As a second search strategy complementing the keyword searches and as suggested by Webster and Watson (2002), we scanned the table of contents of journals and conference proceedings. All eight journals listed in the Senior Scholars' Basket of Journals were considered. The journal Business & Information Systems Engineering (BISE)/WIRTSCHAFTSINFORMATIK as relevant outlet for the German-language Business Informatics community and two further relevant journals, the Journal of Simulation (JS) and the Business Process Management Journal (BPMJ), were added for which focus and scope comply with the focus of this study. Additionally, proceedings of nine conferences were added to the sample of sources to also account for more recent publications. Seven of the chosen conferences are organised by or affiliated with associations relevant to the disciplines of Information Systems or Business and Information Systems Engineering. The conferences included in the search are the Americas Conference on Information Systems (AMCIS), European Conference on Information Systems (ECIS), Hawaii International Conference on System Sciences (HICSS), International Conference on Enterprise Information Systems (ICEIS), International Conference on Information Systems (ICIS), Internationale Tagung Wirtschaftsinformatik (WI) and the Winter Simulation Conference (WSC). The proceedings of the Conference on Advanced Information Systems Engineering (CAISE) are added to the sources as it includes contributions from the Workshop on Enterprise & Organizational Modeling and Simulation (EOMAS) which addresses topics including BPS; proceedings of the International Conference on Business Process Management (BPM conference series) are also included as the conference directly addresses BPM as research field. The final sample of sources consists of 11 journals and 9 conference proceedings. As a result of manually scanning the table of contents of these sources and viewing titles, abstracts and, in doubt, the full texts of publications, we added 15 journal articles and 54 articles published in conference proceedings to the sample (a list of these publications is available upon request from the authors).

Illustrating the limitations of database searches, several publications on BPS which we encountered afore when selectively reviewing the field of research were not yet included in the sample. These publications include journal and conference articles not published in a source in our sample of journals and conference proceedings and not indexed in the queried electronic databases as well as articles published in anthologies and publications published in German. As a third step, we thus added these 18 publications on BPS to the sample. To obtain additional relevant publications, such as monographs and articles published in anthologies, backward and forward searches based on ten articles, identified as key articles for the literature retrieval, were performed (vom Brocke et al., 2015, pp. 215f). Based on reviewing the current sample and requiring a consensus among the authors, the following publications were chosen as key articles: Tumay (1995), Tumay (1996), Giaglis et al. (1999), Paul et al. (1999), Desel and Erwin (2000), Greasley (2003), Jansen-Vullers and Netjes (2006), Barjis (2007), Barjis and Verbraeck (2010) and Liu and Iijima (2015). The selection of key articles is based on two criteria: (1) a key article is cited multiple times in several articles on BPS; or (2) a key article provides an overview of the field of BPS. To accomplish backward and forward searches, we scrutinised the bibliographies of the key articles resp. the results of forward searches using the search engine Google Scholar for publications not covered so far by our search strategies—by reason of publication date, type, or source—leading to 11 additional results by backward searches and 17 additional results by forward searches. The literature search process at this stage resulted in a sample of 300 publications—after removing duplicates.

As a next step, publications outside of the focus of this study were excluded from the sample. The fulfilment of all of the following criteria was required for a publication to be included in the resulting final sample: (1) original research contribution; (2) focus on simulation of business processes using graphical process models as starting point; (3) detailed description of the simulation approach. Hence, editorials, book reviews, tutorials, textbooks or parts of textbooks as well as education-related publications were excluded. Likewise, publications only marginally referring to BPS were excluded, for example, publications only briefly mentioning BPS as a functionality of a software tool (e.g. Junginger et al., 2000). The same applied to suggested frameworks, for example, aimed at business process redesign which do not present details on performing a simulation. Also, publications on conceptual and/or process modelling as means for developing simulation models are excluded from the sample if they do not start from a graphical process model, e.g., Wagner et al. (2016) and Guizzardi and

Wagner (2011). Moreover, publications focusing on the use of historical data for construction of simulation models are excluded (e.g. van der Aalst, 2010). The third inclusion criterion refers to the level of detail regarding the considered simulation approach: Only publications are included which provide a traceable presentation about specifying the underlying process modelling language of constructing business process models as basis for simulation and the simulation approach. Also, publications not written in English or German language were excluded. In this pruning process, all 300 publications were reviewed and discarded if they did not meet the inclusion criteria by considering titles, abstracts, and, in doubt, a review of the full-text was performed. Excluding a publication required a consensus among the researchers. The final sample of 38 publications is shown in Tab. 3 (classified by publication type). A list of the bibliographical data of the final sample and the sample of 300 publications before excluding publications outside of our focus is available as supplementary material online via: https://doi.org/10.5281/zenodo.1213120

The first step of the subsequent analysis educed the publication profile in terms of the numbers of scientific publications over time and publication types (e.g. monographs, journal and conference articles). As a next step, the first two authors purposefully read the publications in the final sample to structure and classify the field with regard to the following *dimensions of analysis* which were developed based on a selective review of literature on BPS and refined during the analysis of the final sample, see Tab. 2 (Levy and Ellis, 2006, p. 199; Fettke, 2006, pp. 260f):

Dimension of analysis	Publications
Application purposes and simulation objectives	Oberweis (1996); Gladwin and Harrell (1997); Desel et al. (1999); Desel and Erwin (2000); Desel and Erwin (2003); Barjis (2007); Rozinat et al. (2008); Wynn et al. (2008); Xie (2008a); Xie (2008b); Chan et al. (2009); Kanalici et al. (2009); Han et al. (2009); Rozinat et al. (2009); Kloos et al. (2010); Kloos et al. (2011); Holzmüller-Laue et al. (2013); Bocciarelli et al. (2014a); Bocciarelli et al. (2014b); Cartelli et al. (2014c); Cimino and Vaglini (2014); García et al. (2014); Cartelli et al. (2015); Lübbecke et al. (2015); Antonacci et al. (2016); Bisogno et al. (2016); Cartelli et al. (2016); D'Ambrogio and Zacharewicz (2016); D'Ambrogio et al. (2016); Joschko (2014); Stankevicius and Vasilecas (2016)
Obstacles to applying BPS	Gladwin and Harrell (1997); Barjis (2007); Wynn et al. (2008); Xie (2008a); Xie (2008b); García-Bañuelos and Dumas (2009); Han et al. (2009); Kanalici et al. (2009); Kloos et al. (2009); Rozinat et al. (2009); Vasilecas et al. (2013); Bocciarelli et al. (2014c); Bocciarelli et al. (2014b); Bocciarelli et al. (2014a); García et al. (2014); Lübbecke et al. (2015); Antonacci et al. (2016); Bisogno et al. (2016)
Approaches to constructing simulation models	Oberweis (1996); Gladwin and Harrell (1997); Desel et al. (1999); Desel and Erwin (2000); Desel and Erwin (2003); Barjis (2007); Rozinat et al. (2008); Wynn et al. (2008); Xie (2008a); Xie (2008b); Chan et al. (2009); García-Bañuelos and Dumas (2009); Han et al. (2009); Kanalici et al. (2009); Kloos et al. (2009); Rozinat et al. (2009); Kloos et al. (2010); Kloos et al. (2011); Bocciarelli et al. (2012); Holzmüller-Laue et al. (2013); Vasilecas et al. (2013); Bocciarelli et al. (2014a); Bocciarelli et al. (2014b); Bocciarelli et al. (2014c);); Cartelli et al. (2014a); Cimino and Vaglini (2014); García et al. (2014); Kloos (2014); Joschko (2014); Cartelli et al. (2015); Lübbecke et al. (2015); Antonacci et al. (2016); Bisogno et al. (2016); Cartelli et al. (2016); D'Ambrogio and Zacharewicz (2016); D'Ambrogio et al. (2016)

Table 2. Articles in the final sample classified by dimensions of analysis (multiple assignments possible).

Application purposes and simulation objectives: As a quantitative analysis technique (Dumas et al. 2013, p. 235), BPS has important practical applications (e.g. Dumas et al., 2013, pp. 235–243; van der Aalst, 2010, p. 2; Greasley, 2003, p. 409), yet a structured enquiry into application purposes and objectives discussed in literature is not available at present. Hence, the first dimension of analysis is targeted at identifying and compiling application purposes and objectives, and to investigate if specific purposes and/or concrete objectives have emerged, increased, or decreased over time—to reach an in-depth understanding of the evolution of the research field.

Obstacles to applying BPS: Pertinent literature points at various obstacles to applying BPS in practical applications (e.g. van der Aalst, 2010, pp. 1f)—relating, inter alia, to a perceived complexity of applying BPS and tool support. Hence, the second dimension of analysis is aimed at achieving insights into the discussed obstacles in practical applications—including how to mitigate the obstacles.

Approaches to constructing simulation models: Simulating a business process presumes an executable business process model or a model-to-model-transformation to an executable simulation model. Thus, approaches to BPS can broadly be distinguished into two categories (e.g. Kloos, 2014, pp. 52–59): (i) Approaches using (extended) graphical process models for simulation have been proposed. Petri nets and approaches, e.g., based on the EPC, have been proposed for modelling business processes for simulation—as an executable business process model presumes a formal syntax and semantic (e.g. Desel and Erwin, 2000, p. 130; Barjis, 2007). Moreover, for example, the BPSim standard (Workflow Management Coalition, 2016) has been suggested describing an approach to extend business process models constructed with BPMN. (ii) Approaches in the second category are based on the idea of transforming a graphical process model into an executable simulation model, e.g., transforming extended BPMN models into Discrete Event Systems Specification (DEVS) models (D'Ambrogio and Zacharewicz, 2016) or transforming UML activity diagrams into executable simulation models in the process-oriented discrete event simulation language General Purpose System Simulation, GPSS (Xie, 2008b; Xie, 2008a). The third dimension of analysis aims to achieve an overview of process modelling languages used to construct graphical process models as starting point for simulation, and to investigate the subsequent extension or transformation to obtain an executable simulation model—including obstacles accompanying the construction of simulation models.

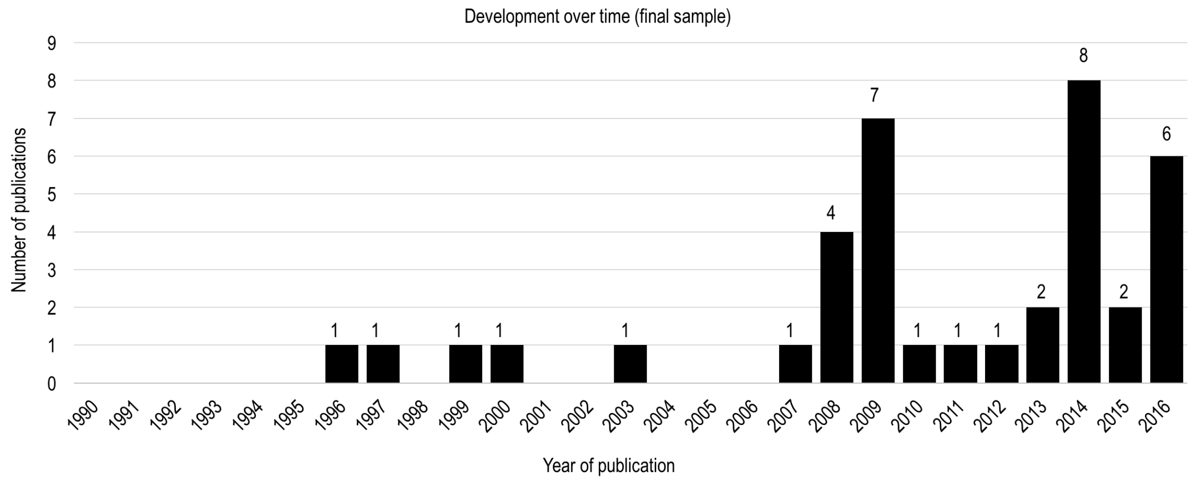

Figure 2. Numbers of publications in final sample from 1990 to 2016.

3 Findings

3.1 Publication profile

Considering the year of publication of all publications in the final sample, it becomes apparent that the interest in BPS indicated by the number of publications has increased since the 1990s, especially in the past decade with peaks in 2009 and, more recently, in 2014 and 2016 (see Fig. 2). Especially in recent conference proceedings, BPS attracted an increasing interest as research topic (see Tab. 3).

Regarding the publication types represented in the final sample, most of the 38 contributions—precisely 26 of 38—are published as conference articles (see Tab. 3)—besides 6 journal articles, 3 book chapters, 2 doctoral dissertations (Joschko, 2014; Kloos, 2014) and 1 monograph (Oberweis, 1996).

Journal articles	Han et al. (2009); Rozinat et al. (2009); Kloos et al. (2011); Vasilecas et al. (2013); Cimino and Vaglini (2014); Bisogno et al. (2016)
Conference articles	Gladwin and Harrell (1997); Barjis (2007); Rozinat et al. (2008); Wynn et al. (2008); Gruhn and Richter (2009); Bocciarelli et al. (2012); Bocciarelli et al. (2014c); Cartelli et al. (2016); Desel and Erwin (2000); Xie (2008a); Xie (2008b); Chan et al. (2009); García-Bañuelos and Dumas (2009); Kanalici et al. (2009); Kloos et al. (2009); Kloos et al. (2010); Holzmüller-Laue et al. (2013); Bocciarelli et al. (2014a); Bocciarelli et al. (2014b); Cartelli et al. (2014); Cartelli et al. (2015); Lübbecke et al. (2015); Antonacci et al. (2016); D'Ambrogio et al. (2016); D'Ambrogio and Zacharewicz (2016); Stankevicius and Vasilecas (2016)
Others	Oberweis (1996); Desel et al. (1999); Desel and Erwin (2003); García et al. (2014); Kloos (2014); Joschko (2014)

Table 3. Articles in the final sample classified by publication type.

3.2 Application purposes and objectives

Several publications presume that a common purpose of BPS is to evaluate the performance of business processes and objectives concerning quantitative measures—the so-called ex-ante evaluation of business processes—for example, regarding process cycle time, waiting time, process costs, or bottlenecks in processes (Tumay, 1995; Tumay, 1996; Bisogno et al., 2016; Kanalici et al., 2009, p. 1; Cartelli et al., 2014a; Bocciarelli et al., 2014b, p. 278). Also, the objective of quantifying effects of randomness, uncertainty, and interdependencies of resources is mentioned (e.g. Gladwin and Harrell, 1997, p. 594). Additionally, approaches characterised by starting from a non-empty starting state of the process and aiming at a purpose distinct from ex-ante evaluation are discussed which mainly focus on supporting operational decision support for already implemented processes (e.g. Wynn et al. 2008; Rozinat et al., 2009). García et al. (2014, p. 308) also emphasise to support making strategic decisions—tactical and operational. Recent contributions aim to perform reliability analysis taking into account possible failures of resources (e.g. D'Ambrogio and Zacharewicz, 2016) and considering uncertainty, inaccuracy, variability and dynamicity inherent to a process (e.g. Cimino and Vaglini, 2014, p. 321).

Further contributions propose to apply BPS as a basis for "What-if" analysis for testing the impact of process improvements, for example, on organisational performance (e.g. Barjis, 2007; Cartelli et al., 2014a; Kloos et al., 2010; Xie, 2008b; Xie, 2008a). Related to that, the objective of predicting the behaviour of business processes before their implementation is emphasised in (Bocciarelli et al., 2014c, p. 199; Cartelli et al., 2015; D'Ambrogio et al., 2016).

Another but rarely addressed objective is graphically displaying the dynamic behaviour of business processes in the form of an animation as means for discussing business processes, fostering understanding of business processes, and validating their representations as models involving stakeholders (e.g. Tumay 1996, p. 93; Holzmüller-Laue et al. 2013, p. 51; Oberweis 1996, p. 250; Kanalici et al. 2009, p. 1).

Starting in the 2010s, approaches to BPS referring to a specific application area were identified. For example, Lübbecke et al. (2015) suggest an approach to support decision making in the specific application area of Green BPM. In case of long-time running business processes, Stankevicius and Vasilecas (2016) propose to support decision making by applying BPS. In the domain of healthcare, Antonacci et al. (2016) provide an approach aimed at improving healthcare processes by reducing costly reworks, and in life science, Holzmüller-Laue et al. (2013) report on a BPM-based process automation approach.

3.3 Obstacles to applying BPS

On the contrary to the development of publication numbers, indicating increasing research efforts, low usage of applying BPS in practise and research is claimed for a number of different reasons: The complexity of performing simulation studies and missing expertise, especially technical expertise of users, are assessed as reasons for low usage of approaches suggested in the field of BPS in practise (Xie, 2008a, p. 2931; Gladwin and Harrell, 1997, p. 594; Bocciarelli et al., 2014c, p. 199). A gap between business users and simulation experts possibly resulting in inconsistencies is presumed (García et al., 2014, p. 310). Especially, Petri net based models are assessed to be difficult to understand and unsuitable by prospective users (e.g. Barjis, 2007, p. 264; Wynn et al., 2008, p. 74; Gruhn and Richter, 2009, p. 132; Han et al., 2009, p. 1250). As a possible solution to mitigate obstacles with regard to missing expertise, an increasing use of animation is suggested (Barjis, 2007, p. 264).

Constructing simulation models is also identified as an obstacle, acknowledging that business process models are in most cases created for other purposes (Kloos et al., 2009, p. 83). Bocciarelli et al. (2014c, p. 199) and Bocciarelli et al. (2014b, p. 278) report on a "semantic gap" between a business process model and the operational semantics of simulation engines as one issue concerning the use of BPS.

Further obstacles to applying BPS emerge regarding the efforts and costs to gather and prepare data needed for constructing simulation models (e.g. Antonacci et al., 2016, p. 124; Bocciarelli et al., 2014c, p. 199; Bocciarelli et al., 2014b, p. 278; Cimino and Vaglini, 2014, p. 322).

At the end of the 2000s, García-Bañuelos and Dumas (2009, pp. 199f) state that many commercial business process modelling tools provide tool support for simulation with limitations regarding the import of models and extensibility. Kanalici et al. (2009, pp. 1f) presume improvements in business process modelling tools and their user interfaces to allow users to apply simulation with no or only few experience. So far, BPM tools provide integrated support for simulation but are limited in capabilities, for example, concerning customisation or configuration and merely implement animation of (graphical) simulation models (e.g. Bocciarelli et al. 2014a, p. 3012; Bocciarelli et al. 2014b, p. 278). Interestingly, Vasilecas et al. (2013, p. 231) report on missing support for the BPMN in the general-purpose simulation tool AnyLogic, although the BPMN is seen as the de facto standard for business process modelling (e.g. Kocbek et al, 2015).

It is assessed that integration between process modelling and simulation tools is still missing (García et al. 2014, p. 310). In recent articles, business process modelling tools and simulation tools are contrasted with regard to their suitability for BPS (Lübbecke et al., 2015, p. 871; García et al., 2014, p. 308): Tools originating from business process modelling are assessed to have limited simulation capabilities and functionalities (e.g. Bocciarelli et al., 2014b, p. 278; Bocciarelli et al., 2014a, p. 3012), and general simulation tools are assessed to not provide a direct import and processing of business process models created with a conceptual modelling language such as BPMN or EPC.

3.4 Approaches to constructing simulation models

The reviewed approaches to constructing simulation models start from a conceptual model of a business process provided by different modelling languages, i.e., BPMN, Petri nets, UML, EPC as well as idiosyncratic process model notations used in modelling tools, referred to as others (see Tab. 4). Figure 3 shows the development in time of modelling languages chosen as foundation for BPS.

3.4.1 Petri net-based approaches

The Petri net-based approaches in the final sample suggest to directly simulate a Petri net representing a business process. Broadly, simulation is suggested to be performed by generating runs of the Petri net (Oberweis 1996; Desel et al., 1999; Desel and Erwin, 2000; Desel and Erwin, 2003). The framework to applying BPS based on the DEMO methodology proposed in Barjis (2007) suggests to construct a business process model using an extended Petri net notation and, also, to directly simulate this representation.

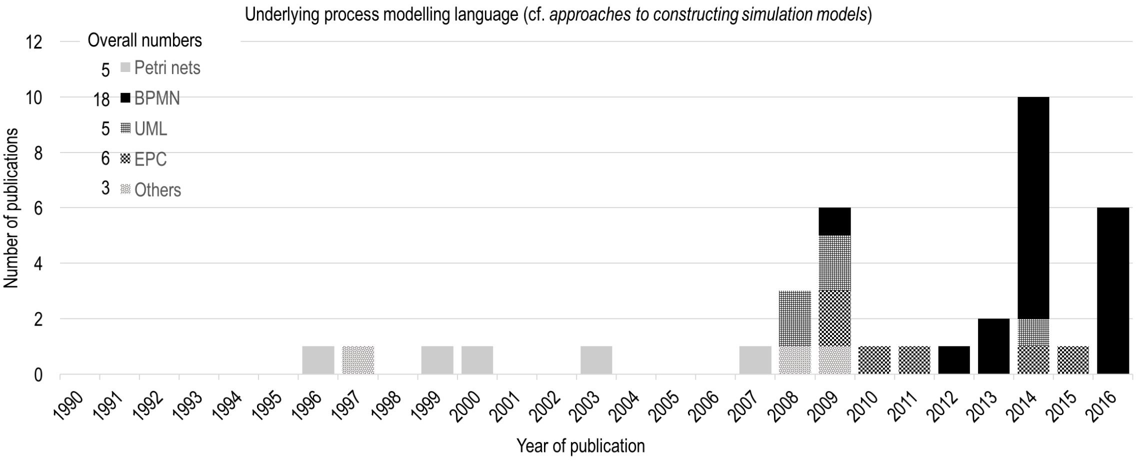

Figure 3. Number of approaches to constructing simulation models in the final sample according to year of publication differentiated by the underlying modelling language.

3.4.2 BPMN-based approaches

Before the release of BPMN 2.0 in 2011, it was suggested to transform BPMN models into Coloured Petri nets (e.g. García-Bañuelos and Dumas 2009). The BPMN models are extended with parameters needed for simulation (García-Bañuelos and Dumas, 2009, p. 202). Cartelli et al. (2016) propose a transformation of a BPMN 2.0 model integrated with a context model including a resource, a data, and an environment model into a timed Coloured Petri net (e.g. Cartelli et al., 2014a; Cartelli et al., 2015, Cartelli et al., 2016, p. 25). Simulation is performed by using an implemented process simulator building on previous work.

Based on BPMN 2.0, automatic model transformation with the aim of generating executable simulation code utilising the domain-specific language eBPMN is suggested in Bocciarelli et al. (2014a; 2014b; 2014c). A BPMN 2.0 model is extended with additional information needed for simulation by including text annotations specified according to the syntax of the lightweight BPMN extension Performability-oriented BPMN (PyBPMN) (Bocciarelli and D'Ambrogio, 2011). Transformation of such an extended BPMN model is performed resulting in eBPMN code. In previous work (Bocciarelli et al., 2012), a two-step approach requiring an UML activity diagram as intermediate transformation model was proposed. García et al. (2014) suggest an approach to automatically generate executable simulation models from BPMN 2.0 as basis for BPS by extending BPMN 2.0 models followed by a transformation step into a tool-independent discrete event simulation model (García et al., 2014, pp. 310f). D'Ambrogio and Zacharewicz (2016) suggest to automatically transform a BPMN 2.0 model into a Discrete Event Systems Specification (DEVS) model by extending BPMN 2.0 models according to PyBPMN. Another automated model transformation based on enriching BPMN 2.0 models based on PyBPMN is proposed in Antonacci et al. (2016). In Vasilecas et al. (2013), a BPMN 2.0 model is extended by a Real-Time UML collaboration diagram with extensions for concurrency and a resource model (Vasilecas et al., 2013, p. 234f).

In contrast to the approaches mentioned above, Holzmüller-Laue et al. (2013) propose to extend already constructed BPMN models with information needed for simulation as data objects, input and output data of activities and transforming the models into XML representation. Worth mentioning, the business process models are enriched with screenshots, screencasts, and videos to support visualisation and animation. Cimino and Vaglini (2014) developed a simulation system, called Interval Bimp (IBimp), based on interval-valued parameters instead of conventional single-valued or probability-valued parameters. Also based on BPMN 2.0, Cimino and Vaglini (2014, p. 329) start from a BPMN model and automatically translate this model into a business execution language to generate a machine-readable representation of the business process (the XML representation is extended with information).

In Kloos (2014), an approach aimed at transforming business process models constructed with a modelling language into simulation models by introducing one intermediate transformation model for different underlying process modelling languages and different simulation environments is suggested (Kloos, 2014, p. 4). The approach is specified for BPMN 2.0 models, extended Event-Driven Process Chain (eEPC) models and UML activity diagrams as starting point. The required intermediate transformation model is an idiosyncratic sequence diagram, denoted as Process to Simulation Transformation (ProSiT) sequence diagram.

In Joschko (2014), an approach integrating domain-specific partial simulation models into BPS based on BPMN 2.0 is introduced and evaluated in a case study. For that, an extension of BPMN 2.0 is developed which links model elements of the BPMN to domain-specific models. The approach is realised as a prototypical software framework building on the plugin-framework Empinia and the discrete event simulation library DESMO-J.

Bisogno et al. (2016) suggest a modelling and simulation method which employs two standards, BPMN 2.0 and the Business Process Simulation Specification (BPSim 1.0), primarily to measure key performance indicators of business processes and to test potential process improvements (Bisogno et al., 2016, p. 56).

3.4.3 UML-based approaches

Xie (2008b), Xie (2008a), Han et al. (2009), and Gruhn and Richter (2009) report on simulation models based on UML activity diagrams. These can be segmented into approaches (i) extending activity diagrams for process simulation by using UML profiles including stereotypes (resulting in extended UML activity diagrams) which can be transformed into executable simulation models (Xie, 2008b; Xie, 2008a); (ii) workflows modelled as UML activity diagrams which are transformed into Petri nets (Han et al., 2009, pp. 1251f); (iii) integrating UML activity diagrams with reusable models of a business domain created as Coloured Petri nets by domain experts followed by a transformation into executable Coloured Petri nets (Gruhn and Richter, 2009, pp. 134–137). In addition, and as already mentioned, the transformation approach requiring an intermediate transformation model suggested in Kloos (2014) is specified for UML activity diagrams as starting point.

3.4.4 EPC-based approaches

Kloos et al. (2010) and Kloos et al. (2011) provide a transformation approach utilising eEPC models, based on previous work (Kloos et al., 2009). An EPC is transformed into a simulation model requiring an intermediate transformation model. The approach presented in Kloos (2014) constitutes an extension

Modelling language	Publications
Petri nets	Oberweis (1996); Desel et al. (1999); Desel and Erwin (2000); Desel and Erwin (2003); Barjis (2007)
BPMN	García-Bañuelos and Dumas (2009); Bocciarelli et al. (2012); Vasilecas et al. (2013); Holzmüller-Laue et al. (2013); Bocciarelli et al. (2014a); Bocciarelli et al. (2014b); Bocciarelli et al. (2014c); Cartelli et al. (2014a); Cimino and Vaglini (2014); Joschko (2014); Kloos (2014); García et al. (2014); Cartelli et al. (2015); Antonacci et al. (2016); D'Ambrogio and Zacharewicz (2016); Bisogno et al. (2016); Cartelli et al. (2016); D'Ambrogio et al. (2016)
UML (Activity diagrams)	Xie (2008b); Xie (2008a); Han et al. (2009); Gruhn and Richter (2009); Kloos (2014)
EPC	Chan et al. (2009); Kloos et al. (2009); Kloos et al. (2010); Kloos et al. (2011); Kloos (2014); Lübbecke et al. (2015)
Others	Gladwin and Harrell (1997); Kanalici et al. (2009); Wynn et al. (2008)

Table 4. Publications in the final sample by underlying modelling language (multiple assignments possible).

of this prior work. Another EPC-based approach in Chan et al. (2009) suggests extending an EPC with further information needed for simulation, followed by a transformation into Coloured Petri nets (Chan et al., 2009, pp. 77–79). Furthermore, with an EPC as starting point, Lübbecke et al. (2015) suggest transformation into a simulation model as input for the simulation software Plant Simulation (Lübbecke et al., 2015, p. 871). The transformation step is performed due to predefined transformation rules.

3.4.5 Other approaches

Wynn et al. (2008, pp. 70–73) start from an intermediate execution state, i.e., a simulation model is generated considering a non-empty state of the process. Starting with a YAWL workflow model, a transformation step into Coloured Petri nets is realised. Further approaches focus on introducing tools for BPS or use tools with idiosyncratic process model notations (Kanalici et al., 2009; Gladwin and Harrell, 1997).

4 Discussion

The primary objective of this literature review was to compile an overview of the state of research in the field of business process simulation by identifying, structuring, evaluating and summarizing pertinent prior work comprehensively. The search strategy therefore included not only general IS outlets but also specific outlets including conference proceedings, monographies and anthologies. In total, 300 unique publications between 1990 and 2016 were identified in the literature search between 1990 and 2016—giving an idea of the size of the body of knowledge in the field of BPS by approximation (subject to the limitations of the search strategy outlined in Sec. 2). The subsequently reviewed subset of prior work reduces the sample by concentrating on 38 contributions which presuppose a graphical model representation as a starting point for business process simulation. This subset is of particular interest as it ties in with work on business process modelling. Summarizing and structuring the prior work along the chosen dimensions of analysis closes an important research gap in BPM and IS research and fosters progress of knowledge in the field of business process simulation.

Reviewing application purposes and simulation objectives produces the expected and unsurprising three prevalent purposes mentioned in pertinent literature: (1) ex-ante evaluation of business processes in conjunction with (2) “What-if”-type sensitivity analyses and (3) animation of business processes accompanying BPS, especially aimed at fostering an understanding of simulation runs. Interestingly, these purposes have recently been adapted for applications in new areas as, for example, Green BPM (e.g. Lübbecke et al., 2015) or healthcare (e.g. Antonacci et al., 2016). Moreover, the review indicates that another purpose has emerged in the past ten years: (4) Short-term, operational decision support for already implemented business processes using historical data to construct simulation models (e.g. Wynn et al., 2008; Rozinat et al., 2008; Rozinat et al., 2009; see Martin et al. 2016 for a recent literature review). Apart from this discovery, the review confirms the three typical, yet very high-level application purposes and simulation objectives conveyed, e.g., in textbooks (Dumas et al., 2013, pp. 235–243).

One of the major research gaps turning up in our study is that insights into the use of BPS in practise are scarce in the review sample. For an investigation into the use of business process simulation in practical applications which does not focus on graphical process models as a foundation for simulation, see Melão and Pidd (2003). However, a current structured enquiry into the diffusion of BPS in practise and prevalent application purposes and underlying objectives is not available at present. A further differentiated and detailed understanding of these purposes, objectives and corresponding functional and non-functional requirements thus is required to better understand existing and possible future application scenarios. A potential path for future research, hence, lies in surveying practical applications of BPS, especially with regard to application purposes, simulation objectives and user requirements, and in cumulatively compiling a knowledge base which informs future research on BPS.

Reviewing obstacles to apply BPS suggests that principle barriers prevent BPS research to transfer to practical applications. rior work points at (1) the complexity of purposeful process simulation and the corresponding difficulty to design meaningful simulations; (2) the lack of ease-of-use of software tools;

and (3) postulate the need to bridge the 'expertise gap' between simulation experts, modelling experts and business users.

Two research gaps emerge from reviewing obstacles to apply BPS: First, a systematic investigation into barriers to adopting BPS is missing and the reasoning about the underlying rationale for these barriers preventing the practical application of BPS remains mainly anecdotal in the review sample. Second, suggestions on how to overcome barriers to adopting BPS remain only marginally addressed in the reviewed work (e.g. Barjis, 2007). This constitutes another anchor point for future research: As a first step to overcoming barriers to adoption, gaining an in-depth understanding of those obstacles appears as a fruitful avenue for future research. Along this path, it should be clarified whether there is a discrepancy between the obstacles purported in literature and those expressed by (prospective) users. Moreover, enquiries into user requirements contribute to the scientific knowledge base which in turn informs future design research on approaches to BPS and on BPS tools.

Reviewing approaches to BPS suggests that, broadly, three categories deserve distinction (extending Kloos, 2014, pp. 52–59): (1) Approaches which extend graphical process models, i.e., direct simulation (e.g. Oberweis, 1996; Desel and Erwin, 2003; Barjis, 2007); (2) approaches providing a direct transformation of a business process model into a simulation model (e.g. Bocciarelli et al., 2014b; Bocciarelli et al., 2014c; Xie, 2008a; Xie, 2008b), and (3) approaches which require an intermediate transformation model, which is, subsequently, transformed into a simulation model, i.e., indirect transformation (e.g. Kloos et al., 2011; Kloos, 2014). Tracing reported approaches in literature over time confirms the intuition that the focus shifted from Petri nets as a foundation for BPS to EPC, UML activity diagrams and, more recently, to BPMN 2.0 which has since its publication in 2011 been predominantly employed as modelling approach to prepare for process simulation. As a closely related topic, transformations of BPMN models and extensions to the BPMN have been increasingly discussed since then (e.g. Bocciarelli et al., 2014c; García et al., 2014; Bisogno et al., 2016) where approaches to automatically transform BPMN models into simulation models is observed to have progressed continually (e.g. Bocciarelli et al., 2014b; García et al., 2014).

Another major research gap emerging from our study is that only few reviewed approaches to BPS address obstacles accompanying the construction of simulation models and only few contributions aim at overcoming limitations identified and discussed for existing simulation approaches (e.g. Wynn et al., 2008). Hence, discussing these limitations, for example regarding reliability and interpretation of simulation results (e.g. Dumas et al., 2013, p. 243; van der Aalst, 2015), and to what extent the limitations are addressed by existing approaches opens another fruitful research direction informing future research on approaches and tools for BPS. Regarding extensions of the BPMN for BPS, it is striking that the BPSim standard (Workflow Management Coalition, 2016) is only considered by Bisogno et al. (2016) constituting another anchor point for future research on interoperability regarding standard conformance.

The present literature review is subject to a number of limitations: Even though the search strategy outlined in Sec. 2 employs several measures to include all pertinent prior work, an exhaustive literature review does not necessarily lead to a complete census of relevant literature due to the vast number of sources and publications (vom Brocke et al., 2009, p. 2207). Moreover, our sampling and filtering process entails the risk of misleading decisions, i.e., to have overlooked relevant sources or to have erroneously misjudged an excluded publication. We report the selection of publications in detail to render the search procedure including our decisions transparent and intersubjectively traceable to make them accessible to critique. The scope of this literature review is limited to the chosen focus involving graphical process models, and to the chosen dimensions of analysis. Other dimensions of analysis are not addressed in detail in this research as, for example, limitations of existing approaches to BPS (e.g. Dumas et al., 2013; van der Aalst, 2015), tool support for BPS (Jansen-Vullers and Netjes, 2006; Bosilj-Vuksic et al., 2007) or visualisation of simulation outcomes (Holzmüller-Laue et al., 2013)—each representing a review topic in its own right. Hence, research following-up this literature study may review and structure prior work on these specific aspects of BPS, with the aim to broaden the overview of research on BPS and deepening insights into those specific aspects.

5 Conclusion

Spanning a time frame of 27 years from 1990 to 2016, the present comprehensive literature study arrives at a total of 300 publications characterizing the body of knowledge in the field of business process simulation. Focussing on graphical process models as a foundation for business process simulation, 38 publications are identified and reviewed in detail. We deem both findings as surprisingly low considering the importance of business process simulation for BPM. Analysing prior work with regard to application purposes, obstacles and approaches to BPS leads us to outline three major paths for future research: (1) surveying practical applications of BPS, especially with regard to application purposes, simulation objectives and user requirements; (2) enquiries into barriers to adopting BPS; and (3) investigating limitations identified and discussed for existing simulation approaches. Overall, the present findings suggest research efforts in which empirical research and design research jointly advance our knowledge on business process simulation and its applications, e.g., to jointly build a common knowledge base on purposes, requirements, user needs, from which to engage in further research in business process simulation. Such research will also benefit BPM practitioners by providing new techniques and tools for simulating business processes.

Acknowledgements

We would like to thank the Associate Editor and reviewers for their constructive comments and suggestions which helped us to improve the present article, especially the discussion of future research on limitations of existing approaches to BPS.

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