Ranjan (2014) "An Empirical Study of Error Patterns in Industrial Business Process Models." *IEEE Transactions on Services Computing*, 7(2): 140-153.

Rozman, T., G. Polančič, and R. Vajde Horvat (2008). "Analysis of Most Common Process Modelling Mistakes in BPMN Process Models." *BPM and Workflow Handbook: Methods, Concepts, Case Studies and Standards in Business Process Management and Workflow*, pp. 233– 246.

Sadiq, S., M. Orlowska, W. Sadiq and C. Foulger (2004). "Data flow and validation in workflow modelling." *15th Austr. Database Conf.*, vol. 27. Austr. Comp. Society, Inc., Darlinghurst, pp. 207-214.

Silingas, D. and E. Mileviciene (2011). Refactoring BPMN Models: From 'Bad Smells' to Best Practices and Patterns in: Shapiro, R. et al.: *BPMN 2.0 Handbook, Second Edition*, Future Strategies, Incorporated

Suchenia, A., T. Potempa, A. Ligeza, K. Jobczyk and K. Kluza (2017) "Selected Approaches Towards Taxonomy of Business Process Anomalies." *Advances in Business ICT: New Ideas from Ongoing Research, Studies in Computational Intelligence* 658, Springer.

Trčka, N., W. M. P. van der Aalst and N. Sidorova (2009). "Data-Flow Anti-patterns: Discovering Data-Flow Errors in Workflows". *Conf. on Advanced IS Engineering (CAiSE) 2009*. pp 425-439

Vidacic T., and V. Strahonja (2014). "Taxonomy of Anomalies in Business Process Models." *Information System Development: Improving Enterprise Communication*, Springer.

van der Aalst, W.M.P., K. M. van Hee, A. H. M. ter Hofstede, N. Sidorova, H. M. W. Verbeek, M. Voorhoeve and M. T. Wynn (2011). "Soundness of workflow nets: classification, decidability, and analysis." *Formal Asp. Comput.*, vol. 23, no. 3, pp. 333-363.

von Stackelberg, S., S. Putze, J. Mülle and K. Böhm (2014). "Detecting Data-Flow Errors in BPMN 2.0". *Open Journal of Information Systems* (OJIS), 1(2), 2014.

Webster, J. and R. T. Watson (2002). Analyzing the Past to Prepare for the Future: Writing a Literature Review. MIS Quarterly, 26(2): xiii–xxiii.Winkelmann, A. and B. Weiß (2011) "Automatic identification of structural process weaknesses in flow chart diagrams." *Business Process Management Journal*, 17(5): 787-807.