A survey on modeling dynamic business processes

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Abstract

Dynamic and flexible systems offer huge advantages for businesses in addressing dynamic uncertain factors and implementing dynamic business processes (DBP). However, DBP remains a challenge from the perspectives of modeling, simulation, and implementation because of a nontrivial understanding of "*What is a dynamic business process?*". A variety of approaches for DBP modeling and implementation have been proposed over the past years, yet few comprehensive studies analyzing DBP from different particular perspectives (e.g., business process (BP) variability, aspect oriented BP, service compositions, etc.) and research questions that lay the foundation for the development of a meaning of a DBP have been reported. The motivation behind this review is to examine DBP meaning from a global perspective and, consequently, answer the previously presented research question. Therefore, in this paper, we present a systematic literature review (SLR) comprised of 67 papers from five respective digital libraries, which index Computer Science (CS), Information Systems (IS), and Software Engineering (SE) journals and conference proceedings. Two points of view are analyzed in the selected papers. First, we observe the similarities and differences between the proposed approaches to DBP modeling and implementation. From these observations, we define six main requirements for DBP (DBPR). In addition, the comparison of the selected papers according to DBPR shows that most of the approaches analyzed limit BP dynamicity, since they use partially predefined BP models. Secondly, we analyze the papers based on a visualization perspective that shows the less explored areas as follows: more flexible process modeling approach and its implementation in IS should be developed; usage of historic data should be extended; domain knowledge usage, like goal-orientation, multi-criteria optimization, domain knowledge, artificial intelligence, etc., should be included and extended to ensure BP dynamicity. As such, this study makes important contributions and serves as a useful resource for future DBP studies and practice. Moreover, we expect that our results could inspire researchers and practitioners towards further work aimed at bringing forward the field of DBP modeling and implementation.

Keywords

Dynamic business process; flexible business process; variable business process; declarative business process; adaptive business process; business process modeling; survey; systematic literature review.

Introduction

Business processes (BP) are dynamic due to the changing nature of their environment (van der Aalst, Pesic & Schonenberg, 2009; Pang et al., 2011; Vasilecas, Kalibatiene & Lavbič, 2016). This can include regulatory adaptations (e.g., changes in raw material prices), market evolution (e.g., stock price changes), changes in customer behavior (e.g., rapid change in customer needs), process improvement, enterprise policy shifts, and exceptions defined through business rules (BR). Therefore, as presented in (Pang et al., 2011), BPs must be able to support structural and functional changes, such as adding a new activity, substituting an activity, and changing the execution order of multiple activities. Consequently, the models that represent them should be able to reflect this dynamicity. However, classical BP models are intended to represent predefined processes that are more or less structured, and thus do not incorporate enough flexibility. Moreover, dynamic changes usually take place in a run-time environment, i.e., involve making changes "on the fly", and we cannot abort BPs and restart them from the beginning after changes. In this context, BP dynamicity is defined across a spectrum. This ranges from completely static BP (a dynamicity level of zero percent), where all activities and their sequences are predefined in the model without the possibility of changing them, to completely dynamic BP (a dynamicity level of 100 %), where each subsequent process activity is chosen from a predefined set of activities, or even defined as required (according to the internal or external context, or historical data) by rules.

Some level of dynamicity is represented by ad-hoc (Reichert & Dadam, 2009), agile (Gong & Janssen, 2012), flexible (Rosa et al., 2017; Reichert & Weber, 2012), adaptive (Reichert & Dadam, 2009), variable (Rosa et al., 2017), customizable (Rosa et al., 2017), declarative (Jimenez-Ramirez, Barba & Del Valle, 2018; Eshuis, 2018), and dynamic BP (Vasilecas et al., 2016). However, as outlined in (Gong & Janssen, 2012), the concepts of agility and flexibility overlap nevertheless, and in representing a system's ability to respond to environmental changes, agility has a stronger influence than flexibility on the characteristic of speed. According to (Pucher, 2010), dynamic BP are meant to be a variant of agile processes and enable a business user to make changes in the process at run-time, e.g., by selecting a different sub-process at predefined decision points. Author of (Kiedrowicz, 2017) has noted that dynamics are obtained during process implementation, with an initially non-defined form of such processes completely or in part. In (Vasilecas et al., 2016a), authors define dynamic BP as a set of activities, which might change at a certain point in time due to the changes occurring in the BP context. Therefore, in dynamic BP a sequence of activities cannot be predefined in advance. According to some (Rosa et al., 2017; Reichert & Weber, 2012), processes in which customization decisions are made at run-time are known as flexible processes.

81   According to (Rosa et al., 2017), variable BP models families of BP variants, where a family of
82   BP variants is presented via a single model, from which each variant can be derived via certain
83   transformations of the model. Moreover, Rosa et al. (2017) have named a consolidated model of
84   process variants by concept customizable process model, from which the individual variants can
85   be derived via transformations, for example, adding or deleting fragments. Decisions between
86   process variants can be made either at design time or during run-time. A design-time
87   customization affects all instances of the customized process executed in this setting. In contrast,
88   a run-time customization is punctual and affects only one or very few process instances.
89   However, all types of variable processes have predefined process models. A variable BP consists
90   of variable and non-variable segments and only the variable segments of a process could be
91   changed (Alférez et al., 2014), at run-time. In (Aiello et al., 2010), authors remark that variability
92   is very closely related to flexibility. Flexibility offers adaptation and the potential change of a
93   process, whereas variability deals with different versions of a process.
94   According to some (Jimenez-Ramirez, Barba & Del Valle, 2018; Eshuis, 2018), declarative
95   models specify what should be done without specifying how it should be done. Authors of
96   (Goedertier, Vanthienen, & Caron, 2015) state that these models specify a set of constraints,
97   BRs, event conditions, or other (logical) expressions that define the properties of, and
98   dependencies between, activities in a BP. So, BP instances are constructed according to
99   predefined BRs and do not violate them. These rules restrict the final execution path without
100   defining the process model. Authors of (Eshuis, 2018) states that declarative artifact-centric
101   process models, which present *knowledge-intensive* processes, use BRs that define how
102   knowledge experts can make progress in a process. However, in many business situations
103   knowledge experts have to deal with uncertainty, which cannot be modelled by BRs in a classical
104   way, assuming clear-cut boundaries between di☐erent states of the world. Therefore, in (Eshuis,
105   2018), the author proposes to model uncertain situations using fuzzy logic and to extend
106   declarative artifact-centric process models with fuzzy sentries.
107   Declarative BP modeling approaches are based on rules, such as (Eshuis, 2018; Zugal et al.,
108   2015), etc. However, as stated in (Goedertier, Vanthienen & Caron, 2015), the differences
109   between declarative BP modeling approaches lie in a different perception of main elements as
110   the following. Business concerns, including the ConDec language (Pesic & van der Aalst, 2006;
111   Pesic, Schonenberg & van der Aalst, 2007), and the PENELOPE language (Goedertier &
112   Vanthienen, 2006), only allow the expression of BRs relating to sequence and timing constraints,
113   i.e., the control flow aspects (Heinl et al., 1999). The state space describes a discrete set of
114   relevant BP states in terms of the entity types that occur in that space, such as the event history in
115   ConDec and the system time in PENELOPE. Constraint types in ConDec express temporal
116   constraints that must hold between activities in a trace, and PENELOPE discusses business
117   constraint types that are essentially temporal deontic assignments. Knowledge representation and
118   reasoning paradigms can also differ, like Linear Temporal Logic (LTL) in ConDec and the Event
119   Calculus in PENELOPE.

120   In summarizing the definitions above, some authors use terms such as "adaptive" and "flexible"

121   as synonyms, whilst others hold those concepts as distinct. Therefore, there is still some

122   uncertainty around which approach maps to which level of dynamicity of a BP. Consequently,

123   one of the objectives of this research is to analyze the level of dynamicity achieved in the

124   proposed approaches, and thereafter the subsequent degree of implementation achieved. So, the

125   main research questions of this study are the following:

126   RQ1: *What level of dynamicity is achieved by the existing approaches?*

127   RQ2: *What are the differences between approaches to modeling dynamic BP?*

128   RQ3: *What are the features of a dynamic BP?*

129   RQ4: *What are the general limitations or research gaps that exist in the literature on dynamic*

130   *BP modeling that may require further work?*

131   RQ5: *What literature reviews on BP dynamicity are known?*

132   RQ6: *What are the levels of description and refinement of the BP dynamicity approaches*

133   *analyzed?*

134   A comprehensive state-of-the-art review is needed to better understand the current state of

135   knowledge in the field of dynamic BP (DBP), and to answer the questions formulated. Although

136   there are a number of scattered studies reviewing different approaches to achieving some level of

137   dynamicity, there is a need to analyze them collectively, and thus to obtain a global view of

138   modeling such BP. Put simply, there is a need to compare levels of dynamicity of BP.

139   Therefore, this paper draws together a systematic literature review (SLR) of approaches to

140   modeling BP with some level of dynamicity, identifies and classifies main approaches in the

141   field, and provides a comparative evaluation.

142   **Rationale for the review**

143   Nowadays, BP are dynamic due to the changing nature of their environment, which include

144   regulatory adaptations (e.g., changes in raw material prices), market evolution (e.g., stock price

145   changes), changes in customer behavior (e.g., rapid change in customer needs), process

146   improvement, enterprise policy shifts, and exceptions defined through business rules (BR).

147   Therefore, BPs must be able to support structural and functional changes. However, classical BP

148   models are intended to represent predefined processes that are more or less structured and do not

149   incorporate enough flexibility. Moreover, dynamic changes usually occur in a run-time

150   environment, and we cannot abort BPs and restart them from the beginning after changes. Some

151   dynamicity level is represented by ad-hoc, agile, flexible, adaptive, variable, customizable,

152   declarative, and dynamic BP (DBP). However, there is still some uncertainty around which

153   approach maps to which level of dynamicity of a BP. In the absence of a clear understanding of

154   what is DBP, a comprehensive analytical study is necessary. This SLR provides a clear and

155   comprehensive overview of the available evidence. In addition, our work helps to identify

156   research gaps in our current understanding of the field. The objective of this review is to provide

157   a basis for the developers of DBP models. Our findings laid the foundation for intelligent BP.

158   **Intended audience**

159 The article is intended to support academic and industry researchers working on DBP. We expect
160 that our results inspire researchers and practitioners for further work aiming at bringing forward
161 DBP modeling and implementation.
162
163 The remainder of this paper is organized into a number of sections. Section 2 presents the scope
164 of the survey by defining the main terms and concepts associated with BP and their level of
165 dynamicity. Section 3 presents related works and existing literature reviews on BP and different
166 levels of dynamicity. Section 4 describes the research method used for the analysis of BP with
167 different levels of dynamicity. Sections 5 presents the results of the analysis performed on the
168 basis of the method defined in the previous section. In Section 6, we discuss the results of the
169 analysis and answer the research questions. Section 7 then concludes the paper.

170 The scope of the survey

171 A number of approaches propose different ways of modeling and implementing dynamic BP.
172 Their differences lie in their understandings of the concept of dynamic. Therefore, we start our
173 survey with the concepts used to define what it is to be dynamic.

174 The definition of the term "dynamic"

175 In different dictionaries, the term dynamic is understood as *continuously moving or changing*[1] or
176 *constant change or motion*.[2] A dynamic process is therefore one that *constantly changes and*
177 *progresses*[3] – a process of agile change, action, and/or progress.[4] According to IGI-Global
178 dictionary[4] and authors of (Reichert & Dadam, 2009), dynamic process change "refers to a
179 (structural) change that is applied to the schema of a running process instance during run-time.
180 After the change, process execution continues based on the new schema version of the process
181 instance." Ad-hoc process change refers to a process change which is applied in an ad-hoc
182 manner to a given process instance, and is necessary to deal with exceptions or situations not
183 anticipated at the process design stage (Reichert & Dadam, 2009). Adaptive process refers to the
184 ability of the process-aware information system (PAIS) to dynamically adapt the schema of
185 ongoing process instances during run-time. As presented in (Reichert & Dadam, 2009), process
186 schema evolution "refers to the continuous adaptation of the schema of a particular process type
187 to cope with evolving needs and environmental changes." The need for a dynamic change is
188 detected in long-running processes, and then becomes necessary in order to migrate already
189 running process instances to the new schema version (Reichert & Dadam, 2009). According to
190 Oracle,[5] a dynamic process is a collection of activities or tasks without a predetermined sequence
191 of execution. It provides flexibility for knowledge workers to define the process flow at run-time
192 based on the information available to them. Oracle allows the creation of a dynamic process by
193 selecting a particular pattern or starting from scratch. In addition, a user should define all

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[1] https://www.ldoceonline.com/dictionary/dynamic
[2] https://www.yourdictionary.com/dynamic
[3] https://www.collinsdictionary.com/dictionary/english/dynamic
[4] https://www.igi-global.com/dictionary/dynamic-process/69549
[5] https://docs.oracle.com/en/cloud/paas/integration-cloud/user-processes/create-dynamic-process1.html#GUID-99737D0A-DF4C-484E-820A-D30108073951

194 activities that can be used within a dynamic process. During run-time, knowledge workers decide
195 the course of activities in a dynamic process, start and complete activates, assign activities to
196 roles, and complete and close process instances. Moreover, each dynamic process has milestones
197 that are sub-goals defined within a process, and are used to track progress.
198 A BP model can be seen as a scheme defining the "algorithm" of process execution (van der
199 Aalst, Weske & Grünbauer, 2005). During the execution of a BP, the system uses the BP model
200 as a "recipe" to determine the sequence of activities to be executed. A BP model is described by
201 a specific BP modeling language, such as BPMN, which plays a determining role in the way that
202 the prescribed process can be executed. The weaker this prescription is, the easier it is to deviate
203 from the predefined process (Pesic & van der Aalst, 2006). However, most process models
204 enforce the prescribed procedure without deviations. Flexible BP should allow users to deviate
205 from the prescribed execution path (Pesic & van der Aalst, 2006; Heinl et al., 1999).
206 Authors of (Vasilecas, Kalibatiene & Lavbič, 2016) propose distinguishing BP modeling
207 approaches according to *the levels of dynamicity*. The first and lowest level of dynamicity is
208 described as using *decision points*, in which a human or an automated system decides what to do
209 next according to predefined rules. Almost all of today's approaches and tools implement this
210 level of dynamicity. The second, middle level of dynamicity is understood as the ability to
211 *automatically configure* BP, like choosing an alternative template or paths for processing
212 activities, or changing activities or their execution order in a process when context changes. Most
213 of today's approaches fall within this level of dynamicity, a good example of which is the use of
214 variable models (Rosa et al., 2017; Alférez et al., 2014; Milani et al., 2016). The third and
215 highest level of dynamicity is achieved in the case of, for example, a *goal-driven* BP that can be
216 changed at run-time according to the new conditions and the customer's needs, as in (Vasilecas
217 et al., 2016). Therefore, these BP have no predefined sequence of activities. Summing up the
218 defined dynamicity levels, they depend on the ability to create a BP instance according to the
219 predefined BP model, or conversely to define specific activities and their sequences at run-time.
220 **Approaches to achieving dynamicity of BP**
221 All of the processes mentioned previously (i.e., ad-hoc, agile, flexible, adaptive, variable,
222 customizable, declarative, and dynamic) can be context-sensitive, rule-based, event-based,
223 policy-based, case-handled, etc. According to (Saidani & Nurcan, 2006; Nunes, Werner &
224 Santoro, 2011), a context-aware, or *context-sensitive*, process is able to adapt BP instances at
225 run-time to the changing context, which is defined by the minimum values of the variables that
226 contain all relevant information that impacts the design and execution of a BP (Rosemann &
227 Recker, 2006). In (Coutaz et al., 2005), a context is a set of entities, a set of roles that entities
228 may satisfy, a set of relations between the entities, and a set of situations that denote specific
229 configurations of entities, roles, or relations. Moreover, context can be internal and external. An
230 internal context is represented by the state of resources in a system, such as the availability raw
231 materials, and an external context is represented by the state of a system environment, such as
232 the price of raw materials in the market, as defined by a set of variables. Existing approaches
233 allow for the definition of one type of context individually: internal, as with the current state of

234   system resources in (Hu, Wu & Chen, 2014), or external (Saidani & Nurcan, 2006; Nunes,
235   Werner & Santoro, 2011; Mejia Bernal et al., 2010) only, without considering both.
236   In *rule-based* BP, rules can describe different aspects by ensuring some level of BP dynamicity.
237   For example, the authors use rules to define the relationships between events, which caused
238   during BP execution when changing a state of resources, and to filter the interesting ones in their
239   proposed CEVICHE architecture (Hermosillo, Seinturier & Duchien, 2010). When an event that
240   is important for BP adaptation is detected, the Complex Event Processing (CEP) engine notifies
241   the responsible component to adapt the BP (instance or model) with the corresponding activity at
242   run-time. Authors of (Milanovic, Gasevic & Rocha, 2011) use BR patterns to enrich BP in terms
243   of possible cases and to increase BP flexibility. Pesic & van der Aalst (2006) use constraints to
244   define relationships among tasks in their proposed ConDec language. At every moment during
245   the execution of a process model, there is a judgement about whether or not the model satisfies
246   the defined constraints. In (Mejia Bernal et al., 2010), the authors propose deconstructing BP into
247   an ECA (Event-Condition-Action) rule set and adapting it to the external context data, describing
248   user's priorities to provide a service. The authors describe expressing transitions between
249   activities in the form of ECA rules, where an event is generated when an activity has finished its
250   execution, a condition used to verify which workflow part is enabled, and where a rule action
251   determines the next activity that has to be executed. The adaptation at run-time is then
252   performed. All processes have a strictly defined sequence of activities, and this sequence of
253   activities can be changed according to the defined set of rules (Mejia Bernal et al., 2010).
254   Here, based on the related works, we can summarize that BRs can ensure the dynamicity of a BP
255   as follows: 1) each activity in a process is selected according to the defined conditions at BP run-
256   time, and 2) the content of an activity is chosen based on the changing internal and/or external
257   context. However, the rule-based approaches reviewed above do not cover both of these aspects.
258   In some papers (Xiao et al., 2011), process dynamicity is ensured through predefined *process*
259   *fragments* and the defining of their relationships, which are specified in a constraint-based way.
260   The *policies* contain a set of rules to select, whereby concrete fragment implementations will be
261   used in the BP. Processes are dynamically generated based on constraints and adaptation policies
262   according to their operating environments. Process fragments provide a modularized view on
263   process models (Xiao et al., 2011). Consequently, the process can be changed at run-time by
264   adding, substituting, or removing fragments, or modifying their relationships, which allows the
265   process to be adapted dynamically. In some cases, this *policy-based* approach is similar to a rule-
266   based approach, since a process schema is composed from fragments, the relationships between
267   which are specified by the predefined rules. In addition, other researchers propose to ensure
268   some level of BP dynamicity through an *event-based* approach (Hermosillo, Seinturier &
269   Duchien, 2010; Hermosillo, 2012), which is discussed previously, as it uses rules to combine
270   events into one complex one. Those complex events are necessary to notify the responsible
271   component, which in turn searches for the corresponding aspect to adapt the BP.
272   In (van der Aalst, Weske & Grünbauer, 2005), the authors proposed a *case handling* paradigm
273   for supporting flexible and knowledge intensive BP, which are based on data. As the authors

274   state, case handling focuses on what can be done to achieve a business goal. The central concepts
275   in a case handling approach are the case and its data as opposed to the activities and routing rules
276   in traditional workflow[6] management systems. Usually, case-handled systems present all data
277   about a case at any time to the user. In such systems, many cases can be handled in parallel and
278   these cases are logically independent. According to (Mutschler, Weber & Reichert, 2008), in
279   case-handling a system is more flexible compared to a workflow management system, since
280   there is no error-prone "context tunneling" as in workflow based approaches. The case-handling
281   paradigm is considered as "a more flexible approach" because users work with whole cases and
282   can, for different reasons, modify the predefined process model (van der Aalst, Weske &
283   Grünbauer, 2005).
284   Authors of (Sabatucci & Cossentino, 2019) views dynamic workflows as a promising approach
285   to provide flexible BP execution in the dynamic business environment. Their main contribution
286   is an automated procedure to extract implicit goals from a BPMN workflow description. This
287   study is highly dependent on BPMN workflows, functional dimension of workflows, and
288   availability of services, which implement workflows. Comparing, in this review, we concentrate
289   on dynamic changes at the business level, but not at the implementation level, as presented in
290   (Sabatucci & Cossentino, 2019).

291   **The definition of a dynamic BP (DBP)**

292   This research focuses on different approaches to achieving BP dynamicity. Therefore, we present
293   a study allowing us to determine what level of dynamicity is achieved by various approaches.
294   Moreover, for our survey we are going to use the definition of a dynamic BP (DBP) as follows.

295   **Definition 1:** A **dynamic business process** (DBP) is a process that is able to support structural
296   and functional changes (i.e., has no predefined activities nor sequence of activities) at DBP
297   instance run-time according to its context and rules, and that can be implemented with minimal
298   delay.

299   A **context** refers to an internal context and an external context of DBP. As outlined in a number
300   of papers, an external context is a set of variables and context rules defining a particular state of
301   the environment. If the current state of the environment changes, then the external context also
302   changes. An internal context is the current state of system resources. If the current state of
303   system resources changes, then the internal context also changes.

304   According to the DBP definition, the DBP requirements (DBPR) adopted from (Vasilecas,
305   Kalibatiene & Lavbič, 2016) are defined as the following:

306   DBPR-1. DBP should not have a predefined sequence of activities.
307   DBPR-2. DBP should react to the change of the context.
308   DBPR-3. Every subsequent activity should be selected according to predefined rules and a
309   context. If there is no activity for further execution, it should be possible to do the following:
310   3.1. to terminate the execution of a DBP instance; or
311   3.2. to define a new activity and related rules for a DBP instance execution.

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[6] As defined in (Zur Muehlen, 2004), a workflow is a formal, or implementation-specific, representation of a BP.

312   DBPR-4. DBP changes can be initiated by any role involved, at any time, with possibly low
313   latency compared to a DBP execution time.
314   DBPR-5. Before selecting the next activity, the historical data detailing instances of execution of
315   the same DBP should be analyzed and the next activity selected should not cause the execution
316   of an unacceptable sequence of activities, as defined by prior experience.
317   DBPR-6. DBP execution should align with a particular business goal.
318   We argue that DBP is a BP which meets all of the requirements presented. Implementing all six
319   requirements provides more freedom in BP modeling. However, this freedom can be constrained
320   by adding BRs, which depend on the requirements of the application domain. Moreover, the
321   advantage of implementing the proposed requirements is that it allows DBP to be goal-oriented.

322   Related works

323   Using the research strategy presented in the "Survey methodology" section, we have identified a
324   number of existing literature reviews on BP dynamicity. There are a number that align closely
325   with our research (Rosa et al., 2017; Pourshahid et al., 2012; Ayora et al., 2015; Cognini et al.,
326   2014; Cognini et al., 2018; Kapuruge, Han & Colman, 2010; Goedertier, Vanthienen & Caron,
327   2015).
328   Authors of (Rosa et al., 2017) present a survey of papers on BP variability modeling by aiming
329   to identify the commonalities and differences of approaches, criteria to select between different
330   approaches, and research gaps that exist in the literature. As the authors identified, a standard
331   process model is extended to capture process variants into a customizable process model. A
332   model of each variant can be changed by adding or deleting process model fragments according
333   to the context. The authors assessed their identified approaches using the 14 criteria described in
334   their paper and produced a report that identified a number of gaps in these approaches. Firstly,
335   they recognized a lack of effective methods and tools to support and assist users in the creation,
336   use, and maintenance of the proposed approaches, leading to their limited adoption in practice.
337   Another gap was that around half of the approaches reviewed have been validated through case
338   studies. As the authors noticed, there is a lack of comparative empirical evaluations with end-
339   users, which might provide evidence that one variability modeling approach is more usable than
340   others in a particular setting. Though the paper presents very detailed analysis of the state-of-the-
341   art, the authors do not present their survey method, which differs from others presented in
342   literature reviews, such as (Ivarsson & Gorschek, 2011). Moreover, there is no access to the
343   appendices of the research, where some important information about the survey is presented.
344   Therefore, not all of the criteria that is outlined can be understood completely.
345   Pourshahid et al. (2012) present SLR on aspect-oriented approaches for BP adaptation. They
346   have observed that current methods focus on the following: 1) composing and swapping services
347   based on Quality of Service, cost, rules, policies, and constraints, as well as in the event of
348   failure; 2) extracting roles and cross-cutting concerns from composite services; 3) customizing
349   process instances based on user profiles or Service Level Agreements; 4) adapting service
350   composition and collaboration policies; and 5) using monitoring aspects to detect undesired
351   situations. As a result of the review, authors proposed their own aspect-oriented process

352   modeling and adaptation framework, which considers organizational goals, performance, and
353   constraints as a whole when improving BP. The main limitation of the (Pourshahid et al., 2012)
354   study is that it focuses on service-based BP adaptation, i.e., implementation level of BP.
355   Authors of (Ayora et al., 2015) present an evaluation of variability support in process-aware
356   information systems (PAIS). Based on the results of their literature review, the authors presented
357   the VIVACE framework, which allows for the systematic assessment and comparison of existing
358   approaches to process variability. As the authors state, VIVACE enables process engineers to
359   select the variability approach that best meets their requirements, as well as helping them in
360   implementing PAIS supporting process variability. Specifically, VIVACE comprises a core set
361   of variability-specific language constructs and a core set of features that foster process variability
362   along the process lifecycle. These constructs allow the assessment of the expressiveness of
363   existing process variability approaches regarding the modeling of process variability. Despite the
364   advantage of the (Ayora et al., 2015) study and the detailed analysis of BP, this study is limited
365   to variable BP only.
366   Authors of (Cognini et al., 2014) present a literature review on BP adaptation by aiming to find
367   what raises the need for adaptation within the BP domain, which BP life cycle management
368   phases require support for adaptation, which are the instruments used to express and support BP
369   adaptation, whether there are any real experiences of BP adaptation, and what the challenges
370   associated with the BP adaptation are. Whilst the authors have identified a large amount of
371   interest in the analised topic, there are some gaps left in the research, namely the lack of
372   application of research results to real BP adaptation scenarios. They identified just three real BP
373   adaptation scenarios: the car logistic of the seaport of Bremen (Germany) (Bucchiarone, Mezzina
374   & Pistore, 2013), the warehouse management (Marconi et al., 2009), and the clinical (Dadam &
375   Reichert, 2009) scenarios. Other main issues associated with the BP adaptation include: the need
376   for dynamic languages for BP modeling; current languages for BP modeling failing to support
377   adaptation constructs; the adaptation of BP running instances; the verification of adapted BP; and
378   evolving BP.
379   In (Kapuruge, Han & Colman, 2010), authors have analyzed BP flexibility in the scope of
380   service composition according to the following criteria: 1) process definition flexibility
381   according to the possibility of BP modifications during the analysis and design phases; 2)
382   process instance flexibility according to the possibility of process instance change at run-time; 3)
383   services relationship flexibility according to a service composition in terms of the relationships
384   among the different entities of the composition. During the survey, the authors found that there is
385   a lack of support for modeling service relationships, which describes the mutual obligations,
386   constraints, etc., in defining the BP of a service composition. Compared to the current study,
387   (Kapuruge, Han & Colman, 2010) focuses on and is limited to the BP flexibility in the scope of
388   service composition.
389   Authors of (Cognini et al., 2018) present a literature review on BP flexibility with a focus on
390   software systems related aspects. They define flexibility as the ability to properly manage the
391   coordination between challenges in organizational aspects and technical environments, and their

392   changes. The authors' literature review is based on the guidelines presented in (Kitchenham,
393   2007). The results obtained have confirmed the increasing relevance of the BP flexibility topic,
394   aided by the authors' analysis of papers on BP flexibility over a broader timescale, ranging from
395   2000 to 2015. As the authors have found, flexibility issues influence all BP life-cycle stages.
396   Whilst there are a number of approaches proposed to support BP flexibility, there is still a lack of
397   application of the proposed approaches in concrete and complex cases. Moreover, the authors
398   identified several research directions in this field that require further investigation. They are as
399   follows: modeling languages for flexibility implementation in BP; verification of the flexible BP
400   model; adaptation of BP instances at run-time; and evolving BP.
401   In (Goedertier, Vanthienen & Caron, 2015), authors focused on the literature review of
402   declarative BP modeling principles and languages. They have chosen eight declarative process
403   modeling approaches and languages with distinct declarative specifications, such as BPCN (Lu,
404   Sadiq & Governatori, 2009), ConDec (Pesic & van der Aalst, 2006), etc. These approaches are
405   compared according to the state space, which is a specific configuration of the facts about
406   entities (e.g., BP activities) in a state space corresponding to a specific context of a BP, the
407   transition types among states, and rules (e.g., transition rules). As the authors stated, the
408   approaches that they analyzed differ mainly on the matter of interests, because approaches were
409   developed to represent some reality, as with the ConDec language, which expresses BRs only
410   about sequence and its items' timing constraints. Other differences lie in a differing
411   understanding of a state space, constraint types expressing different ways of transitions, and
412   knowledge representation and reasoning paradigms, which use additional different ontologies.
413   Moreover, as the authors have concluded, flexibility costs money, and therefore the efficiency of
414   executing declarative models may be complicated. This is because of the extended possibilities
415   of choosing suitable execution paths, managing BRs, etc.
416   In drawing this together, it is evident that the surveys that were analyzed examine BP dynamicity
417   from different perspectives. These include: variability (Rosa et al., 2017; Ayora et al., 2015);
418   aspect-oriented and services based (Pourshahid et al., 2012); service compositions (Kapuruge,
419   Han & Colman, 2010); flexibility (Cognini et al., 2014; 2018); and declarative (Goedertier,
420   Vanthienen & Caron, 2015). Therefore, the results obtained and conclusions drawn by the
421   authors are limited to their particular respective areas. Consequently, there is a need for more
422   general studies in the area of BP dynamicity. In this study, however, we are not going to compete
423   with existing studies but to supplement them in terms of both time and the scale of their scope.
424   The main advantage of the current study is that it provides the analysis of a DBP meaning from a
425   global perspective.

426   ## Survey Methodology

427   In this section, a research method is presented that begins with a brief literature review of papers
428   published on DBPs, proceeds to a detailed review of the refined set of papers, and ends with
429   conclusions. The research method schema is presented in Figure 1, and is adapted from (Ivarsson
430   & Gorschek, 2011; Kitchenham, 2007; Kitchenham et al., 2009).
431

432   Figure 1. The research method schema

433

434   **The list of searching sources**

435   As the study is focused on BP dynamicity, i.e., BP modeling approaches and their

436   implementation into software systems, relevant papers should be searched in databases covering

437   Computer Science (CS), Information Systems (IS), and Software Engineering (SE). Due to

438   technical limitations only free access sources were chosen, of which there were a limited number

439   (see Table 1). However, the initial study of sources shows that they contain a significant number

440   of papers relevant to the research questions.

441

442   Table 1. List of sources

443

444   **A search query and keywords**

445   According to the scope of the survey, keywords and a search query were defined. First, we

446   defined the main keywords taking into account synonyms and terms related to each of the three

447   concepts, as shown in Table 2.

448

449   Table 2. Keywords used for the search

450

451   Other search terms – such as agile, ad-hoc, or customizable – were not used as keywords for the

452   search. Adding those terms increased the number of papers found, but additional papers did not

453   expand the knowledge provided on the research topic. They were excluded from the search but

454   are still found together with the keywords used. The scope of the survey shows that our search

455   query results cover the topic of BP dynamicity. The proximity operator, i.e., *, was used to find

456   more relevant results by allowing variations of the same terms, for example business process and

457   business processes, dynamic and dynamicity, dynamical, etc.

458

459   Secondly, the queries were combined from the keywords using Boolean operators as follows.

460   **SQ1:** ("dynamic* business process*" OR "business process* dynamic*" OR "dynamic* in

461   business process*" OR "dynamic* BP" OR "BP dynamic*" OR "dynamic* in BP")

462   **SQ2:** ("flexib* business process*" OR "business process* flexib*" OR "flexib* in business

463   process" OR "flexib* BP" OR "BP flexib*" OR "flexib* in BP")

464   **SQ3:** ("variab* business process*" OR "variab* in business process*" OR "business process*

465   variab*" OR "variab* BP" OR "variab* in BP" OR "BP variab*")

466   **SQ4:** ("adapt* in business process*" OR "business process* adapt*" OR "adapt* business

467   process*" OR "adapt* in BP" OR "BP adapt*" OR "adapt* BP")

468   The results of the search according to the defined queries are presented in Table 3.

469

470   Table 3. Results of the performed search (May, 2019)

471

472 The search in the databases was restricted to title, abstract, and keywords, except in WoS where

473 it was done according to the topic (the other option was to search a title or a full text separately).

474 Google Scholar is more a search engine than a digital database. Therefore, we used it to

475 supplement the search results and to reduce the threats caused by the specifics of some databases.

476 Other important primary quality criteria were applied during the search. Publications that

477 featured the following restrictions were excluded from the results obtained:

478 1. A publication that is non-peer-reviewed – including books, Master's/PhD theses, keynotes,

479 tutorials and editorials, etc.

480 2. A publication that is not available in the English language.

481 3. Two or several papers that are the same. Duplicates of papers were excluded using Mendeley,[7]

482 since some papers are included into several databases and repeated.

483 After applying a set of *primary quality criteria*, the number of papers decreased from 662 to 457.

484 However, evidently there were still too many papers to perform an analysis. Therefore, an

485 additional refinement was applied to the results in order to decrease the number of papers, and to

486 ensure their relevance to the analyzed topic.

487 As a result, the titles and abstracts of the papers were additionally reviewed to exclude those that

488 were deemed irrelevant. The *additional quality criteria* used were defined as follows:

489 1. Exclude papers which contain relevant keywords, but within which DBP analysis is not the

490 main topic of the paper, as in the fields of: education, medicine, energy efficiency, trade-off,

491 fault identification, economic, artificial intelligence, programming, and hardware.

492 2. Exclude papers with a length of less than six pages, as such short papers present only a general

493 idea and omit details of an overall approach.

494 After the refinement of the papers obtained in the earlier stages, we were left with 229 papers to

495 be studied in further detail.

496 **Study selection**

497 From the title and abstract of a paper, only incomplete information can be gathered regarding the

498 context and the proposed approach presented in the study. Therefore, the remaining 229 papers

499 were reviewed in more detail, manually applying the following steps and deciding to include or

500 exclude the paper:

501 1. Read the abstract of the paper.

502 2. Read the introduction to the paper.

503 3. If a decision to include or exclude the paper is not made, read the discussion and conclusions.

504 4. If it is still unclear, search for the keywords in the text of the paper and evaluate their

505 contextual suitability to the scope of our study.

506 Moreover, the refined quality criteria for selecting papers were as follows:

507 1. The paper should present a method or a technique on the subject of BP dynamicity.

508 2. The paper should not present a language without its application in a case study.

509 3. The paper should present an evaluation, which can be understood as: an application, a test or

510 illustration, a toy example, a case study, an experiment, or any sort of empirical evaluation.

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[7] https://www.mendeley.com

511   After the application of the detailed review process, 145 papers remained for review via the
512   reading of the full text. After reading the full texts of these papers, 67 papers were selected for
513   data extraction and detailed analysis.

Threats to validity

515   The papers for analysis were chosen based on the strategy described previously, which included:
516   1) searching sources; 2) selection via keywords and queries; and 3) selection via quality criteria.
517   All of these variabilities were selected based on the related works analysis in the corresponding
518   BP dynamicity area. However, there exists the possibility of missing important studies, because
519   not all papers can be located using defined keywords that are related to the research questions. In
520   order to reduce these threats to validity, the following measures were taken:
521   • A manual checking of the references in the extracted papers was patiently carried out in order
522   to identify those papers that might be missed during the initial search using the keywords that we
523   had defined. In addition, a precise definition of the paper selection quality criteria that complied
524   with the research questions was enforced to avoid the incorrect exclusion of suitable papers.
525   • The snowballing search method, applied from (Jalali & Wohlin, 2012), was used on the found
526   literature reviews on BP dynamicity approaches. We went forward by reviewing the reference
527   lists of these literature reviews by identifying papers cited in the reviews and assessing them
528   according to our defined study selection criteria. We have discovered additional 10 papers
529   meeting our inclusion criteria via this snowballing procedure.
530   • Reading the abstract and the title of the papers introduces a threat, because the abstract and the
531   title allows the exclusion of papers that are not relevant at the first glance. Even if it did not
532   necessarily reflect what is actually presented in the papers, this threat allowed us to exclude
533   papers that were definitely not relevant (Ivarsson & Gorschek, 2011);
534   • Reading the full-text of papers and evaluating them according to the defined paper selection
535   criteria allowed us to limit a set of relevant papers and exclude papers that possessed defined
536   keywords, but that were not relevant to the area of BP dynamicity that was analyzed.
537   • The sources searched (see Table 1) were limited to the most relevant sources, and included only
538   peer-reviewed papers. Note that Google Scholar was used as a supplementary search engine.
539   Finally, to minimize the threat associated with inaccurate extraction of data, the following threats
540   to validity were used:
541   • Including only papers from journals and proceedings classified as CS, IS, and SE categories
542   limits the possibility of generalizing the results to other forums, in which SE technologies are
543   published.
544   • Primary, additional, and refined paper extraction criteria were used to select papers.
545   • All of the selected papers were assessed using the questions presented in Table 2.

Data extraction strategy

547   In this step, data were extracted from the selected relevant papers regarding BP dynamicity
548   according to the features defined in Table 4, and presented in the table rows. Each feature could
549   be clearly understood in the context of BP dynamicity after answering one or several questions,
550   presented within a feature. These features and questions are based on dynamic BP requirements

551   presented in Vasilecas et al. (2016b). If a feature is not explicitly mentioned in the paper, it is
552   mapped according to this survey analysts' understanding. In some cases, a paper can describe
553   several studies. Therefore, the primary study is selected according to the scope of the survey.
554   Table 4 consists of four columns, where the first column presents research questions related to
555   the feature. The second column presents features and questions. The third column presents
556   possible answers to the questions. As can be seen, there are two types of questions. First are
557   those that concern the approach, and elicit a yes or no answer. Second are those that concern
558   either an approach or a description of the approach, eliciting a yes, part, or no answer. The fourth
559   column represents the scaling of answers, where 1 means a strong description (i.e., a feature is
560   described to the degree where a reader can understand and compare it to the same aspect in
561   another paper), 0.5 represents a medium description (i.e., a feature in which the study performed
562   is mentioned or presented in brief, but not described to the degree to which a reader can clearly
563   understand and compare it to the same feature in other paper), and 0 where there is a weak
564   description or indeed none at all.
565   At the end of the examination of the approach, presented in the paper on the basis of scaling, a
566   ranking, denoting the level of dynamicity of an approach and based on features 1-7, 9, and 10
567   from Table 4, and a rigor, denoting the level of description of an approach and based on features
568   8-11 from Table 4, are summed up. Thus, all papers are ranked according to their BP dynamicity.
569   The larger the ranking value, the larger the dynamicity level that is achieved by the proposed
570   approach. Also, the larger the rigor value, the larger the level of description, i.e., the better
571   quality of approach, is achieved in the paper. Other examination features, such as problem
572   definition, etc., can be added to Table 4. However, they are neglected intentionally in order to
573   optimize assessment procedure. We consider that the global aim of those studies is the same.
574
575   Table 4. Data extraction template according to the requirements of DBP
576
577   The results of the data extraction are presented in the "Results" section.
578   **Comparison of literature reviews on BP dynamicity**
579   Among the papers presenting BP dynamicity approaches, papers with literature reviews were
580   also found. For the comparison of those papers we have developed assessment criteria which is
581   based on questions presented elsewhere (Cognini et al., 2018; Ivarsson & Gorschek, 2011;
582   Kitchenham et al., 2009), and shown in Table 5. In the table, the first column presents the
583   number of a question, the second presents the question itself, the third presents possible answers
584   to the questions, the fourth presents the scale or value of an answer, the fifth notes whether the
585   question belongs to the relevance category, and the sixth notes whether the question belongs to
586   the rigor category. Thus, in this paper, each literature review is assessed according to the
587   questions presented and, based the answers provided, relevance, denoting the level of similarity
588   of an analyzed survey to the present survey, and rigor, denoting the quality and presentation of
589   an analyzed survey, are calculated. The scaling of answers is then the same as in Table 4.
590

591   Table 5. Assessment questions for evaluating existing literature reviews
592

Results

594   The main results obtained during the survey of the selected papers consist of three main parts as
595   follows: 1) surveys on the topic of BP dynamicity; 2) papers proposing new BP dynamicity
596   approaches; and 3) analysis of tools for DBP modeling and simulation.

Comparison of literature reviews on BP dynamicity (RQ5)

598   A summary of the results, obtained during the deep analysis of literature reviews according to the
599   questions from Table 5, is presented in Table 6 and Table 7.
600

601   Table 6. Summary of reviews on DBP
602

603   Table 7. An initial data on literature reviews comparison
604

605   As can be seen from Table 7, though, the publication years of the analyzed surveys on BP
606   dynamicity differs. The main period of the papers analyzed is in the range from 2000-2015, and
607   the refined and overlapped period of analyzed papers is in the range from 2004-2013. The
608   surveys analyzed and the present survey generated a set of about 500 research papers, which
609   concern research questions on BP dynamicity. All surveys have analyzed BP dynamicity from
610   different perspectives as follows: BP variability (Rosa et al., 2017; Ayora et al., 2015); aspect
611   oriented (Pourshahid et al., 2012); service compositions (Kapuruge, Han & Colman, 2010); BP
612   flexibility (Cognini et al., 2014; 2018); and declarative BP (Goedertier, Vanthienen & Caron,
613   2015). The surveys most similar to this survey are (Cognini et al., 2014; 2018). As the survey
614   presented in (Cognini et al., 2018) is newer and more sophisticated than (Cognini et al., 2014), it
615   was selected to compare with this survey according to the sources used. This comparison shows
616   that 58% of the sources analyzed in this survey differ from the sources used in (Cognini et al.,
617   2018). Such partial overlapping can be explained by the similarity of the topic analyzed.
618   However, as the analysis of our references shows, this survey covers the most up to date papers
619   on BP dynamicity, including the year 2018, which could not have been be analyzed in another
620   survey under review because they only covered papers in the period of 2000-2015. Moreover, the
621   research questions defined in both surveys differ, and distinctions can also be seen in keywords.
622   One additional keyword used in our search query was "dynamic" and its variations. The primary
623   difference among this survey and that presented by (Cognini et al., 2018) lies in different paper
624   selection criteria, i.e., exclusion and inclusion criteria. In this survey only the most
625   comprehensive and non-duplicated papers by the same authors were chosen for detailed analysis,
626   but not all papers from the same authors.
627   Another interesting and important aspect observed during the comparison of the surveys
628   analyzed is the quality assessment of the search that was undertaken to identify relevant papers.
629   Only two surveys from those analyzed have presented such an assessment. In (Rosa et al., 2017),
630   two authors assessed each approach independently, and third author combined the results, after

631   which confirmation was finally sought from the authors of each primary paper. In (Cognini et al.,
632   2018), a quite different assessment of the selected papers was employed. The data collected were
633   validated by three experts with more than 10 years of experience in BP management, along with
634   other related expertise. The feedback from experts was reconsidered by the authors in a meeting
635   to consolidate the final version of the questions. Additionally, a validation based on the
636   snowballing search method (Jalali & Wohlin 2012) was used on the selected research papers
637   before the next steps in the analysis. Other authors do not present any assessment procedures.
638   Table 7 presents data obtained from the answering of the questions from Table 5. As can be seen
639   from the results, the maximum relevance have achieved by (Cognini et al., 2018) (8 points). This
640   can be explained by the fact that it is the most similar to the present survey. The differences
641   between both surveys were discussed previously in this section. The maximum rigor of 5.5
642   points is achieved by (Ayora et al., 2015) and (Cognini et al., 2018), denoting that the
643   presentation of surveys is at a high level in their papers.
644
645   Figure 2. An overview of rigor-ranking scores for the papers on literature reviews on BP
646   dynamicity
647
648   In Figure 2, we have presented an overview of rigor-ranking scores for the literature reviews on
649   BP dynamicity. As can be seen, the reviews analyzed have achieved middle or high levels of
650   sophistication in presenting the results of analysis on the topic of BP dynamicity. However, some
651   gaps in reviews still remain. They are as follows: presenting a research methodology (Q5 and
652   Q6) (Ayora et al., 2015); threats to validity (Q7) (Rosa et al., 2017; Cognini et al., 2014;
653   Kapuruge, Han & Colman, 2010; Goedertier, Vanthienen & Caron, 2015); and quality
654   assessment of the performed search (Q8 and Q9) (Ayora et al., 2015; Pourshahid et al., 2012;
655   Cognini et al., 2014) (see Figure 3).
656
657   Figure 3. An overview of answers on the assessment of the papers on literature reviews on BP
658   dynamicity
659
660   **Comparison of papers on BP dynamicity**
661   Here we present the results of comparison between papers on BP dynamicity. After the primary
662   review of the full texts of papers, a set of 67 papers remained for in-depth analysis. It should be
663   noted that similar papers from the same authors were merged by choosing the most complete and
664   up to date paper. Figure 4 presents the number of papers on BP dynamicity selected for in-depth
665   analysis varying by years. As can be seen from this figure, the number of papers on BP
666   dynamicity rises slightly. The results of papers' assessments according to the predefined features
667   of BP dynamicity (Table 4) is presented in Table 8. They are discussed below by proceeding
668   through each column and answering the previously defined research questions. The
669   categorization of the analyzed papers according to the process dynamicity influencing features
670   (Table 4) are presented in Annex 1.

671
672   Figure 4. The number of papers on BP dynamicity selected for in-depth analysis by year
673
674   Table 8. Initial data on BP dynamicity
675
676   In Table 8, the first three columns (1.1, 1.2, and 1.3) represent the dependency of all process
677   instances from a predefined BP model, i.e., 1.1, 1.2, and 1.3 correspond to the features from
678   Table 4 that influence process dynamicity. According to whether the process model is predefined
679   or not, in 88% of the papers analyzed (59 papers), approaches consider BP dynamicity through
680   the change of the existing process model by using: process variants, which are implemented by
681   the restriction or extension of activities in a process instance (Rosa et al., 2017; Ayora et al.,
682   2016; Hallerbach, Bauer & Reichert, 2010); generic process model (Abderrahmane, Mili &
683   Boubaker, 2014) or process meta-model (Mattos et al., 2014), which is used to generate a
684   process; or process cases (Sprovieri et al., 2016), when possible activities are known in advance
685   (i.e., at design-time), but their sequencing is defined at run-time depending on the context. Other
686   parts of the approaches analyzed (12%: eight papers) consider that there is no predefined process
687   model, i.e., the process is made up of process fragments (Haarmann et al., 2015) or composed of
688   rules, like ECA rules in Mejia Bernal et al. (2010), which are selected at process instance run-
689   time according to the context. Moreover, in only 45% (30 papers) of approaches is it possible to
690   modify activities at process instance run-time.
691   The next three columns (2.1–2.3) in Table 8, which correspond Table 4, allow us to investigate
692   the extent to which a process is dependent on the context, which can change at run-time.
693   Columns 2.1 and 2.2 indicate the type of a context, i.e., external (technological evolution, new
694   working methods, changes in laws, changes in the target goal, exceptions, economic
695   requirements, etc. (Cognini et al., 2018)) or internal (such as an organization's resources). In
696   about half of these papers, an external (51%) or internal (51%) context is considered, and in
697   other part of papers context is not considered at all. In 27% both external and internal contexts
698   are considered. In 58% (39 papers) of approaches, a process instance can react to the change in
699   an external and/or internal context at run-time.
700   The third set of columns (3.1–3.4) shows the use of rules in approaches. As can be seen from
701   column 3.1, 82% (55 papers) of approaches use rules (van Eijndhoven, Iacob & Ponisio, 2008;
702   Mejia Bernal et al., 2010; Santo Carvalho et al., 2013) or policies (Cao et al., 2009) to select the
703   next activity in a process instance. However, only 9% (six papers) feature authors discussing
704   changes in rules (3.2) and reacting to those changes (3.3) during process instance run-time. In
705   30% (20 papers), rules are used for other purposes, such as transformation rules that are used to
706   generate process variants from patterns in (Abderrahmane, Mili & Boubaker, 2014).
707   The fourth column, in essence, repeats or summarizes whether the proposed approach allows
708   changes (change of activities, change of context, and change of rules) in a process instance at
709   run-time. We found that 82% (55 papers) of the papers analyzed consider changes at process
710   instance run-time.

711   The fifth set of columns (5.1–5.5) presents the accumulation of experience of BP dynamicity. It
712   was found that only 18% (12 papers) use historical data for some purpose, such as data mining,
713   to generate possible process variables in (Abderrahmane, Mili & Boubaker, 2014), or to build a
714   model in (Mattos et al., 2014). Only 8% (five papers) calculate values, including time, cost, etc.,
715   for each executed process instance and use them to improve process results.
716   The sixth column considers whether a process is goal-oriented or not. As can be seen from the
717   results obtained, in only 28% (19 papers) of cases is there mention of the goal-orientation of a
718   process. We might conclude that other approaches assume that their processes are goal-oriented,
719   but do not express as much explicitly.
720   The seventh column shows the usage of ontology in their approaches. Our research indicated that
721   ontology is used for process model creation or knowledge about domain extraction in only 15%
722   (10 papers) of approaches. The eighth set of columns (8.1 and 8.2) is used to present the
723   completeness of the description of the proposed approach. As we found, all approaches are
724   described in some way, and 37% (25 papers) of papers present a formal or semi-formal
725   description of the proposed approach by using formulas.
726   The ninth set of columns (9.1–9.5) presents an approach to implementing BP dynamicity. In 31
727   papers, authors consider a variant-based approach, in four papers – a case-handling approach, in
728   11 papers – a declarative approach, in 12 papers – a goal-based approach, and in 11 papers – an
729   "other" approach. These "other" approaches include a policy-based approach and a generic
730   process model for workflow management (Cao et al., 2009), cognitive models and a function–
731   behavior–structure (FBS) model (Kannengiesser et al., 2014), or service relationships (Kapuruge,
732   Han & Colman, 2011). The tenth set of columns (10.1–10.5) is intended to describe the
733   implementation perspective of approaches. As evidenced, 75% (50 papers) of papers had a case
734   study and/or prototype description of their approaches. In 73% (49 papers), a clear description of
735   an implementation with text, screen shots, and code lines was presented. Only 18% (12 papers)
736   presented validation of the results obtained, whether from experts or other such sources.
737   The answers for question 10.2 are summarized below in Table 9, to avoid enlarging Table 8.
738
739   Table 9. Technology, language or other approaches used in the implementation section of the
740   papers analyzed
741
742   The analysis of question 10.2 demonstrates that the most popular architecture used for the
743   implementation of DBP is SOA (49%, 33 papers of the 67 analyzed). Among popular languages
744   for BP modeling are BPMN (22.39%, used in 15 papers) and BPEL (15%, used in 10 papers). In
745   five papers (7.46%), the authors do not provide any information about implementation, with the
746   exception of some descriptive examples. Other implementation aspects are also interesting, as
747   with the usage of rule engines, e.g., Jboss Drools 5.1 in (Abderrahmane, Mili & Boubaker,
748   2014), Jess Java rule Engine (Mounira & Mahmoud, 2010; Wang & Wang, 2006), Goh with
749   IBM WebSphere Business Modeler (Ramakrishnan, 2009). For other aspects of implementation
750   see the "Implementation aspects of DBP" section.

751   The last set of columns (11.1 and 11.2) shows that 96% (64 papers) had conclusions, and 18%
752   (12 papers) discussed their results.
753   According to Table 8, possible values of ranking are in the interval [0; 24] and possible values of
754   rigor are in the interval [0; 13]. However, as can be seen from Table 8, Figure 5, and Figure 6, all
755   of the papers analyzed fall within the ranking interval of [1.5; 17] and the rigor interval of [2; 9].
756   Moreover, the rigor of papers has been divided into intervals as follows:
757   • [2; 4) – low rigor, i.e., the paper has a poor description of an approach, an implementation, and
758   a discussion with conclusions (2 papers of 67, colored in blue).
759   • [4; 7) – middle rigor, i.e., the paper has a fair description of these elements (46 papers of 67,
760   colored in red).
761   • [7; 9] – high rigor, i.e., the paper has strong a description of these elements (19 papers of 67,
762   colored in green).
763   According to ranking, papers have been divided into intervals, also, as follows:
764   • [1; 7) – low ranking, i.e., the paper has a low level of dynamicity presented by their approach.
765   In such papers the aspects analyzed (see Table 4) have weak descriptions or are not mentioned at
766   all (30 papers of 67).
767   • [7; 14) – middle ranking, i.e., the paper has a fair level of dynamicity presented by their
768   approach. In such papers the aspects analyzed (see Table 4) have a fair description or some of the
769   analyzed aspects, such as process model, context or rules, and implementation, have strong
770   descriptions (35 papers of 67).
771   • [14; 22] – high ranking, i.e., the paper has a fair or strong description of all of the aspects
772   analyzed (2 papers of 67).
773   Summing up, the majority of papers have middle or high rigor and low or middle ranking (Figure
774   5 and Figure 6).
775   In Figure 5, we present the ranking of papers, calculated based on the results presented in Table
776   8, according to the year of each papers' publication. The size of the bubbles depends on the rigor
777   of papers per year. As can be seen from the figure, there are two periods – 2008-2011 (30
778   publications) and 2014-2016 (22 publications) – when more papers on the topic of BP
779   dynamicity were published.
780
781   Figure 5. Ranking of papers according to rigor
782
783   The number of papers according to their rigor and ranking during the two identified periods
784   (2008-2011 and 2014-2016) are presented in Table 10.
785
786   Table 10. Number of papers according to their rigor and ranking during periods
787
788   As can be seen from Table 10, in 2008-2011 half of the papers have high rigor (15 papers of 30).
789   The remainder of the papers have low (12 papers of 30) or middle (three papers of 30) rigor in
790   this period. In 2014-2016, almost half of the papers have high rigor (14 papers of 30). The

791 remainder of the papers have low (two papers of 30) or middle (nine papers of 30) rigor in this
792 period. In 2008-2011, half of the papers analyzed have a low ranking, and the other half of the
793 papers have a middle ranking (15 papers of 22). In 2014-2016, half of the papers (11 papers of
794 22) have a low ranking. The remainder of the papers have a middle (9 papers of 220) or high (2
795 papers of 22) ranking in this period.
796 In Figure 6, we present the ranking of dependency based on the rigor of papers. The size of the
797 bubbles depends on the number of papers with the same ranking-rigor score. The red lines
798 represent intervals of rigor and ranking, as described previously.
799
800 Figure 6. Overview of rigor-ranking scores for the papers
801
802 The number of papers according to the rigor-ranking scores are presented in Table 11.
803
804 Table 11. The number of papers according to the rigor-ranking scores
805
806 As can be seen from Table 11, the largest portion of the papers is distributed in the interval of
807 middle to high rigor and middle to high ranking (63 papers of 67). The remaining other sets are
808 much smaller (see Table 11 and Figure 6).
809 In Figure 7, we have presented the summed dependency of rankings according to the papers'
810 publication years. The size of the bubbles depends on the rigor of the papers. Ranking and rigor
811 is summarized by the years, and from this figure we can see that all studies can be divided into
812 four sets as listed below:
813 1. Set "A" (the earlier period of 2005 – 2007) – papers of this period have low or middle rigor [2;
814 6) and low or middle ranking [7; 14).
815 2. Set "B" (the middle period of 2008 – 2011) – papers of this period have above the middle
816 rigor [4; 6) and above the middle ranking [7; 14).
817 3. Set "C+D" (the later period of 2012 – 2018) – papers of this period have different rigor and
818 ranking, starting from low values and finishing at high values.
819 In Figure 7, a sequence of numbers (red bubbles) shows the number of papers per year.
820
821 Figure 7. Ranking of papers according to years
822
823 The numbers of papers according to the rigor-ranking scores in the periods identified are
824 presented in Table 12.
825
826 Table 12. Numbers of papers according to the rigor-ranking scores in identified periods
827
828 As can be seen from Table 12 and Figure 7, the tendency of distribution of papers according to
829 the rigor-ranking scores in the periods identified remained the same. The largest portion of
830 papers have a high rigor and a middle ranking. Another large, but slightly smaller, set of papers

831 has a middle rigor and a low or middle ranking. Other sets are generally much smaller (see Table
832 12 and Figure 7).
833 To analyze the evolution of research, Figure 8 shows how the variables of rigor and relevance
834 have changed over time together with the number of papers included each year. Rigor and
835 relevance are scored on the left y-axis, while the number of papers is given on the right y-axis.
836 Rigor is in a range of [3.83; 8.00]. Ranking is in a range of [5.50; 13.00]. The results indicate an
837 improvement in both rigor and ranking (see the linear trend line for both AVG Ranking and
838 AVG Rigor).
839
840 Figure 8. The evolution of research on BP dynamicity
841
842 **Implementation aspects of DBP**
843 As our primary research, as presented in (Vasilecas, Kalibatiene & Lavbič, 2016) was on DBP
844 modeling and simulation approaches and tools, in this section we review the implementation
845 architectures proposed in the papers analyzed.
846 More detailed analysis of the implementation perspectives of the selected papers was conducted
847 because of the practical interest. The authors (Hermosillo, Seinturier & Duchien, 2010;
848 Hermosillo, 2012) propose the CEVICHE framework and deal with the architecture for DBP
849 adaptation. The main drawback of the suggested approach is that decision or variation point and
850 adaptation rules should be predefined in the BP model and CEVICHE can only handle known
851 specific cases (Pourshahid et al., 2012). Thus, the proposed framework is not general and can be
852 used to execute already known alternative processes after detecting predefined situations. The
853 authors of (van der Aalst, Weske & Grünbauer, 2005) identified and classified the main entities
854 of case handling systems in a meta-model and implemented it in the case-handling system
855 FLOWer using a realistic example. Moreover, as the authors (van der Aalst, Weske &
856 Grünbauer, 2005) stated, more flexibility may pose many problems, ranging from unauthorized
857 actions to incomplete cases. The authors of (van der Aalst, Pesic & Schonenberg, 2009) state that
858 the main limitations of their proposed declarative approach are as follows: a) a constraint-based
859 approach is not very suitable for processes that are of a strict procedural nature; b) declarative
860 workflow specifications may be less readable if many (interacting) constraints are added; and c)
861 the efficiency of the Declare engine decreases when dealing with large specifications.
862 Among existing PAIS, there are highlighted: YAWL (van Der Aalst & Ter Hofstede, 2005),
863 Flower (Dumas, van der Aalst & Ter Hofstede, 2005), DECLARE (Pesic & van der Aalst, 2006,
864 September) and ADEPT (Reichert, Rinderle & Dadam, 2003), where each supports flexibility in
865 a different way. As authors of (Santo Carvalho, Santoro & Revoredo, 2015) state that none of
866 them support adaptation in terms of adequacy for business, but only in ensuring that any
867 adjustment will not somehow corrupt the process. Moreover, the analysis and consequent
868 changes proposed in these PAIS are done manually. A decision on adaptation is not recorded,
869 nor is an analysis made regarding it.

870   In (Hallerbach, Bauer & Reichert, 2010), a number of Provop process variants are defined and
871   proposed through a set of change operations in Provop, which forces the deployment of all
872   process variants using conditional branching. According to (Ayora et al., 2012, September;
873   2012), this is not an example of real adaptability, as all alternatives are transformed into
874   executable versions.
875   Authors of (Jiang et al., 2016) found that expressing dynamicity through constraint-based
876   declarative approaches are not good at precisely describing the procedure of process models,
877   tending to describe all the activities of the process model and the main constraints describing the
878   relationships among these activities, as DECLARE (Pesic, Schonenberg & van der Aalst, 2007)
879   and ConDec (Pesic & van der Aalst, 2006). They therefore have to work together with
880   imperative approaches.
881   An approach presented in (Jiang et al., 2016) is based on vertical and horizontal activity
882   refinement. However, as the authors state, the dynamic refinement of flexible activities remains a
883   challenge in the modeling and application of flexible workflows. Authors of (Jiang, Li & Yang,
884   2017) propose the use of a knowledge tree and various constraints to solve this issue.
885   As the analysis shows, the most significant part of these approaches is implemented as a case
886   study (as in (Mejia Bernal et al., 2010; Hermosillo, Seinturier & Duchien, 2010), or the
887   automation of the proposed approach at some level.
888   **Analysis of the existing tools on DBP modeling and simulation**
889   For more comprehensive study, some BP modeling and simulation tools are compared in Table
890   13 according to the previously defined requirements (DBPR). Table 13 shows whether a system
891   provides full (+), partial (+/−) or no support (−) for a particular feature (see DBPR).
892
893   Table 13. Comparison of DBP modeling and simulation tools
894
895   We can determine from Table 13 that all of the five tools analyzed need an initial BP model (1).
896   This limits the dynamicity of BP. All BP modeling and simulation tools allow the allocation of
897   resources to activities (2.1). In some analyzed tools, like IBM Websphere and Simprocess, it is
898   possible to define not only the cost and time attributes of the resource, but also other attributes
899   such as volume, color, etc. It is not possible to define external context (2.2) in all five analyzed
900   tools. Whilst all of the tools support features of rule modeling within BP; none of them support
901   an analysis of these rules at BP runtime (3.4). Usage of historical data (4) is supported in almost
902   all of the tools analyzed (except AssuProcess). As can be seen from Table 13, existing tools are
903   well developed to model, analyze, and simulate static BP (5). However, those tools are not
904   suitable for the proper simulation/execution of DBP.
905   **Discussion, answers to the research questions and future work**
906   In this section, we present the discussion regarding the results obtained on BP dynamicity, and
907   therefore the answers to the research questions posed in this paper.
908   The most frequently proposed approaches on BP dynamicity deal with the predefined process
909   model, in which some dynamicity is ensured through changing a process model or a process

910   instance at the design stage or at run-time by adding or restricting some behavior. However,
911   adaptation or customization of a process based on a predefined process model allows the
912   achievement of only some level of dynamicity (RQ1). Some authors propose the generation of a
913   process model or its instance from a set of activities or process fragments. These fragments can
914   vary according to the contexts and rules at process instance run-time. In many cases, however,
915   activities or fragments, variants, and rules are predefined that limit process dynamicity (RQ1). In
916   some domains, it is difficult or impossible to predict all possible changes of a context and thus
917   predefine possible sequences of activities, fragments, or rules. Therefore, the most dynamic BP
918   should not have a predefined set and sequence of activities. Instead, a goal should be known and
919   defined. One way to achieve the goal is to apply a multi criteria process optimization. A goal-
920   oriented approach implies a focus on achieving some state in the system's resources, instead of
921   the execution of a predefined set and sequence of activities. The primary advantage of this
922   approach is that we achieve more dynamicity and the strong goal-orientation of a BP (RQ1).
923   According to (Cangemi & Taylor, 2018), artificial intelligence (AI) can provide support in
924   choosing the next most suitable activity at process instance run-time, i.e., answering the question
925   of which activity should be executed. As processes become increasingly branched and
926   individualized early, AI can help to route the respective flow units through the process (Satyal et
927   al., 2018, October). Additionally, AI-algorithms can determine patterns in the data and create
928   new process variants, as the process is being executed in the shadows, without affecting
929   customers or process actors (Satyal et al., 2018, October). We offer the dynamicity of BP
930   obtained through BRs, as presented in (Vasilecas, Kalibatiene & Lavbič, 2016). Moreover, in
931   this research the topic of AI is out of scope.
932   During the analysis of BP dynamicity in the papers selected, the difference of approaches lies
933   largely at the process instance level. These differences are as follows: whether the process
934   instance can be changed at run-time and to what extent; whether the process instance responds to
935   changes in the internal and external contexts; whether there are any rules for choosing the next
936   activity for the execution; whether the process instance is executed according to the process goal;
937   and whether the process instance uses the experience gained previously (RQ2).
938   We can now define the main features of a dynamic BP (RQ3) (see Table 14), which are
939   determined based on this SLR. As can be seen from the obtained results, the most relevant
940   features are the following: rule-based, changes at run-time, context-sensitive, and DBP
941   feasibility. The importance of the rule-based feature can be explained by the phenomenon that
942   BRs are widely agreed between researchers and practitioners as a way to express business
943   knowledge and govern BP (Valente et al., 2016; Valente et al., 2016, November; Vasilecas,
944   Kalibatiene & Lavbič, 2016). Consequently, there is a number of researches appling busyiness
945   rules for ensuring BP dynamicity. The changes at run-time feature reflect the business's need to
946   adapt to changing environmental conditions continually. The importance of the context-sensitive
947   feature means that for the successful BP it should react not only to the changing environment,
948   but also to the needs of the customer. Finally, DBP should be implemented in a particular way to
949   support its business effectively.

950

951   Table 14. Main features of a dynamic BP (RQ3)

952

953   Other found DBP features (i.e., goal-oriented, accumulation of experience, align with a process
954   ontology and not predefined process model) are not so common with comparison to the
955   previously discussed features. This is because those features are not directly expressed in a
956   process model. BPs are designed and implemented into software systems to achieve business
957   goals. However, many existing classic BP modeling approaches do not provide means for the
958   direct expression of a business goal. Most often, the goal is expressed in BP by BRs. The same is
959   with ontology, i.e., it is usually meant but not directly expressed and used for BP modeling.
960   Summing up, the automation of nowadays BP cannot be achieved by solely focusing on process
961   activities and using classical BP modeling techniques. It requires a holistic approach that also
962   captures the business environment's social aspects, such as corporate strategies, organization
963   policies, negotiations, and cooperation (Kir & Erdogan, 2021).
964   The results obtained highlight the main limitations and gaps related to dynamic BP (RQ4). In the
965   research area, surrounding this topic there is a lack of research and approaches that consider how
966   dynamic BP achieves a goal and how this is implemented. The advantages of the mining and
967   usage of historical data is well known in different areas. However, there are no approaches
968   relating to the accumulation of experience during dynamic process execution and subsequent use
969   of it for more effective goal implementation. A limited amount of research and approaches
970   enable the rule changing during process instance execution, which is especially important when
971   working with long-running processes.
972   An in-depth analysis of the selected papers, according to their perspectives on implementation,
973   shows that the implementation and collection of experimental results remains insufficient in most
974   research projects. Therefore, DBP modeling and implementation still requires more research.
975   The analysis of the selected literature reviews on BP dynamicity shows that they are not
976   analyzing dynamicity as a feature of a BP (RQ5). They analyze process variability, but not
977   enough attention is placed on BP dynamicity. Gaps in literature reviews still remain, primarily in
978   presenting a research methodology, considering threats to validity, and the quality of assessment
979   of the search performed.
980   Moreover, the analysis of the visualized results allows us to state that a portion of these papers
981   lack a clear description of the approaches presented. The largest portion of these papers have no
982   description of the proposed approach, lack models on DBP in a formal language, and have no
983   evaluation of the results obtained. At first glance, the majority of papers have some
984   implementation of the proposed approach by presenting a case study, simulation examples, or a
985   prototype. However, these are not complete, and perhaps the lack of an evaluation of the results
986   obtained can be explained by the complexity of this task (RQ6).

987   **Conclusions**

988   In this paper, we have presented a literature review on DBP. After applying a research procedure
989   based on keywords and inclusion and exclusion quality criteria, we identified 67 papers for

990 detailed study. Those papers were assessed based on the features defined, which allowed us to
991 determine a scientific ranking, denoting the level of dynamicity of the presented approach, and
992 rigor. We were also able to denote the level of description of the approach presented in each
993 paper, and to answer the research questions initially defined in this paper.
994 The processed and visualized results allow us to determine that the approaches presented reach
995 the middle level of dynamicity. We are also able to note that topics remain for further
996 development, such as the presence or absence of a more dynamic initial process model, the usage
997 of historic data for BP dynamicity including quality cost calculation, goal-orientation in DBP,
998 and the semantics of DBP.
999 The analysis of the selected approaches allows us to identify the main features of DBP as
1000 follows: an undefined process model; process instances that respond to the changing context; the
1001 sequence of process activities and content of each activity being dependent on rules; all possible
1002 changes being able to be made by any role involved at process instance run-time with possibly
1003 low latency; the selection of each process activity being aligned with a process goal; all process
1004 components being aligned with a process ontology; the selection of each process activity being
1005 aligned with historical data; and the feasibility of the process being ensured.
1006 According to the analysis of literature reviews on DBP, they tend to analyze the variability of
1007 processes, but not enough attention is given to BP dynamicity. The main issues in literature
1008 reviews remain in presenting a research methodology, threats to validity, and the quality
1009 assessment of the search being performed.
1010 The following future directions are defined:

1011 • in depth analysis of modeling languages and standards that cover DBP;
1012 • an interdependence analysis among the defined research questions;
1013 • in depth analysis of context in the definition of DBP (i.e., how authors define and model
1014   these contexts? What is the relationship between ontologies and context models?);
1015 • in depth analysis of technical details about modeling and implementing of DBP;
1016 • extending the current study by including the newest papers on DBP;
1017 • performing a statistical analysis of the obtained results.
1018

1019 Acknowledgments
1020 The authors wish to thank Marlon Dumas for his feedback on a draft of this article.

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List of sources

Table 1. List of sources

Data source	Website
1. ACM Digital Library	https://dl.acm.org
2. IEEE Xplore	http://ieeexplore.ieee.org/Xplore/home.jsp
3. ScienceDirect	http://www.sciencedirect.com/
4. Scopus	https://www.scopus.com/
5. Web of Science (WOS)	https://apps.webofknowledge.com/
6. Google Scholar	https://scholar.google.lt

Keywords used for the search

Table 2. Keywords used for the search

Main Concept	Related terms	Keywords used in the search
Business process	BP	Business process*, BP, process
Dynamic	dynamicity, dynamism, dynamics, dynamically, dynamical, adaptability, adaptation, adaptable, adapt, adaptive, flexible, flexibility, variable, variability declarative	dynamic* adapt* flexib* variab* declarative

Results of the performed search (May, 2019)

Table 3. Results of the performed search (May, 2019)

Data source	SQ1	SQ2	SQ3	SQ4	Total:
1. ACM Digital Library	15	7	6	13	**41**
2. IEEE Xplore	50	27	2	58	**137**
3. ScienceDirect	25	20	9	13	**67**
4. Scopus	120	118	41	94	**373**
5. Web of Science (WoS)	10	15	5	14	**44**
Total:	**220**	**187**	**63**	**205**	**662**

Data extraction template according to the requirements of DBP

1   **Table 4. Data extraction template according to the requirements of DBP**

RQ	Process dynamicity influencing features that are mentioned in analyzed papers	Possible answers	Scale	Ranking (RQ1)	Rigor (RQ6)
	Meta information: Study ID and reference of a paper.				
RQ1 RQ2 RQ3 RQ4	1. Process model predefined (Essential) (see DBPR-1): 1.1. Does a process have a predefined sequence of activities, i.e., a predefined process model? 1.2. Is a process based on meta-model, general model, generic model, or abstract model? 1.3. Is it possible to define additional activities and to change or delete existing activities or skip to other activities at process instance run-time?	Yes/No Yes/No Yes/Part/No	0/1 0/1 1/0.5/0	X X X	
RQ1 RQ2 RQ3 RQ4	2. Context aware (Essential) (see DBPR-2): 2.1. Does an external context affect the execution of the process? 2.2. Does an internal context affect the execution of the process? 2.3. Is a process instance affected by the change of a context at run-time?	Yes/No Yes/No Yes/No	1/0 1/0 1/0	X X X	
RQ1 RQ2 RQ3 RQ4	3. Rule-based[1] (Essential) (see DBPR-3): 3.1. Is every subsequent activity in a process selected according to the predefined rules at process instance run-time? 3.2. Is it possible to define new rules, or change or delete existing rules, at process instance run-time? 3.3. Does process instance react to the rule changes made at process instance run-time? 3.4. Are rules used to solve other tasks?	Yes/Part/No Yes/No Yes/No Yes/No	1/0.5/0 1/0 1/0 1/0	X X X	
RQ1 RQ2 RQ3 RQ4	4. Changes (Essential): Are changes implemented at process instance run-time with low latency? (see DBPR-4)	Yes/No	1/0	X	
RQ1 RQ2 RQ3 RQ4	5. Accumulation of experience (see DBPR-5): 5.1. Is the experience of each process instance execution stored? 5.2. Is it possible to classify executed instances of a process as a "good practice" and a "bad practice"? 5.3. Are time, cost, etc. values calculated and stored for each process instance? 5.4. Is it possible to restrict the execution of process instances that are named "bad instances"? 5.5. Is historical data used for solving other	Yes/No Yes/No Yes/No Yes/No Yes/No	1/0 1/0 1/0 1/0 1/0	X X X	

	related tasks?				
RQ1 RQ2 RQ3 RQ4	6. Goal: Is a process goal-oriented? (see DBPR-6)	Yes/No	1/0	X	
RQ1 RQ2 RQ3 RQ4	7. Ontology: Is domain ontology or process ontology used in an approach?	Yes/No	1/0	X	
Completeness of description of process dynamicity approach and its implementation					
RQ2 RQ3 RQ4 RQ6	8. Approach description: 8.1. Does the paper present a clear description of the proposed approach on BP dynamicity? 8.2. Does the paper present a description of the proposed approach on dynamic BP in a formal language?	Yes/Part/No Yes/Part/No	1/0.5/0 1/0.5/0		X X
RQ1 RQ2 RQ3 RQ4 RQ6	9. Dynamicity implementation approach (if 1.1. is yes): 9.1. Is the process dynamicity realized through variants? 9.2. Is the process dynamicity realized through cases? 9.3. Is the process dynamicity realized through a declarative approach? 9.4. Is the process dynamicity realized through goal-orientation? 9.5. Is the process dynamicity realized through other approaches?	Yes/No Yes/No Yes/No Yes/No Yes/No	1/0 1/0 1/0 1/0 1/0	X X X X X	X X X X X
RQ2 RQ3 RQ4 RQ6	10. Implementation of the proposed approach: 10.1. Is any case of implementation of a proposed model presented in the paper? 10.2. What approach, language or technique is used for the implementation of the proposed approach? 10.3. Does the paper present a case study or a prototype or a descriptive example?[4] 10.4. Does the paper present a clear description of an implementation with text, screen shots, and code lines? 10.5. Does the paper evaluate the results obtained?	Yes/No Answer Yes/Part/No Yes/Part/No Yes/Part/No	1/0 1/0.5/0 1/0.5/0 1/0.5/0	X	X X X X
RQ4 RQ6	11. Discussion and conclusions: 11.1. Does the paper present an appropriate discussion on dynamicity? 11.2. Does the paper present grounded conclusions about dynamicity?	Yes/Part/No Yes/Part/No	1/0.5/0 1/0.5/0		X X

2 [1] – Here a rule role is analyzed in a process. In analyzed approaches, rules are used for different tasks (3.4),
3 as with transformation rules that are used to generate the process variants from patterns in Abderrahmane

4   et al. (2014), etc. In some approaches, like Bucchiarone et al. (2017), the rule concept is not used at all.

5   Authors use "transition relations," which in general can be termed rules.

6   [2] – A variant-based process here means that process change can be made in predefined variation points. A

7   case-based process definition is the same as in van der Aalst et al. (2005).

8   [3] – Historical data is used in some a way, for example a log file used to build a model (Mattos et al.,

9   2014), etc.

10   [4] – If a paper presents a case study or a prototype, then the answer is *yes*. If a paper presents a descriptive

11   example, then the answer is part. If a paper does not present any implementation, then the answer is *no*.

12   [5] – This means that some type of validation, i.e., Experts or other, is presented here.

Assessment questions for evaluating existing literature reviews

1   **Table 5. Assessment questions for evaluating existing literature reviews**

No	Questions	Answers	Scale	Relevance	Rigor
Q1	Whether the aims of the analyzed survey and this survey match?	Yes/Part/No	1/0.5/0	X	
Q2	Whether the sources used in the analyzed survey and in this survey match?	Yes/Part/No	1/0.5/0	X	
Q3	Whether the meaning of research questions in the analyzed survey and in this survey similar?	Yes/Part/No	1/0.5/0	X	
Q4	Whether the search keywords in the analyzed survey and this survey cover the similar field of research?	Yes/Part/No	1/0.5/0	X	
Q5	Is the analyzed survey based on literature review guidelines agreed in software engineering?	Yes/No	1/0	X	X
Q6	Is the analyzed survey based on authors' defined approach? (if previous question is No)	Yes/No	0.5/0	X	X
Q7	Does the analyzed survey identifies and mitigates its threats to validity?	Yes/Part/No	1/0.5/0	X	X
Q8	Does the analyzed survey include a quality assessment of the performed search?	Yes/Part/No	1/0.5/0	X	X
Q9	Does the analyzed survey include a quality assessment of primary studies?	Yes/Part/No	1/0.5/0	X	
Q10	Are the results presented in the analyzed survey described properly?	Yes/Part/No	1/0.5/0		X
Q11	Does the analyzed survey have described examples of flexibility or variability?	Yes/Part/No	1/0.5/0	X	X
Q12	Does the analyzed survey have answered to the defined research questions?	Yes/Part/No	1/0.5/0	X	X
Q13	Does the analyzed survey have presented evident conclusions?	Yes/Part/No	1/0.5/0		X
Maximum value			12	11	8
Minimum value			0	0	0

Summary of reviews on DBP

Table 6. Summary of reviews on DBP

Reference	Scope	Data sources	Period	Methodology	Data extraction	Quality assessment	Threats to Validity
(Rosa et al., 2017)	BP variability by restriction and by extension	Concentration not on sources, but on particular approaches	2000-2014	Not presented	66 relevant papers: 23 approaches, out of which 11 main approaches subsume the other 12 approaches	Not presented	Not presented
(Pourshahid et al., 2012)	Aspect-oriented approaches for BP adaptation	One source, not specified	2000-2012	Presented, usual to literature reviews	56 papers	Quality criteria for selecting papers	1) Searched on article titles and only one meta-search engine used 2) Looking at commonly cited articles by the authors of the papers found, and by comparing the authors' conclusions with some more generic surveys and studies
(Ayora et al., 2015)	Evaluation of variability support in process-aware IS	SpringerLink, IEEE Xplore Digital Library, ACM Digital Library, Science Direct – Elsevier, Wiley Inter Science, World Scientific	2004-2013	Presented, usual to literature reviews	63 papers	Quality criteria for selecting studies	Selection bias, inaccuracy in data extraction and analysis, and reliability
(Cognini et al., 2014)	BP adaptation	IEEEExploer, ACM Digital Library, Citeseerx Library, ScienceDirect, Springer Link, Web Of Science	2000-2013	Presented, usual to literature reviews	84 papers	Three inclusion criteria and four exclusion criteria	Not presented
(Cognini et al., 2018)	BP flexibility with a focus on software systems	IEEEExplorer, ACM Digital Library, Citeseerx Library, Scopus Science Direct, SpringerLink, WOS	2000-2015	The method proposed in (Kitchenham, 2007)	164 papers	Two inclusion criteria, two exclusion criteria, and seven questions developed by (Dyba and Dingsoyr, 2008)	A validation based on the snowballing search method (Jalali & Wohlin 2012)
(Goedertier et al., 2015)	Declarative process modeling languages and principles	Concentration not on sources, but on particular approaches	Languages of period 1998-2009	A set of criteria is chosen	8 languages	Not discussed	Not discussed
(Kapuruge et al., 2010)	Process flexibility in the context of service compositions	Not presented	Not presented	Not presented	7 papers	Not described	Not presented
This study	BP dynamicity and flexibility	ACM Digital Library, IEEE Xplore, ScienceDirect, Scopus, WOS	2005-2017	The method proposed in (Ivarsson and Gorschek 2009)	60 papers	Three stage exclusion procedure, described in Section 4	Presented in Section 3.5

An initial data on literature reviews comparison

Table 7. An initial data on literature reviews comparison

Reference	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Relevance	Rigor
(Rosa et al., 2017)	0.5	0.5	0.5	0.5	0	1	0	1	0.5	0.5	1	0.5	1	6	5
(Pourshahid et al., 2012)	0.5	0	0	0.5	1	0	1	0	1	1	0	0	1	4	4
(Ayora et al., 2015)	0.5	0	0	0.5	1	0	1	0	1	1	1	1	0.5	6	5.5
(Cognini et al., 2014)	1	1	0.5	1	1	0	0	0	1	1	0	1	1	6.5	4
(Cognini et al., 2018)	1	1	0.5	1	1	0	0.5	1	1	1	0	1	1	8	5.5
(Kapuruge et al., 2010)	0.5	0	0	0	0	1	0	0	0	0.5	1	0	1	2.5	3.5
(Goedertier et al., 2015)	0.5	0	0	0.5	0	1	0	0	0	1	1	1	1	4	5
SUM	4	2.5	1.5	3.5	4	2	2.5	2	4.5	5	3	3.5	5.5	33	27.5
AVG	0.643	0.357	0.214	0.571	0.571	0.429	0.357	0.286	0.643	0.857	0.571	0.643	0.929	5.286	4.643
MIN	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.500	2.500	3.500
MAX	1.000	1.000	0.500	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	8.000	5.500

Initial data on BP dynamicity

Table 8. Initial data on BP dynamicity

Reference	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	3.4	4	5.1	5.2	5.3	5.4	5.5	6	7	8.1	8.2	9.1	9.2	9.3	9.4	9.5	10.1	10.3	10.4	10.5	11.1	11.2	Ranking	Rigor
(Abderrahmane et al., 2014)	0	0	1	1	1	0	1	0	0	1	1	0	0	0	0	1	0	1	1	0	0.5	0	0	0	0	1	1	1	1	1	0	9.5	6.5
(van der Aalst et al., 2005)	1	0	0.5	1	1	1	1	0	0	0	1	0	0	0	0	0.5	0	0	1	1	0	0.5	0	0	0	1	1	1	0.5	0	1	8.5	7.0
(Asuncion et al., 2010)	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	1	1	1	0	0	1	6.0	6.0
(Awadid & Gnannouchi, 2015)	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0.5	1	0	0.5	0	0	1	4.5	3.5
(Ayora et al., 2016)	0	1	1	1	0	1	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0.5	0	0	0	0	1	1	1	0.5	1	0	7.5	6.0
(Ayora et al., 2012)	0	1	1	0	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0.5	0	0	0.5	0	1	1	1	0	0	1	9.0	6.0
(Boffoli et al., 2012)	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	1	1	0	0	1	4.5	5.5
(Boffoli et al., 2009)	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	1	1	0.5	1	1	3.5	7.0
(Bögl et al., 2016)	0	0	0	1	1	1	1	0	0	1	1	1	0	1	0	1	0	0	1	0	0.5	0	0	0	0	1	1	0.5	0	0	1	10.5	5.0
(Borrego & Barba, 2014)	0	1	0	0	0	1	0	0	1	0	1	0	1	0	1	0	1	1	0	1	0	0	1	0	0	1	1	1	0	1	1	9.0	8.0
(Bucchiarone et al., 2013)	0	1	0	1	0	1	1	0	0	1	1	0	0	0	0	0	1	0	1	1	0.5	0	0	0	0	1	1	1	0	0	1	8.5	6.5
(Bucchiarone et al., 2011)	0	0	1	1	0	1	1	0	0	1	1	1	0	0	0	1	1	0	1	0	0	0	0	0.5	0	1	1	1	1	0	1	10.5	6.5
(Cao et al., 2009)	0	1	1	0	1	1	1	0	0	0	1	1	0	0	0	1	0	0	1	0	0	0	0	0	0.5	1	1	1	0	0	1	9.5	5.5
(Châtel et al., 2010)	0	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0.5	0	0	0	0	1	1	1	0	0	1	6.5	5.5
(Cherif et al., 2015)	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	1	1	0	0	1	5.5	5.5
(Czepa et al., 2016)	0	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	1	0	0.5	0	0	0	1	1	1	1	1	1	11.5	7.5
(Dadam & Reichert, 2009)	0	0	1	0	1	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	1	1	0	0	0	7.5	4.5
(Deb et al., 2015)	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0	1	1	1	1	0	1	6.0	8.0

Reference																																	
(Demeyer et al., 2010)	0	1	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0	1	1	1	0	0	1	7.0	7.0
(Gong & Janssen, 2011)	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0.5	1	0	1	0.5	0.5	0	1	1	7.5	6.5
(Haarmann et al., 2015)	0	0	1	0	0	0	1	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0.5	0	0	0	1	1	1	0	0	1	7.5	5.5
(Hallerbach et al., 2010)	0	0	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0.5	0	0	0	0	1	1	1	1	0	1	5.5	7.5
(Hermosillo et al., 2010a)	0	1	1	1	0	1	1	0	0	0	1	1	0.5	0	0	0	0	0	1	1	0.5	0	0	0	0	0.5	0.5	1	1	1	1	9.0	7.5
(Jiang et al., 2016)	0	0	1	1	0	1	1	0	0	1	1	0	0	0	0	0	0	0	1	1	0.5	0	0	0	0	1	1	1	1	0	1	7.5	7.5
(Kannengiesser et al., 2014)	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0.5	1	1	1	1	0	0	1	4.5	6.5
(Kapuruge et al., 2011)	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	1	1	0	0	0	0.5	1	1	1	1	0	0	1	5.5	6.5
(Khriss et al., 2008)	1	1	1	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0.5	1	1	1	0	0	0	1	7.5	5.5
(Kim et al., 2007)	0	1	1	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0.5	0	0	0	1	1	1	1	7.5	5.5
(Li & Du, 2016)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0.5	0	0	0	0	1	0.5	0.5	0	0	1	2.5	5.5
(Liu et al., 2012)	1	1	1	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0.5	0	0	0	0	1	1	1	0	0	1	8.5	6.5
(Marconi et al., 2009)	0	0	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0.5	0.5	0	0	0	0	1	1	1	0	0	1	7.5	6.0
(Martinho et al., 2015)	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	1	1	1	0.5	0	0	0	0	1	1	1	0	0	1	5.5	6.5
(Mattos et al., 2014)	0	0	1	1	0	1	0.5	0	0	0	1	0	0	0	0	0	1	0	1	1	1	0	0	0	1	0	1	1	1	1	1	8.5	9.0
(Mejia Bernal et al., 2010)	0	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	1	0	1	0	0	0.5	0	0	1	1	1	1	0.5	0	1	11.5	6.0
(Mounira & Mahmoud, 2010)	0	1	1	1	1	1	1	0	0	0	1	1	0	0	0	1	0	0	1	0	0.5	0	0	0	0	1	1	1	0	0	1	10.5	5.5
(Natschläger et al., 2016)	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	1	1	0	0	1	4.5	5.5
(Oberhauser, 2016)	0	0	1	0	1	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	1	0.5	0	0	1	6.5	5.0
(Prasad et al., 2015)	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0.5	0	1	0.5	0.5	0	0	0	1	5.5	4.5
(Ramakrishnan, 2009)	0	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0.5	0	0	0	0	1	0.5	0.5	0	0	1	6.5	4.5
(Rong et al., 2008)	1	1	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0.5	1	0.5	0.5	0	0	0	0	1	8.5	4.5
(Saidani & Nurcan, 2006)	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	3.0	2.0

Reference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
(Santo Carvalho et al., 2015)	0	1	0	1	0	1	1	1	1	0	1	1	0	1	0	1	1	1	1	1	0	0	0	1	0	1	1	1	1	0	1	14.0	8.0
(Santo Carvalho et al, 2013)	0	1	0	1	1	0	1	0	0	0	0	1	0	0	0	1	1	0	1	0	0	0	0	0.5	0	1	1	1	0	0	1	8.5	5.5
(Santos et al., 2013)	0	0	1	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0	1	1	1	0	0	1	7.0	7.0
(Santos et al., 2011)	0	1	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	0.5	0.5	0	0	1	6.5	4.5
(Sarno et al., 2015)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	1	1	0	0	1	1.5	5.5
(Sprovieri et al., 2016)	0	0	0.5	1	1	1	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0.5	0	0	0	1	0.5	0.5	0.5	0	1	8.0	5.0
(Sun et al., 2011)	0	1	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0.5	0	0	1	1	1	0.5	0	1	6.5	7.0
(Ukor & Carpenter, 2009)	0	1	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0.5	0	0	0	0	0	0	0	1	0	1	5.5	4.5
(van Eijndhoven et al., 2008)	0	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	0.5	0.5	0	0	1	5.5	4.5
(Wang & Capretz, 2007)	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	1	1	0.5	0	0	0	0	1	1	1	0	0	1	5.5	6.5
(Weidlich et al., 2011)	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0.5	0	0	0	0	1	1	1	0	0	1	3.5	6.5
(Xia & Wei, 2008)	0	1	0	1	1	1	1	0	0	1	1	1	0	0	0	0	1	0	1	1	0.5	0	0	0	0	1	1	1	0	1	1	10.5	7.5
(Xiao et al., 2011)	1	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	1	0	0	1	1	1	0	0	1	8.0	7.0
(Yoo et al., 2008)	0	0	0	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0.5	1	1	1	0	0	1	8.5	6.5
(Yousfi et al., 2016)	0	0	0	1	0	1	1	0	0	0	1	0	0	0	0	0	1	0	1	1	0.5	0	0	0	0	1	1	1	1	1	1	6.5	8.5
(Yuliang et al., 2009)	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0.5	1	0.5	0.5	0	0	1	3.5	4.5
(Gottschalk et al., 2008)	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	1	1	0	0	1	4.5	5.5
(Maggi et al., 2012)	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	1	1	0	0	1	6.0	7.0
(Pesic & van der Aalst, 2006)	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0.5	0	0.5	0	0	1	4.5	4.0
(Wang & Wang, 2006)	0	0	1	1	1	1	1	0	0	0	1	0	0	0	0	0	1	0	1	0.5	0	0	1	0.5	0	0.5	0.5	0.5	0	0	1	9.0	5.5
(Baresi & Guinea, 2005)	0	0	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0.5	1	0.5	0.5	0	0	0	1	7.5	4.5
(van der Aalst	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	1	0	0	1	5.0	6.

et al., 2009)																																	0
(Savickas & Vasilecas, 2018)	1	1	1	1	1	1	1	0	0	0	1	1	0	0	0	1	1	0	1	0.5	0	0	0	1	0	1	1	1	0	0	1	13.0	6.5
(Milanovic et al., 2011)	0	0	1	1	0	1	0	1	1	0	1	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	1	0.5	1	0	0	1	7.5	5.0
(Bucchiarone et al., 2017)	0	0	1	1	1	1	0.5	0	0	0	1	0	0	0	0	0	0	0	1	0.5	0.5	0	0	0	0	1	1	1	1	1	1	7.0	8.0
(Vasilecas et al., 2016b)	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	0	0	0	0	1	0	1	1	1	0	1	1	17.0	7.0

Technology, language or other approaches used in the implementation section of the papers analyzed

1   **Table 9. Technology, language or other approaches used in the implementation section of the**
2   **papers analyzed**

Reference	Technology, language, other approach		Results
(Asuncion et al., 2010; Awadid & Gnannouchi, 2015; Bucchiarone et al., 2011; Châtel et al., 2010; Deb et al., 2015; Gong & Janssen, 2011; Hermosillo et al., 2010a; Kapuruge et al., 2011; Khriss et al., 2008; Marconi et al., 2009; Oberhauser, 2016; Prasad et al., 2015; Ramakrishnan, 2009; Rong et al., 2008; Santos et al., 2011; Sun et al., 2011; Ukor & Carpenter, 2009; Wang & Capretz, 2007; Xia & Wei, 2008; Xiao et al., 2011; Yoo et al., 2008; Yuliang et al., 2009; Baresi & Guinea, 2005; Bucchiarone et al., 2017)	SOA		49%
(van der Aalst et al., 2005; Ayora et al., 2016; Bögl et al., 2016; Jiang et al., 2016; Marconi et al., 2009; Martinho et al., 2015; Mattos et al., 2014; Santos et al., 2013; Santos et al., 2011; van Eijndhoven et al., 2008; Yousfi et al., 2016; Milanovic et al., 2011)	BPMN		15%
(Cherif et al., 2015; Hallerbach et al., 2010; Hermosillo et al., 2010a; Kim et al., 2007; Marconi et al., 2009; Sun et al., 2011; Ukor & Carpenter, 2009; Yoo et al., 2008; Yuliang et al., 2009; Baresi & Guinea, 2005)	BPEL		10%
(Abderrahmane et al., 2014; Asuncion et al., 2010; Sprovieri et al., 2016)	MOF, MDA, CMMN		
(Boffoli et al., 2012; Boffoli et al., 2009; Mejia Bernal et al., 2010)	Decision tables		4.48%
(Li & Du, 2016; Liu et al., 2012; Mejia Bernal et al., 2010; Saidani & Nurcan, 2006; Santo Carvalho et al., 2015)	Not provide any		7.46%

Number of papers according to their rigor and ranking during periods

1   **Table 1. Number of papers according to their rigor and ranking during periods**

Rigor/ranking Period	low rigor [2; 4)	middle rigor [4; 7)	high rigor [7; 9]		low ranking [1; 7)	middle ranking [7; 14)	high ranking [14; 22]	Number of papers
2008-2011	3	12	15		15	15	0	30
2014-2016	2	9	14		11	9	2	22
Number of papers	5	11	29		26	24	2	55

The number of papers according to the rigor-ranking scores

1   **Table 11. The number of papers according to the rigor-ranking scores**

Ranking Rigor	low ranking [1; 7)	middle ranking [7; 14)	high ranking [14; 22)
low rigor [2; 4)	2	0	0
middle rigor [4; 6)	15	13	0
high rigor [6; 9]	13	22	2

Numbers of papers according to the rigor-ranking scores in identified periods

1   **Table 12. Numbers of papers according to the rigor-ranking scores in identified periods**

Ranking ⟍ Rigor	low ranking [1; 7) (A/B/C)	middle ranking [7; 14) (A/B/C)	high ranking [14; 22) (A/B/C)
low rigor [2; 4) (A/B/C)	1/1/0	0/0/0	0/0/0
middle rigor [4; 6) (A/B/C)	4/11/0	0/4/9	0/0/0
high rigor [6; 9] (A/B/C)	2/11/0	0/3/19	0/0/2

Comparison of DBP modeling and simulation tools

1   **Table 13. Comparison of DBP modeling and simulation tools**

Comparison criteria	IBM Websphere[1] (v.7.0 2014)	Simprocess[2] (v 2015)	Simul8[3]	AccuProcess[4]	ARIS 9.7[5]
1. Process model predefined (DBPR-1)					
1.1. predefined process model	+	+	+	+	+
2. Context predefined (DBPR-2)					
2.1 Internal context (or resource model) could be defined before simulation/execution	+	+	+	+	+
2.2 External context could be defined before simulation/execution	-	-	-	-	-
3. Rules predefined (DBPR-3)					
3.1. rules integration into BP	+	+	+	+	+
3.2. rules management	+	+	+	+	+
3.3. comparison of rules	+	-	-	-	+/-
3.4. analysis of rules	+	-	-	-	-
4. Accumulation of experience (DBPR-5)					
4.1. Usage of historical data	+	+	+	+	+
4.2. Analysis of historical data	+/-	+/-	+/-	-	+
5. Changes at runtime (DBPR-4)					
5.1. changes of rules	-	-	-	-	-
5.2. changes of context	-	-	-	-	-
5.3. changes of activities	-	-	+/-	+	+/-

3   [1] http://www-03.ibm.com/software/products/en/modeler-advanced
4   [2] http://simprocess.com
5   [3] http://www.simul8.com
6   [4] http://bpmgeek.com/accuprocess-business-process-modeler
7   [5] http://www.ariscommunity.com/business-process-simulation

Main features of a dynamic BP (RQ3)

1   **Table 14. Main features of a dynamic BP (RQ3)**

Feature	Explanation	Origin	
Not predefined process model	The set of process activities is defined partially, and additional activities can be defined at run-time, if needed. The sequence of process activities is not predefined before process execution, and every next activity is chosen to fit a BP goal.	DBPR-1 Table 4 feature 1 Table 8, the first three columns (1.1, 1.2, and 1.3)	Found in 8 of 67 papers
Context-sensitive	Process instance should respond to the changing context, which is external or internal.	DBPR-2 Table 4 feature 2 Table 8, columns 2.1, 2.2, and 2.3	Found in 50 of 67 papers
Rule-based	The sequence of process activities and content of each activity depend on rules, which are defined, and new rules can be added, if needed, at run-time.	DBPR-3 Table 4 feature 3 Table 8, columns 3.1 – 3.4	Found in 55 of 67 papers
Changes at run-time	All possible changes can be done by any role involved at process instance run-time with possibly low latency.	DBPR-4 Table 4 feature 4 Table 8, columns 4, 1.3, 2.3, 3.2	Found in 55 of 67 papers
Goal-oriented	The selection of each process activity should be aligned with a process goal.	DBPR-6 Table 4 feature 6 Table 8, column 6	Found in 19 of 67 papers
Aligned with a process ontology	All process components should be aligned with a process ontology.	Table 4 feature 7 Table 8, column 7	Found in 10 of 67 papers
Accumulation of experience	The selection of each process activity should be aligned with historical data, accumulated throughout this process.	DBPR-5 Table 4 feature 5 Table 8, columns 5.1 – 5.5	Found in 12 of 67 papers
Feasibility	The feasibility of the process should be ensured.	Table 4 features 9 and 10 Table 8, columns 9.1 – 9.5, 10.1 – 10.5	Found in 63 of 67 papers
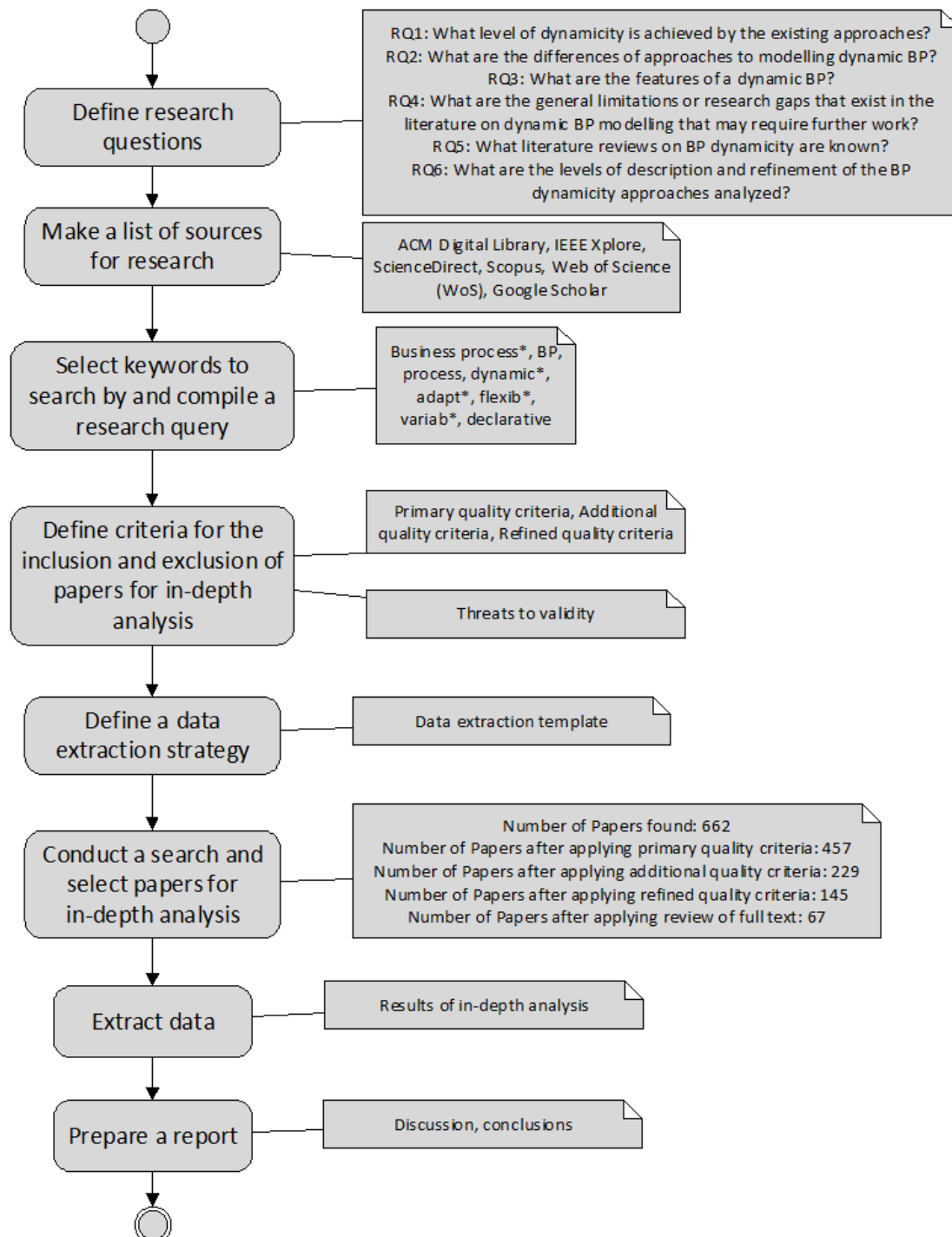
Figure 1

The research method schema

Figure 2

An overview of rigor-ranking scores for the papers on literature reviews on BP dynamicity
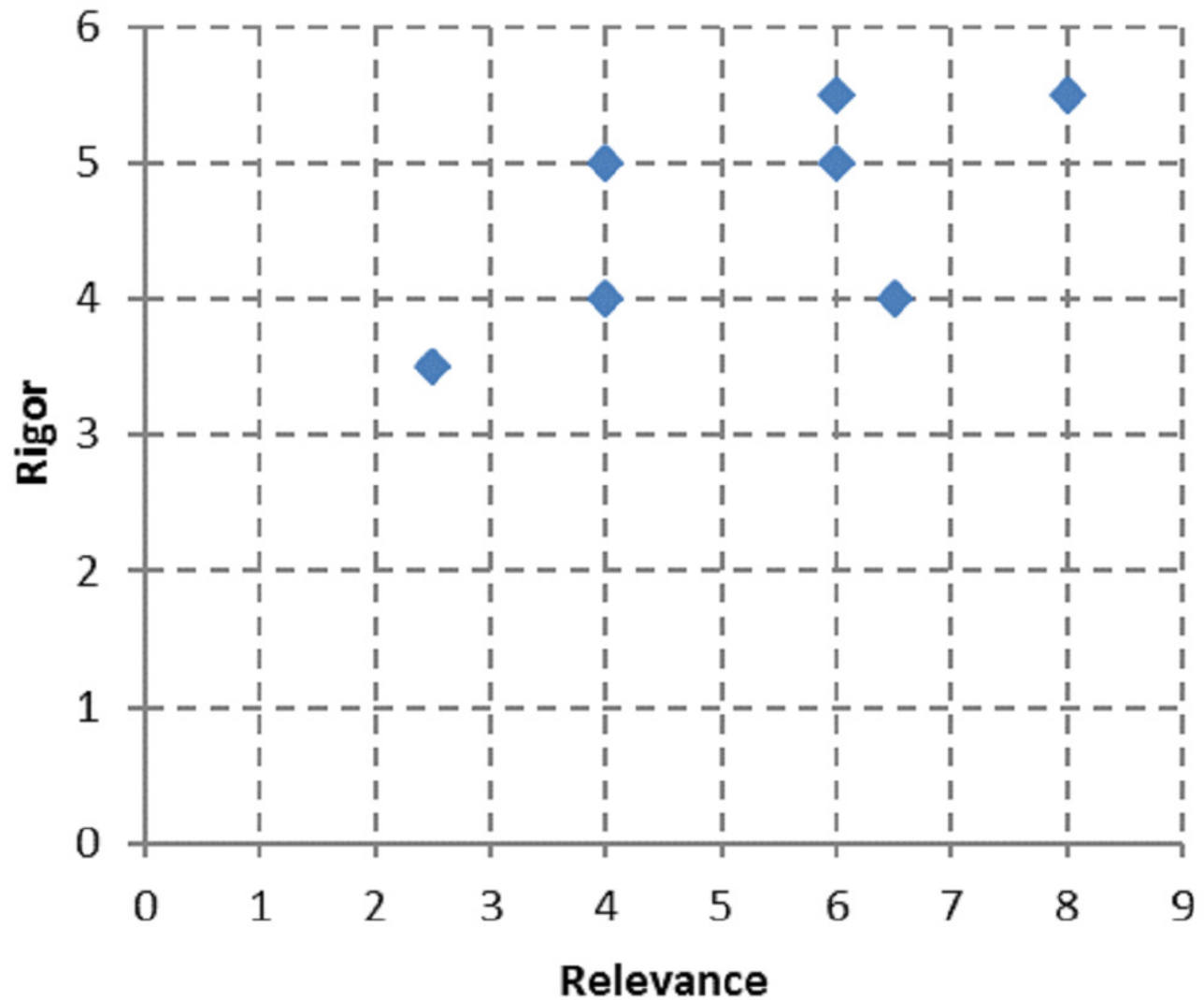
Figure 3

An overview of answers on the assessment of the papers on literature reviews on BP dynamicity
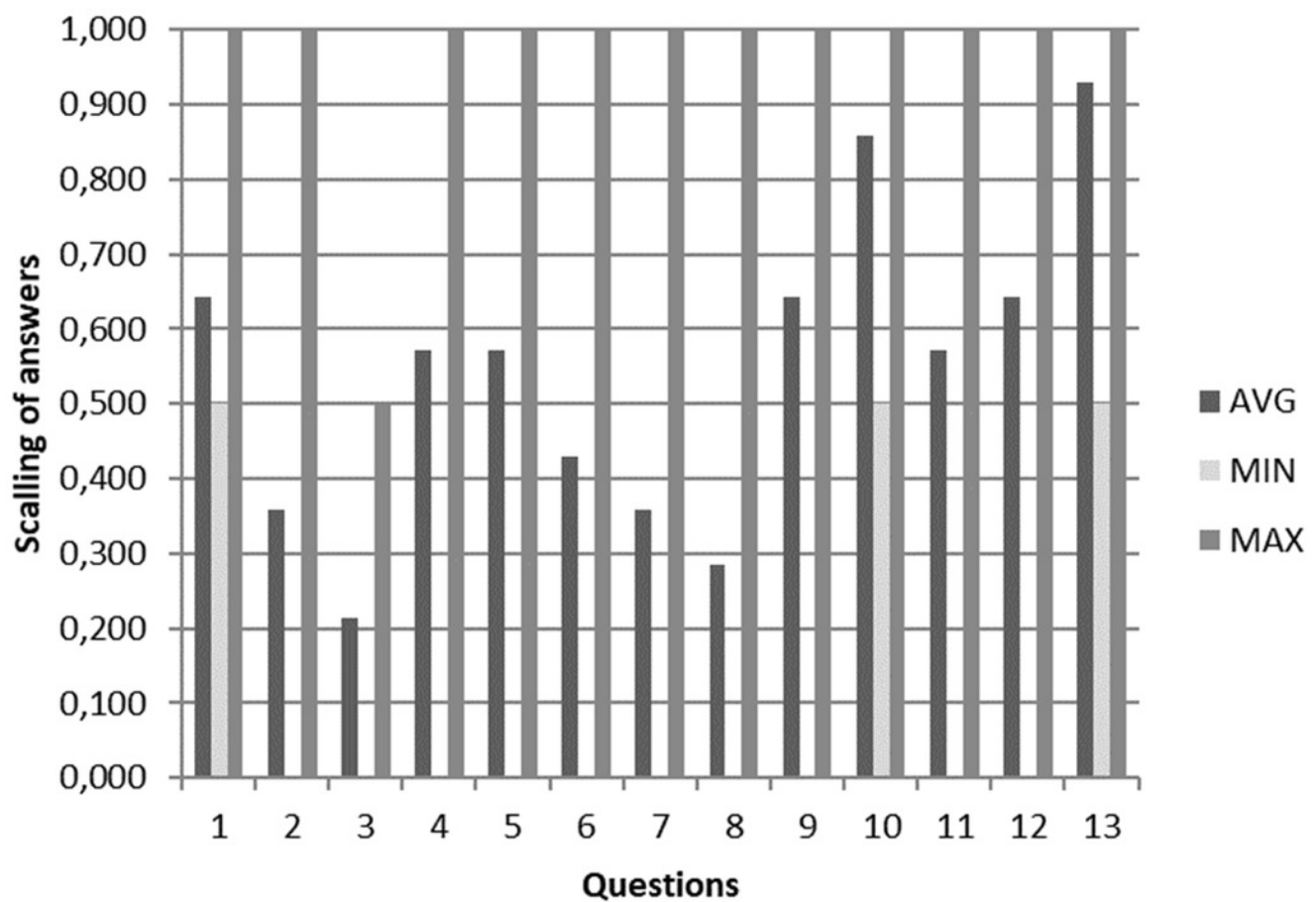
Figure 4

The number of papers on BP dynamicity selected for in-depth analysis by year

Figure 5

Ranking of papers according to rigor

Ranking of papers according to rigor
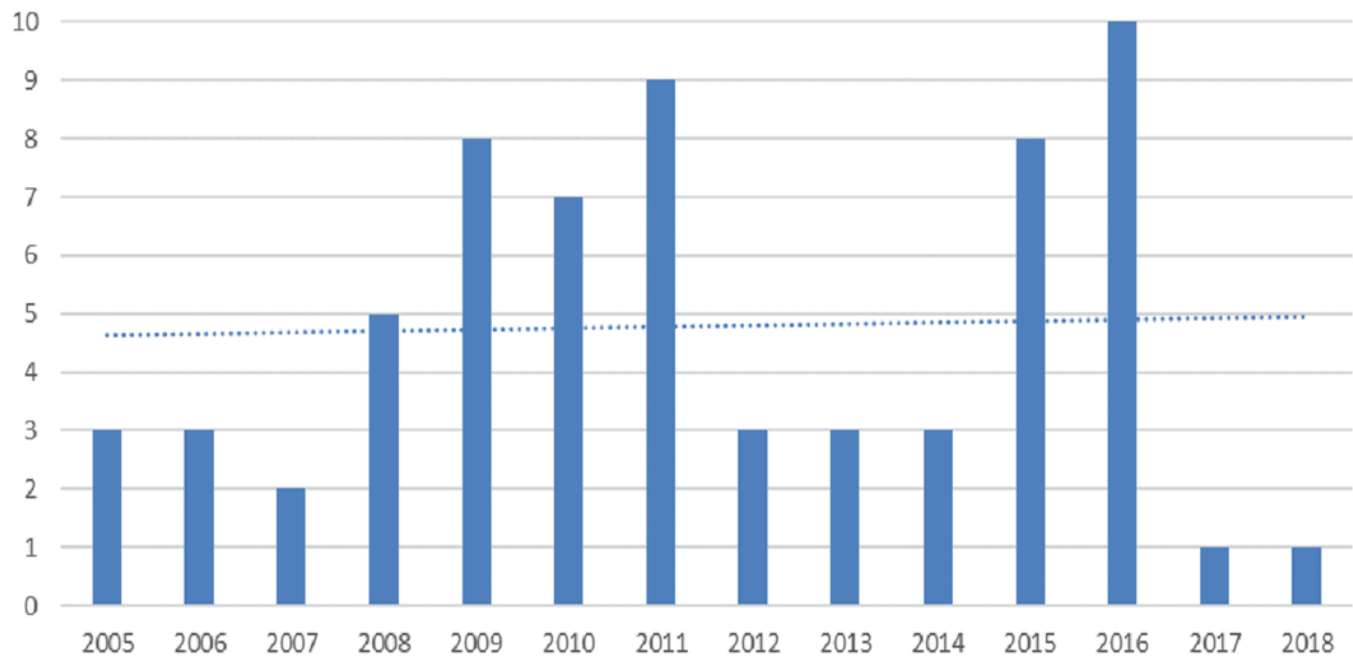
Figure 6

Overview of rigor-ranking scores for the papers

Overview of rigor-ranking scores for the papers
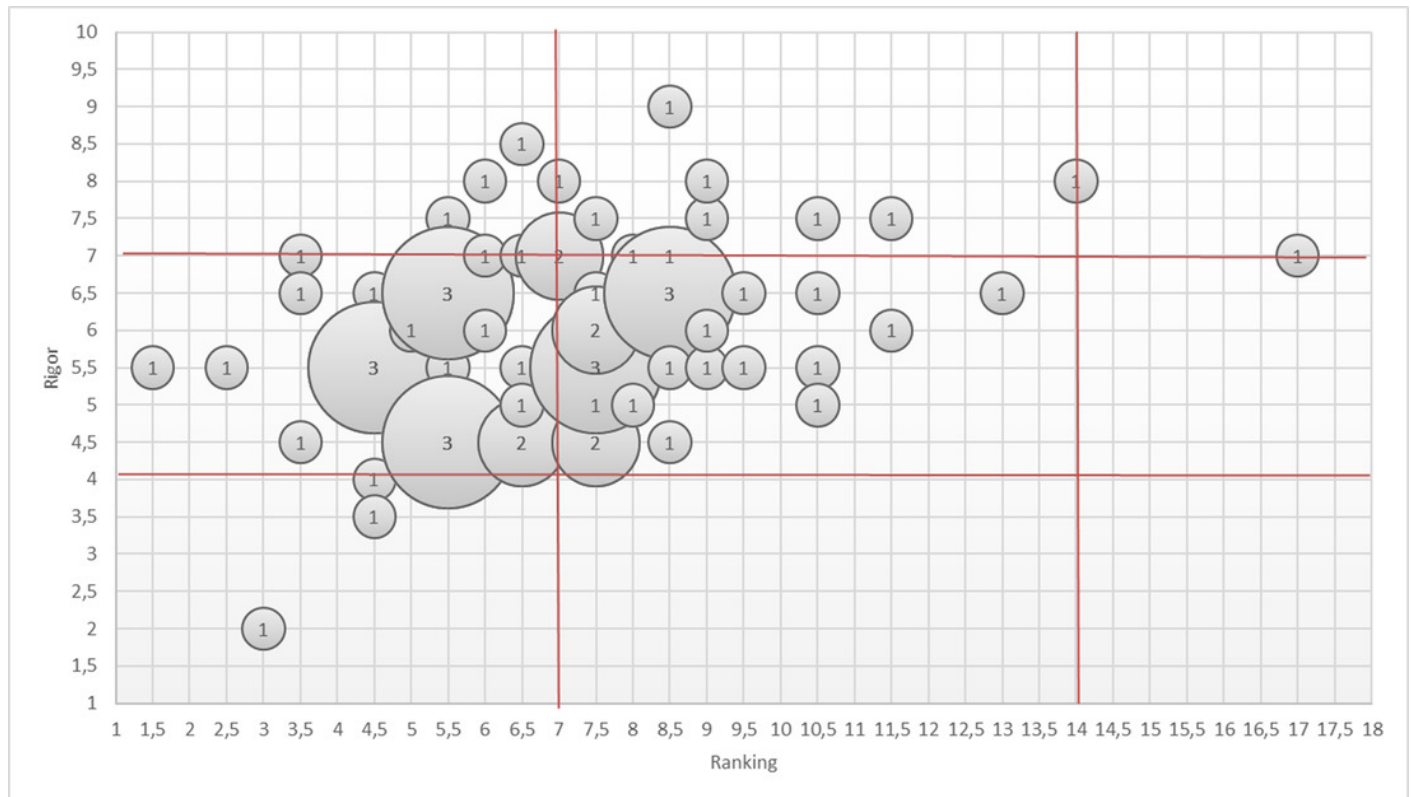
Table 15. Categorization of references used to answer the main research questions on BP dynamicity

Appendix 1 Table 15. Categorization of references used to answer the main research questions on BP dynamicity

1 **Appendix 1**

2   Table 15. Categorization of references used to answer the main research questions on BP dynamicity

RQ	Process dynamicity influencing features	References
RQ1 RQ2 RQ3 RQ4	1. Process model predefined (Essential) (see DBPR-1):	
	1.1. Does a process have a predefined sequence of activities, i.e., a predefined process model?	(Boffoli, Cimitile & Maggi, 2009); (Cao et al., 2009); (Dadam & Reichert, 2009); (Asuncion, Iacob & van Sinderen, 2010); (Châtel, Malenfant & Truck, 2010); (Bucchiarone et al., 2011); (Ayora et al., 2012); (Boffoli et al., 2012); (Bucchiarone, Mezzina & Pistore, 2013); (Abderrahmane, Mili & Boubaker, 2014); (Borrego & Barba, 2014); (Awadid & Gnannouchi, 2015); (Cherif, Djemaa & Amous, 2015); (Deb, Chaki & Ghose, 2015); (Ayora et al., 2016); (Bögl, Natschläger & Geist, 2016); (Czepa et al., 2016); (Demeyer et al., 2010); (Gong & Janssen, 2011); (Haarmann et al., 2015); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kannengiesser et al., 2014); (Kapuruge, Han & Colman, 2011); (Kim, Kim & Kim, 2007); (Li & Du, 2016); (Marconi et al., 2009); (Martinho, Domingos & Varajão, 2015); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Natschläger et al., 2016); (Oberhauser, 2016); (Prasad et al., 2015); (Ramakrishnan, 2009); (Saidani & Nurcan, 2006); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Santos et al., 2013); (Santos et al., 2011); (Sarno et al., 2015); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (Ukor & Carpenter, 2009); (van Eijndhoven, Iacob & Ponisio, 2008); (Weidlich et al., 2011); (Xia & Wei, 2008); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Yuliang et al., 2009); (Gottschalk et al., 2008); (Maggi et al., 2012); (Pesic & van der Aalst, 2006); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (van der Aalst, Pesic & Schonenberg, 2009); (Milanovic, Gasevic & Rocha, 2011) ;(Bucchiarone et al., 2017)
	1.2. Is a process based on meta-model, general model, generic model, or abstract model?	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Boffoli et al., 2012); (Boffoli, Cimitile & Maggi, 2009); (Bögl, Natschläger & Geist, 2016); (Bucchiarone et al., 2011); (Dadam & Reichert, 2009); (Haarmann et al., 2015); (Hallerbach, Bauer & Reichert, 2010); (Jiang et al., 2016); (Kannengiesser et al., 2014); (Kapuruge, Han & Colman, 2011); (Li & Du, 2016); (Marconi et al., 2009); (Martinho, Domingos & Varajão, 2015); (Mattos et al., 2014); (Oberhauser, 2016); (Prasad et al., 2015); (Saidani & Nurcan, 2006); (Santos et al., 2013); (Sarno et al., 2015); (Sprovieri et al., 2016); (van Eijndhoven, Iacob & Ponisio, 2008); (Wang & Capretz, 2007); (Weidlich et al., 2011); (Xiao et al., 2011); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Yuliang et al., 2009); (Gottschalk et al., 2008); (Maggi et al., 2012); (Pesic & van der Aalst, 2006); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (van der Aalst, Pesic & Schonenberg, 2009); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017)
	1.3. Is it possible to define additional activities and to change or delete existing activities or skip to other activities at process instance	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Awadid & Gnannouchi, 2015); (Ayora et al., 2016); (Ayora et al., 2012); (Bucchiarone et al., 2011); (Cao et al., 2009); (Czepa et al., 2016); (Dadam & Reichert, 2009); (Haarmann et al., 2015); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kapuruge, Han & Colman, 2011); (Khriss et al., 2008); (Kim, Kim & Kim, 2007); (Liu et al., 2012); (Marconi et al., 2009); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Oberhauser, 2016); (Santos et al., 2013); (Sprovieri et al., 2016); (Gottschalk et al., 2008); (Maggi et al., 2012);

RQ	Process dynamicity influencing features	References
	run-time?	(Pesic & van der Aalst, 2006); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (van der Aalst, Pesic & Schonenberg, 2009); (Savickas & Vasilecas, 2018); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)
RQ1 RQ2 RQ3 RQ4	2. Context aware (Essential) (see DBPR-2):	
	2.1. Does an external context affect the execution of the process?	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Ayora et al., 2016); (Boffoli et al., 2012); (Boffoli, Cimitile & Maggi, 2009); (Bögl, Natschläger & Geist, 2016); (Bucchiarone, Mezzina & Pistore, 2013); (Bucchiarone et al., 2011); (Cherif, Djemaa & Amous, 2015); (Deb, Chaki & Ghose, 2015); (Demeyer et al., 2010); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Marconi et al., 2009); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Rong, Liu & Liang, 2008); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Santos et al., 2013); (Santos et al., 2011); (Sprovieri et al., 2016); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (Savickas & Vasilecas, 2018); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)
	2.2. Does an internal context affect the execution of the process?	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Ayora et al., 2012); (Boffoli et al., 2012); (Bögl, Natschläger & Geist, 2016); (Cao et al., 2009); (Châtel, Malenfant & Truck, 2010); (Czepa et al., 2016); (Dadam & Reichert, 2009); (Khriss et al., 2008); (Kim, Kim & Kim, 2007); (Liu et al., 2012); (Marconi et al., 2009); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Natschläger et al., 2016); (Oberhauser, 2016); (Prasad et al., 2015); (Ramakrishnan, 2009); (Rong, Liu & Liang, 2008); (Saidani & Nurcan, 2006); (Santo Carvalho et al., 2013); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (Ukor & Carpenter, 2009); (van Eijndhoven, Iacob & Ponisio, 2008); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (Savickas & Vasilecas, 2018); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)
	2.3. Is a process instance affected by the change of a context at run-time?	(van der Aalst, Weske & Grünbauer, 2005); (Ayora et al., 2016); (Ayora et al., 2012); (Bögl, Natschläger & Geist, 2016); (Bucchiarone, Mezzina & Pistore, 2013); (Bucchiarone et al., 2011); (Cao et al., 2009); (Cherif, Djemaa & Amous, 2015); (Czepa et al., 2016); (Dadam & Reichert, 2009); (Demeyer et al., 2010); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Khriss et al., 2008); (Kim, Kim & Kim, 2007); (Liu et al., 2012); (Marconi et al., 2009); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Oberhauser, 2016); (Rong, Liu & Liang, 2008); (Santo Carvalho, Santoro & Revoredo, 2015); (Santos et al., 2011); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (Ukor & Carpenter, 2009); (van Eijndhoven, Iacob & Ponisio, 2008); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (Savickas & Vasilecas, 2018); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)
RQ1 RQ2 RQ3 RQ4	3. Rule-based[1] (Essential) (see DBPR-3):	
	3.1. Is every subsequent activity in a process selected according to the predefined	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Asuncion, Iacob & van Sinderen, 2010); (Ayora et al., 2016); (Ayora et al., 2012); (Boffoli et al., 2012); (Boffoli, Cimitile & Maggi, 2009); (Bögl, Natschläger & Geist, 2016); (Borrego & Barba, 2014); (Bucchiarone, Mezzina & Pistore, 2013);

RQ	Process dynamicity influencing features	References
	rules at process instance run-time?	(Bucchiarone et al., 2011); (Cao et al., 2009); (Châtel, Malenfant & Truck, 2010); (Czepa et al., 2016); (Dadam & Reichert, 2009); (Deb, Chaki & Ghose, 2015); (Demeyer et al., 2010); (Gong & Janssen, 2011); (Haarmann et al., 2015); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kapuruge, Han & Colman, 2011); (Liu et al., 2012); (Marconi et al., 2009); (Martinho, Domingos & Varajão, 2015); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Natschläger et al., 2016); (Oberhauser, 2016); (Prasad et al., 2015); (Rong, Liu & Liang, 2008); (Saidani & Nurcan, 2006); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Santos et al., 2013); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (Ukor & Carpenter, 2009); (van Eijndhoven, Iacob & Ponisio, 2008); (Wang & Capretz, 2007); (Weidlich et al., 2011); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Yuliang et al., 2009); (Gottschalk et al., 2008); (Maggi et al., 2012); (Pesic & van der Aalst, 2006); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (van der Aalst, Pesic & Schonenberg, 2009); (Savickas & Vasilecas, 2018); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)
	3.2. Is it possible to define new rules, or change or delete existing rules, at process instance run-time?	(Czepa et al., 2016); (Mejia Bernal et al., 2010); (Santo Carvalho, Santoro & Revoredo, 2015); (Yoo et al., 2008); (Milanovic, Gasevic & Rocha, 2011); (Vasilecas, Kalibatiene & Lavbič, 2016)
	3.3. Does process instance react to the rule changes made at process instance run-time?	(Czepa et al., 2016); (Mejia Bernal et al., 2010); (Santo Carvalho, Santoro & Revoredo, 2015); (Yoo et al., 2008); (Milanovic, Gasevic & Rocha, 2011); (Vasilecas, Kalibatiene & Lavbič, 2016)
	3.4. Are rules used to solve other tasks?	(Abderrahmane, Mili & Boubaker, 2014); (Asuncion, Iacob & van Sinderen, 2010); (Bögl, Natschläger & Geist, 2016); (Borrego & Barba, 2014); (Bucchiarone, Mezzina & Pistore, 2013); (Bucchiarone et al., 2011); (Châtel, Malenfant & Truck, 2010); (Czepa et al., 2016); (Dadam & Reichert, 2009); (Jiang et al., 2016); (Kannengiesser et al., 2014); (Kim, Kim & Kim, 2007); (Li & Du, 2016); (Martinho, Domingos & Varajão, 2015); (Ramakrishnan, 2009); (Santos et al., 2013); (Santos et al., 2011); (Weidlich et al., 2011); (Xia & Wei, 2008); (Maggi et al., 2012)
RQ1 RQ2 RQ3 RQ4	4. Changes (Essential): Are changes implemented at process instance run-time with low latency? (see DBPR-4)	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Awadid & Gnannouchi, 2015); (Ayora et al., 2016); (Ayora et al., 2012); (Bögl, Natschläger & Geist, 2016); (Bucchiarone, Mezzina & Pistore, 2013); (Bucchiarone et al., 2011); (Cao et al., 2009); (Cherif, Djemaa & Amous, 2015); (Czepa et al., 2016); (Dadam & Reichert, 2009); (Demeyer et al., 2010); (Gong & Janssen, 2011); (Haarmann et al., 2015); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kannengiesser et al., 2014); (Kapuruge, Han & Colman, 2011); (Khriss et al., 2008); (Kim, Kim & Kim, 2007); (Liu et al., 2012); (Marconi et al., 2009); (Martinho, Domingos & Varajão, 2015); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Oberhauser, 2016); (Prasad et al., 2015); (Ramakrishnan, 2009); (Rong, Liu & Liang, 2008); (Santo Carvalho, Santoro & Revoredo, 2015); (Santos et al., 2013); (Santos et al., 2011); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (Ukor & Carpenter, 2009); (van Eijndhoven, Iacob & Ponisio, 2008); (Wang & Capretz, 2007); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008);

RQ	Process dynamicity influencing features	References
		(Yousfi, Saidi & Dey, 2016); (Yuliang et al., 2009); (Gottschalk et al., 2008); (Maggi et al., 2012); (Pesic & van der Aalst, 2006); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (van der Aalst, Pesic & Schonenberg, 2009); (Savickas & Vasilecas, 2018); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)
RQ1 RQ2 RQ3 RQ4	5. Accumulation of experience (see DBPR-5):	
	5.1. Is the experience of each process instance execution stored?	(Bögl, Natschläger & Geist, 2016); (Borrego & Barba, 2014); (Bucchiarone et al., 2011); (Cao et al., 2009); (Haarmann et al., 2015); (Hermosillo, Seinturier & Duchien, 2010); (Mounira & Mahmoud, 2010); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Xia & Wei, 2008); (Savickas & Vasilecas, 2018); (Vasilecas, Kalibatiene & Lavbič, 2016)
	5.2. Is it possible to classify executed instances of a process as a "good practice" and a "bad practice"?	(Hermosillo, Seinturier & Duchien, 2010); (Vasilecas, Kalibatiene & Lavbič, 2016)
	5.3. Are time, cost, etc. values calculated and stored for each process instance?	(Bögl, Natschläger & Geist, 2016); (Borrego & Barba, 2014); (Haarmann et al., 2015); (Santo Carvalho, Santoro & Revoredo, 2015); (Vasilecas, Kalibatiene & Lavbič, 2016)
	5.4. Is it possible to restrict the execution of process instances that are named "bad instances"?	(Vasilecas, Kalibatiene & Lavbič, 2016)
	5.5. Is historical data used for solving other related tasks?	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Bögl, Natschläger & Geist, 2016); (Borrego & Barba, 2014); (Bucchiarone et al., 2011); (Cao et al., 2009); (Haarmann et al., 2015); (Mattos et al., 2014); (Mounira & Mahmoud, 2010); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Savickas & Vasilecas, 2018)
RQ1 RQ2 RQ3 RQ4	6. Goal: Is a process goal-oriented? (see DBPR-6)	(Asuncion, Iacob & van Sinderen, 2010); (Ayora et al., 2012); (Borrego & Barba, 2014); (Bucchiarone, Mezzina & Pistore, 2013); (Bucchiarone et al., 2011); (Deb, Chaki & Ghose, 2015); (Gong & Janssen, 2011); (Kapuruge, Han & Colman, 2011); (Mejia Bernal et al., 2010); (Saidani & Nurcan, 2006); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Sprovieri et al., 2016); (Wang & Capretz, 2007); (Xia & Wei, 2008); (Yousfi, Saidi & Dey, 2016); (Wang & Wang, 2006); (Savickas & Vasilecas, 2018); (Vasilecas, Kalibatiene & Lavbič, 2016)
RQ1 RQ2 RQ3 RQ4	7. Ontology: Is domain ontology or process ontology used in an approach?	(Abderrahmane, Mili & Boubaker, 2014); (Châtel, Malenfant & Truck, 2010); (Czepa et al., 2016); (Gong & Janssen, 2011); (Kannengiesser et al., 2014); (Martinho, Domingos & Varajão, 2015); (Mattos et al., 2014); (Prasad et al., 2015); (Ramakrishnan, 2009); (Santo Carvalho, Santoro & Revoredo, 2015)
RQ2	8. Approach description:	

RQ	Process dynamicity influencing features	References
RQ3 RQ4 RQ6	8.1. Does the paper present a clear description of the proposed approach on BP dynamicity?	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Asuncion, Iacob & van Sinderen, 2010); (Awadid & Gnannouchi, 2015); (Ayora et al., 2016); (Ayora et al., 2012); (Boffoli et al., 2012); (Boffoli, Cimitile & Maggi, 2009); (Bögl, Natschläger & Geist, 2016); (Borrego & Barba, 2014); (Bucchiarone, Mezzina & Pistore, 2013); (Bucchiarone et al., 2011); (Cao et al., 2009); (Châtel, Malenfant & Truck, 2010); (Cherif, Djemaa & Amous, 2015); (Czepa et al., 2016); (Dadam & Reichert, 2009); (Deb, Chaki & Ghose, 2015); (Demeyer et al., 2010); (Gong & Janssen, 2011); (Haarmann et al., 2015); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kannengiesser et al., 2014); (Kapuruge, Han & Colman, 2011); (Khriss et al., 2008); (Kim, Kim & Kim, 2007); (Li & Du, 2016); (Liu et al., 2012); (Marconi et al., 2009); (Martinho, Domingos & Varajão, 2015); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Natschläger et al., 2016); (Oberhauser, 2016); (Prasad et al., 2015); (Ramakrishnan, 2009); (Rong, Liu & Liang, 2008); (Saidani & Nurcan, 2006); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Santos et al., 2013); (Santos et al., 2011); (Sarno et al., 2015); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (Ukor & Carpenter, 2009); (van Eijndhoven, Iacob & Ponisio, 2008); (Wang & Capretz, 2007); (Weidlich et al., 2011); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Yuliang et al., 2009); (Gottschalk et al., 2008); (Maggi et al., 2012); (Pesic & van der Aalst, 2006); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (van der Aalst, Pesic & Schonenberg, 2009); (Savickas & Vasilecas, 2018); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)
	8.2. Does the paper present a description of the proposed approach on dynamic BP in a formal language?	(van der Aalst, Weske & Grünbauer, 2005); (Borrego & Barba, 2014); (Bucchiarone, Mezzina & Pistore, 2013); (Deb, Chaki & Ghose, 2015); (Demeyer et al., 2010); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kannengiesser et al., 2014); (Kapuruge, Han & Colman, 2011); (Li & Du, 2016); (Liu et al., 2012); (Marconi et al., 2009); (Martinho, Domingos & Varajão, 2015); (Mattos et al., 2014); (Santo Carvalho, Santoro & Revoredo, 2015); (Santos et al., 2013); (Sun, Huang & Meng, 2011); (Ukor & Carpenter, 2009); (Wang & Capretz, 2007); (Weidlich et al., 2011); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Maggi et al., 2012); (Wang & Wang, 2006); (Savickas & Vasilecas, 2018); (Bucchiarone et al., 2017)
RQ1 RQ2 RQ3 RQ4 RQ6	9. Dynamicity implementation approach (if 1.1. is yes):	
	9.1. Is the process dynamicity realized through variants?	(Abderrahmane, Mili & Boubaker, 2014); (Ayora et al., 2016); (Ayora et al., 2012); (Boffoli et al., 2012); (Boffoli, Cimitile & Maggi, 2009); (Bögl, Natschläger & Geist, 2016); (Bucchiarone, Mezzina & Pistore, 2013); (Châtel, Malenfant & Truck, 2010); (Cherif, Djemaa & Amous, 2015); (Dadam & Reichert, 2009); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kim, Kim & Kim, 2007); (Li & Du, 2016); (Marconi et al., 2009); (Martinho, Domingos & Varajão, 2015); (Natschläger et al., 2016); (Oberhauser, 2016); (Ramakrishnan, 2009); (Santos et al., 2011); (Sarno et al., 2015); (Ukor & Carpenter, 2009); (van Eijndhoven, Iacob & Ponisio, 2008); (Wang & Capretz, 2007); (Weidlich et al., 2011); (Xia & Wei, 2008); (Yousfi, Saidi & Dey, 2016); (Gottschalk et al., 2008); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017)
	9.2. Is the process dynamicity	(van der Aalst, Weske & Grünbauer, 2005); (Czepa et al., 2016); (Haarmann et al., 2015); (Sprovieri et al., 2016)

RQ	Process dynamicity influencing features	References
	realized through cases?	
	9.3. Is the process dynamicity realized through a declarative approach?	(Borrego & Barba, 2014); (Demeyer et al., 2010); (Gong & Janssen, 2011); (Mejia Bernal et al., 2010); (Santos et al., 2013); (Sun, Huang & Meng, 2011); (Xiao et al., 2011); (Maggi et al., 2012); (Pesic & van der Aalst, 2006); (Wang & Wang, 2006); (van der Aalst, Pesic & Schonenberg, 2009)
	9.4. Is the process dynamicity realized through goal-orientation?	(Asuncion, Iacob & van Sinderen, 2010); (Ayora et al., 2012); (Bucchiarone et al., 2011); (Deb, Chaki & Ghose, 2015); (Gong & Janssen, 2011); (Mattos et al., 2014); (Prasad et al., 2015); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Wang & Wang, 2006); (Savickas & Vasilecas, 2018); (Vasilecas, Kalibatiene & Lavbič, 2016)
	9.5. Is the process dynamicity realized through other approaches?	(Awadid & Gnannouchi, 2015); (Cao et al., 2009); (Kannengiesser et al., 2014); (Kapuruge, Han & Colman, 2011); (Khriss et al., 2008); (Liu et al., 2012); (Mounira & Mahmoud, 2010); (Rong, Liu & Liang, 2008); (Yoo et al., 2008); (Yuliang et al., 2009); (Baresi & Guinea, 2005)
RQ2 RQ3 RQ4 RQ6	10. Implementation of the proposed approach:	
	10.1. Is any case of implementation of a proposed model presented in the paper?	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Asuncion, Iacob & van Sinderen, 2010); (Awadid & Gnannouchi, 2015); (Ayora et al., 2016); (Ayora et al., 2012); (Boffoli et al., 2012); (Boffoli, Cimitile & Maggi, 2009); (Bögl, Natschläger & Geist, 2016); (Borrego & Barba, 2014); (Bucchiarone, Mezzina & Pistore, 2013); (Bucchiarone et al., 2011); (Cao et al., 2009); (Châtel, Malenfant & Truck, 2010); (Cherif, Djemaa & Amous, 2015); (Czepa et al., 2016); (Dadam & Reichert, 2009); (Deb, Chaki & Ghose, 2015); (Demeyer et al., 2010); (Gong & Janssen, 2011); (Haarmann et al., 2015); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kannengiesser et al., 2014); (Kapuruge, Han & Colman, 2011); (Khriss et al., 2008); (Kim, Kim & Kim, 2007); (Li & Du, 2016); (Liu et al., 2012); (Marconi et al., 2009); (Martinho, Domingos & Varajão, 2015); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Natschläger et al., 2016); (Oberhauser, 2016); (Prasad et al., 2015); (Ramakrishnan, 2009); (Rong, Liu & Liang, 2008); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Santos et al., 2013); (Santos et al., 2011); (Sarno et al., 2015); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (van Eijndhoven, Iacob & Ponisio, 2008); (Wang & Capretz, 2007); (Weidlich et al., 2011); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Yuliang et al., 2009); (Gottschalk et al., 2008); (Maggi et al., 2012); (Pesic & van der Aalst, 2006); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (van der Aalst, Pesic & Schonenberg, 2009); (Savickas & Vasilecas, 2018); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)
	10.3. Does the paper present a case study or a prototype or a descriptive example?	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Asuncion, Iacob & van Sinderen, 2010); (Ayora et al., 2016); (Ayora et al., 2012); (Boffoli et al., 2012); (Boffoli, Cimitile & Maggi, 2009); (Bögl, Natschläger & Geist, 2016); (Borrego & Barba, 2014); (Bucchiarone, Mezzina & Pistore, 2013); (Bucchiarone et al., 2011); (Cao et al., 2009); (Châtel, Malenfant & Truck, 2010); (Cherif, Djemaa & Amous, 2015); (Czepa et al., 2016); (Dadam & Reichert, 2009); (Deb, Chaki & Ghose, 2015); (Demeyer et al., 2010); (Gong & Janssen, 2011); (Haarmann et al., 2015); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kannengiesser et al., 2014); (Kapuruge, Han & Colman, 2011); (Khriss et al., 2008); (Kim, Kim & Kim, 2007); (Li & Du, 2016); (Liu et al., 2012); (Marconi et al., 2009); (Martinho,

RQ	Process dynamicity influencing features	References
		Domingos & Varajão, 2015); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Natschläger et al., 2016); (Oberhauser, 2016); (Prasad et al., 2015); (Ramakrishnan, 2009); (Rong, Liu & Liang, 2008); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Santos et al., 2013); (Santos et al., 2011); (Sarno et al., 2015); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (van Eijndhoven, Iacob & Ponisio, 2008); (Wang & Capretz, 2007); (Weidlich et al., 2011); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Yuliang et al., 2009); (Gottschalk et al., 2008); (Maggi et al., 2012); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (van der Aalst, Pesic & Schonenberg, 2009); (Savickas & Vasilecas, 2018); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)
	10.4. Does the paper present a clear description of an implementation with text, screen shots, and code lines?	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Asuncion, Iacob & van Sinderen, 2010); (Awadid & Gnannouchi, 2015); (Ayora et al., 2016); (Ayora et al., 2012); (Boffoli et al., 2012); (Boffoli, Cimitile & Maggi, 2009); (Bögl, Natschläger & Geist, 2016); (Borrego & Barba, 2014); (Bucchiarone, Mezzina & Pistore, 2013); (Bucchiarone et al., 2011); (Cao et al., 2009); (Châtel, Malenfant & Truck, 2010); (Cherif, Djemaa & Amous, 2015); (Czepa et al., 2016); (Dadam & Reichert, 2009); (Deb, Chaki & Ghose, 2015); (Demeyer et al., 2010); (Gong & Janssen, 2011); (Haarmann et al., 2015); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kannengiesser et al., 2014); (Kapuruge, Han & Colman, 2011); (Khriss et al., 2008); (Kim, Kim & Kim, 2007); (Li & Du, 2016); (Liu et al., 2012); (Marconi et al., 2009); (Martinho, Domingos & Varajão, 2015); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Natschläger et al., 2016); (Oberhauser, 2016); (Prasad et al., 2015); (Ramakrishnan, 2009); (Rong, Liu & Liang, 2008); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Santos et al., 2013); (Santos et al., 2011); (Sarno et al., 2015); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (van Eijndhoven, Iacob & Ponisio, 2008); (Wang & Capretz, 2007); (Weidlich et al., 2011); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Yuliang et al., 2009); (Gottschalk et al., 2008); (Maggi et al., 2012); (Pesic & van der Aalst, 2006); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (van der Aalst, Pesic & Schonenberg, 2009); (Savickas & Vasilecas, 2018); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)
	10.5. Does the paper evaluate the results obtained?	(Abderrahmane, Mili & Boubaker, 2014); (van der Aalst, Weske & Grünbauer, 2005); (Ayora et al., 2016); (Boffoli, Cimitile & Maggi, 2009); (Bucchiarone et al., 2011); (Czepa et al., 2016); (Deb, Chaki & Ghose, 2015); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Santo Carvalho, Santoro & Revoredo, 2015); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (Ukor & Carpenter, 2009); (Yousfi, Saidi & Dey, 2016); (Bucchiarone et al., 2017)
RQ4 RQ6	11. Discussion and conclusions:	
	11.1. Does the paper present an appropriate discussion on dynamicity?	(Abderrahmane, Mili & Boubaker, 2014); (Ayora et al., 2016); (Boffoli, Cimitile & Maggi, 2009); (Borrego & Barba, 2014); (Czepa et al., 2016); (Gong & Janssen, 2011); (Hermosillo, Seinturier & Duchien, 2010); (Mattos et al., 2014); (Xia & Wei, 2008); (Yousfi, Saidi & Dey, 2016); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)

RQ	Process dynamicity influencing features	References
	11.2. Does the paper present grounded conclusions about dynamicity?	(van der Aalst, Weske & Grünbauer, 2005); (Asuncion, Iacob & van Sinderen, 2010); (Awadid & Gnannouchi, 2015); (Ayora et al., 2012); (Boffoli et al., 2012); (Boffoli, Cimitile & Maggi, 2009); (Bögl, Natschläger & Geist, 2016); (Borrego & Barba, 2014); (Bucchiarone, Mezzina & Pistore, 2013); (Bucchiarone et al., 2011); (Cao et al., 2009); (Châtel, Malenfant & Truck, 2010); (Cherif, Djemaa & Amous, 2015); (Czepa et al., 2016); (Deb, Chaki & Ghose, 2015); (Demeyer et al., 2010); (Gong & Janssen, 2011); (Haarmann et al., 2015); (Hallerbach, Bauer & Reichert, 2010); (Hermosillo, Seinturier & Duchien, 2010); (Jiang et al., 2016); (Kannengiesser et al., 2014); (Kapuruge, Han & Colman, 2011); (Khriss et al., 2008); (Kim, Kim & Kim, 2007); (Li & Du, 2016); (Liu et al., 2012); (Marconi et al., 2009); (Martinho, Domingos & Varajão, 2015); (Mattos et al., 2014); (Mejia Bernal et al., 2010); (Mounira & Mahmoud, 2010); (Natschläger et al., 2016); (Oberhauser, 2016); (Prasad et al., 2015); (Ramakrishnan, 2009); (Rong, Liu & Liang, 2008); (Saidani & Nurcan, 2006); (Santo Carvalho, Santoro & Revoredo, 2015); (Santo Carvalho et al., 2013); (Santos et al., 2013); (Santos et al., 2011); (Sarno et al., 2015); (Sprovieri et al., 2016); (Sun, Huang & Meng, 2011); (Ukor & Carpenter, 2009); (van Eijndhoven, Iacob & Ponisio, 2008); (Wang & Capretz, 2007); (Weidlich et al., 2011); (Xia & Wei, 2008); (Xiao et al., 2011); (Yoo et al., 2008); (Yousfi, Saidi & Dey, 2016); (Yuliang et al., 2009); (Gottschalk et al., 2008); (Maggi et al., 2012); (Pesic & van der Aalst, 2006); (Wang & Wang, 2006); (Baresi & Guinea, 2005); (van der Aalst, Pesic & Schonenberg, 2009); (Savickas & Vasilecas, 2018); (Milanovic, Gasevic & Rocha, 2011); (Bucchiarone et al., 2017); (Vasilecas, Kalibatiene & Lavbič, 2016)

Figure 7

Ranking of papers according to years

Ranking of papers according to years

Figure 8

The evolution of research on BP dynamicity