Approaches combining methods of operational research with Business Process Model and Notation - a systematic review

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Background: Business process modelling is increasingly used not only by the companies' management but also by scientists dealing with process models. Process modeling is seldom done without decision-making nodes, which is why operational research methods are increasingly included in the process analyses.

Objective: This systematic literature review aimed to provide a detailed and comprehensive description of the relevant aspects of used operational research techniques in Business Process Model and Notation (BPMN) models.

Methods: Web Of Science of Clarivate Analytics was searched for 128 studies of that used operation research techniques and business process model and notation, published in English between 1 January 2004 and 18 May 2020. The inclusion criteria were as follows: Use of Operational Research methods in conjunction with the Business process model and notation, and is available in full-text format. Papers were not excluded based on methodological quality. The background information of the included studies, as well as specific information on the used approaches, were extracted.

Results: In this research, thirty-six studies were included and considered. Eleven specific methods falling into the field of Operations Research have been identified, and their use in connection with the process model was described.

Conclusion: Operational research methods are a useful complement to BPMN process analysis. It serves not only to analyze the probability of the process, its economic and personnel demands but also for process reengineering.

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ABSTRACT

Background: The business processes modelling has long ceased to belong only to the area of company management. This process analysis approach is currently being spread to all possible domains. However, business processes cannot exist without decision-making and unifying conditions, barriers or delays, so this is the reason why it is necessary to focus on the methods of operational research as a means of managing and optimizing the flow of process tokens when analyzing business processes.

Objective: This systematic literature review aimed to provide a detailed and comprehensive description of the relevant aspects of used operational research techniques in Business Process Model and Notation (BPMN) models and present results of bibliometric analysis of found documents. We focused on the analysis of authors, keywords, year of publication, research areas, citations and more. We also analyzed the potential effect of the upgrading of the notations.

Methods: The Web Of Science (WOS) database of Clarivate Analytics was searched for 128 studies that used operation research techniques and Business Process Model and Notation (BPMN), and that was published in English between January 1, 2004, and May 18, 2020. The inclusion criteria were as follows: Use of Operational Research methods in conjunction with the Business process model and notation, and is available in full-text format. Papers were not excluded based on methodological quality. The background information of the included studies, as well as specific information on the used approaches, were extracted.

Results: In this research, thirty-six studies were included and considered. Eleven specific methods falling into the field of Operational Research have been identified, and their use in connection with the process model was described.

Conclusion: Operational research methods are a useful complement to BPMN process analysis. It serves not only to analyze the probability of the process, its economic and personnel demands but also for process reengineering.

INTRODUCTION

It has been more than 15 years since "Business Process Model and Notation" or "Business Process Modelling Notation" (BPMN) is officially a notation for process modelling. During its lifetime, this notation has gained many users and, thanks to its user-friendliness, is used in many areas. It is this expansion that has led to the interconnection and use of other technologies and methods. The fundamental problem of any complex process is decision making. Operational research as a popular scientific approach is so often associated with procedural issues, and its connection to BPMN is more than natural. This article focuses on the analysis of the relationship between the Business Process Model and Notation (BPMN) process modelling and specific methods of operational research.

BPMN was created by the Business Process Management Initiative (BPMI) as an open standard. The

BPMN has very much similarity to flowcharts or Petri net but offers much more sophisticated tools to describe and simulate behaviour. Silver (2009) said that this approach is an "event-triggered behaviour," a description of the "something happened" mode. Business Process Modelling is used to describe, recognize, re-engineer, or improve processes or practices, Tomaskova (2017). Business Process Model and Notation (BPMN) is the language that is used to model business process steps from start to end. The notation has been explicitly designed for wide-ranging use in process analysis, OMG - The Object Management Group (2011). BPMN is both intelligible to non-specialists but at the same time notation allows a complicated process to be represented between different participants. Another, very significant feature of BPMN is its "business-friendly" orientation. This orientation and processes modelling is essential for the company's business and knowledge.

Operational Research (OR) is concerned with formulating, modelling, and solving a variety of decision-making situations in which we try to find optimal or select the best of the acceptable solutions. The company's philosophy and decide over business data are the most crucial management actions. The task of the manager is to select in the real system the problem to be analyzed and to formulate it precisely. The standard way is the expression of the economic model and then the formulation of a mathematical model. It is necessary to build a simplified model of the real financial system, which will include only the essential elements that describe the formulated problem. The manager has to set the goal of the analysis and subsequent optimization. Important is to define all operational or processes that influence this goal, to describe all the factors, and to express the relations between the stated purpose and the mentioned processes and factors verbally.

The paper is divided into the following parts. The "Related works and background" section lists research articles that are relevant to a given combination of BPMN and OR areas. That part briefly provides essential information on the approaches that are fundamental to this systematic review. The "Research methodology" section describes a systematic search, i.e. entry conditions, exclusion criteria and limitations. The "Results" section presents the results of the analysis of articles fulfilling the requirements of the systematic review. we analyzed publications through conditions of the publication time, their citations, scientific areas, the cooperation of authors and keywords. Subsequently, we examined selected articles in terms of methodology, approach and research areas. In the "Discussion", we focus on scientific gaps and future research. We present a research area where we expect an increase in publications, including their specific components. We also discuss the future development of applied methods and approaches. Finally, the "Conclusion" section summarizes the results and benefits of this study.

RELATED WORKS AND BACKGROUND

Background information and related works are listed in the paragraphs below. We first focus on process modelling and BPMN and then Operational Research and its essential methods and approaches.

Organizational processes and decision support can be captured in many ways, and for many areas, we can mention, for example : strategic management by: Maltz and Kohli (1996); Certo (2003); Tomaskova (2009); Maresova (2010); Tsakalidis et al. (2019); product development research and innovation implementation, see Repenning (2002); Garcia (2005); IT and economic analyzes see Shane and Cable (2002); Dedrick et al. (2003); Krenek et al. (2014); Tomaskova et al. (2015); Maresova et al. (2016); Tomaskova et al. (2016); Maresova et al. (2017); Cheng et al. (2019); Tomaskova et al. (2019a,b); Kopecky and Tomaskova (2019, 2020); different simulation approaches analysis, see Sterman (1994); Kozlowski et al. (2013); Cimler et al. (2018) or non-standard optimization techniques by: Gavalec and Tomaskova (2010); Bacovsky et al. (2013); Tomaskova and Gavalec (2013, 2014); Gavalec et al. (2014, 2015); Cimler et al. (2017); Oudah et al. (2018).

Some of the authors try to provide a solution for process model analysis. For example, Melao and Pidd (2000) discussed the strengths and limitations of the various modelling approaches used in business process transformation. The paper by Glassey (2008) compares three process modelling processes used in case studies. The article by Sadiq and Orlowska (2000) analyze process models using graph reduction techniques. Other authors like van der Aalst et al. (2007); Krogstie et al. (2006) use specific tools, frameworks, and methods for process analysis and modelling.

Business process modelling

Process modelling and Business process management (BPM) has a significant impact today. Process modelling is currently mainly a graphical representation of processes, i.e. in what order particular

activities should be implemented and what inputs and outputs processes require for proper functioning. The primary goal of process modelling is to increase the efficiency and effectiveness of the entire process as well as partial activities. Many business process modelling techniques have been proposed over the last decades, so the paper Recker et al. (2009) comparatively assesses representational analyses of 12 popular process modelling techniques to provide insights into the extent to which they differ from each other. The review business process modelling literature and describe the leading process modelling techniques falling to and before 2004 are published in the paper Aguilar-Saven (2004). The topic of visualization of business process models was investigated in publication Dani et al. (2019), where authors performed a systematic literature review in the topic "visualization of business process models". A fascinating article is the publication Kalogirou (2003), which illustrate how AI techniques might play an essential role in the modelling and prediction of the performance and control of the combustion process. Although initially, BPM focused mainly on the industrial, service and business sectors, it has also appeared in other sectors in recent years. The popularity of BPMN is confirmed, for example, by the article by authors Zarour et al. (2019), where the current state of the art of BPMN extensions is presented. Publication De Ramon Fernandez et al. (2019) deals with the optimization of clinical processes.

Business Process Model and Notation

BPMN is a language for creating business process models Silver (2009). Under the auspices of the Object Management Group (OMG), the Business Process Management Initiative (BPMI) created the BPMN as an open standard in 2004 by the first version 1.0. In 2005, BPMI merged with the Object Management Group (OMG). The following year, OMG issued the BPMN specification document. In 2010, BPMN version 2.0 was developed, and the current version of BPMN 2.0.2 was released in December 2013. History of BPMN and notation development is a frequent topic of BPMN publications, we can mention Nisler and Tomaskova (2017); Kocbek et al. (2015); Chinosi and Trombetta (2012); White (2008); Van der Aalst et al. (2012); Recker (2012). BPMN is similar to flowcharts and is based on the concept of Petri nets, but it is a more sophisticated and user-friendly language. The graphic form of BPMN makes it understandable even for non-experts. In BPMN, we distinguish several types of elements that we can use in modelling. The specific standards link these elements. In the base classification, we define four groups of items. These are Flow Objects, Connecting Objects, Swimlanes, and Artifacts, see OMG - The Object Management Group (2011).

Operational Reserach

Operational research (OR) is the well-known approach of applying analytical and advanced methods to help make the best possible decisions. As early as 1980, Article by authors Shannon et al. (1980) presented the results of a survey of the perception of usefulness and knowledge of the twelve OR methodologies commonly used in the practice of industrial engineering. The article by Dubey (2010) defines the relation between OR and another branch of sciences. The paper Gu et al. (2010) presents a detailed survey of the research on warehouse design, performance evaluation, practical case studies, and computational support tools. The paper Negahban and Smith (2014) provides a review of discrete event simulation publications with a particular focus on applications in manufacturing.

Operational research methods are often associated with new technologies. In paper Sarac et al. (2010), a state-of-the-art on RFID technology deployments in supply chains is given to analyze the impact on the supply chain performance. Xu et al. (2011), in their paper, tries to identify future trends of computer-aided process planning (CAPP). Dynamic ride-share systems is investigated in the paper Agatz et al. (2012).

Linear programming

One of the most popular areas of operational research in practice is linear programming (LP). The mathematical model of linear programming tasks contains a single linear purpose function, and the actual constraints of the problem are described only by linear equations and inequalities. In economic practice, these tasks are most often encountered. Linear programming is very well described in books: Dantzig (1998); Schrijver (1998); Dorfman et al. (1987)

Multicriterial decision making

The solving of multi-criteria decision-making (MCDM) tasks comprise the look for optimal values of the unknowns, which are simultaneously assessed according to several often contradictory criteria. Thus, the mathematical model of multi-criteria decision problems contains several purpose functions.

Depending on how the sets of decision variants are defined, we are talking about the tasks of multi-criteria linear programming or multi-criteria evaluation of options. A review of applications of Analytic Hierarchy Process in operational management is inverstigated in Subramanian and Ramanathan (2012). The paper Velasquez and Hester (2013) performs a literature review of common Multi-Criteria Decision Making methods. The authors present the results of a bibliometric-based survey on AHP and TOPSIS techniques in publication Zyoud and Fuchs-Hanusch (2017).

Project planning

Tasks of project management, consist of several separate activities that are interdependent and may be run simultaneously. The most used method is the so-called network analysis, where a network graph is created from the left chronologically arranged project activities representing the project life cycle. The longest possible path from the beginning to the end of the project is recorded by "the critical path". The non-observance of this path will lead to a slowing down of the whole project, whose time duration is to be optimized. The optimistic, pessimistic, and most probable estimate of the implementation of the entire project is determined. The paper Nutt (1983) relates the project planning process and implementation. Critical Path Method (CPM) is found in the paper Jaafari (1984), to be equally useful as a planning tool for linear or repetitive projects.

The Resource-Constrained Project Scheduling Problem (RCPSP) is a general problem in scheduling. The paper Pellerin et al. (2020) examines the general tendency of moving from pure metaheuristic methods to solving the RCPSP to hybrid methods that rely on different metaheuristic strategies.

Cimr et al. (2018)

Nonlinear programming

Non-Linear programming is the case when the purpose function is not linear. Tasks then often have a large number of local extremes and often also have great difficulty finding them.

Dynamic programming

If constraints are functions of some parameter, which is most often time, we are talking about dynamic programming. This approach deals with the modelling of more complex multi-stage optimization problems divisible into related sub-problems. Depending on the time parameter, the system is always in one of the acceptable states during the process. At certain times it is necessary to choose from a set of possible decisions, which again results in the transition to the next state. We call the strategy a sequence of these states of the system and choices, looking for the course with the best valuation. Simulations are often used to model and analyze the operation of complex systems without realization and in less than real-time.

- Queuing theory is a type of dynamic programming task. It deals with streamlining the functioning of systems in which it is necessary to gradually serve all units whose requirements are continuously met on so-called service lines. The challenge is to find the most effective way to handle these requirements.

- Inventory management models address the issue of optimizing the supply process and the volume of inventory stored. Costs associated with ordering, issuing, and keeping stocks in stock should be minimized.

Stochastic programming

Stochastic programming deals with optimization problems in which they act as parameters of their constraints of random variables. Probabilistic calculus methods solve these problems, and their results have the character of random variables. Stochastic processes can also be ranked among tasks with the uncertainty of input data. This approach is used to describe the behavior of systems evolving. We are talking about stochastic processes, a special case is the so-called Markov chains and Markov processes. Basic books on this topic are, for example:Kall et al. (1994); Birge and Louveaux (2011); Shapiro et al. (2014).

RESEARCH METHODOLOGY

Kitchenham and Charters (2007) highlighted three essential elements for systematic literary review. It is the determination of research question(s), the organisation of an unbiased and extensive analysis of related publications, and the determination of precise criteria of inclusion and exclusion.

We identified three research questions:

- 203 • Research question 1 (R1): Greater adaptability of BPMN elements causes higher application of this
- 204   notation in publications.

- 205 • Research question 2 (R2): The connection between BPMN and OR methods is most often applied
- 206   to the business and economic area.

- 207 • Research question 3 (R3): The queue theory is the most widely used method in BPMN processes.

208 The analysis process and criteria are given in the following relevant subsections.

209 Eligibility criteria

210 The main features of the study are publications listed in the database Web Of Science (WOS) of Clarivate
211 Analytics, published between January 1, 2004, and May 18, 2020, and containing the search strings. The
212 year 2004 was selected as the starting time point as it was the BPMN created by the Business Process
213 Management Initiative (BPMI).

214 Exclusion criteria (EC) are:

215 • EC1= The publication is published in a language other than English.

216 • EC2= The publication is not available as full text.

217 • EC3= The publication does not coincide with the topic of systematic research.

218 • EC4= BPMN is used only as a presentation tool and not as part of the research.

219 Information sources and Search

220 The primary source of information for the study is the database Web Of Science (WOS) of Clarivate
221 Analytics. An advanced search was performed for the search query mentiones below. The search was
222 performed in the Topics (TS) section.

223 Especially, the CORE database with the indexes listed in Table 1 was selected. The search was
224 performed for "All document types", "All languages" and the years 2004 - 2020.

Indexes	Abbreviation
Science Citation Index Expanded	(SCI-EXPANDED)
Social Sciences Citation Index	(SSCI)
Arts & Humanities Citation Index	(A&HCI)
Conference Proceedings Citation Index- Science	(CPCI-S)
Conference Proceedings Citation Index- Social Science & Humanities	(CPCI-SSH)
Book Citation Index– Science	(BKCI-S)
Book Citation Index– Social Sciences & Humanities	(BKCI-SSH)
Emerging Sources Citation Index	(ESCI)
Current Chemical Reactions	(CCR-EXPANDED)
Index Chemicus	(IC)

Table 1. Web of Science Core Collection Indexes

225 Study selection

226 The first step of the review process involved title and abstract screening, followed by a full-text review for
227 articles that were not definitively excluded after the title and abstract screening. Two independent assessors
228 verified the title and abstract screening and also full-text review. One assessed the suitability of the result
229 from the perspective of Operation research and second assessed the study from the IT perspective, i.e.,
230 whether it is a BPMN notation and its use. Articles were included if they met all the following criteria: (i)
231 Using the method of operational research ; (ii) a BPMN model was used and (iii) available in English
232 and complete full-text format (i.e., abstracts, commentaries, letters, and unpublished data were excluded).
233 Studies were not excluded based on methodological quality.

234 In this study, selected publications were examined from many perspectives, and each contribution was
235 coded according to different criteria. This study aims to enhance the discipline's fundamental progress in

236 understanding the linkage of operational research methods with BPMN. The results of this study could
237 encourage scientists to use operational research methods for process analysis.
238   The limitation of this review is restricting the review to English-language publications of process
239 analysis using OR and BPMN published from January 1, 2004, to May 18, 2020. This restriction may
240 have omitted some relevant studies in other languages or published after May 18, 2020.

241 **Data collection process**
242 Data was collected based on keywords selected from the article Lane et al. (1993), which analyzed the
243 quantitative techniques of Operation Research. From this document, the 18 Operation Research methods
244 were selected and listed in the table 2.

Query	Results
TS=(Computer AND programming AND BPMN)	6
TS=(Decision AND Analysis AND BPMN)	40
TS=(Decision AND theory AND BPMN)	7
TS=(Dynamic AND programming AND BPMN)	4
TS=(Heuristic AND programming AND BPMN)	0
TS=(Hypothesis AND testing AND BPMN)	2
TS=(Inventory AND control AND BPMN)	1
TS=(Linear AND regression AND BPMN)	2
TS=(Linear AND programming AND BPMN)	3
TS=(Math AND analysis AND BPMN)	0
TS=(Math AND programming AND BPMN)	0
TS=(Network AND analysis AND BPMN)	23
TS=(Nonlinear AND programming AND BPMN)	0
TS=(PERT AND BPMN)	0
TS=(Probability AND BPMN)	14
TS=(Queuing AND BPMN)	9
TS=(Statistic AND BPMN)	2
TS=(Stochastic AND processes AND BPMN)	15

Table 2. Electronic search strategy in WoS

245   The articles found based on these keywords with BPMN intersection were further categorized as to
246 whether they correspond to the given keywords and their meaning. The main results of the systematic
247 literature review were obtained by analyzing by the two main guidelines of PRISMA : Moher et al. (2009)
248 and MECIR : Higgins et al. (2018).

249 **Synthesis of results**
250 First, the individual studies were subjected to bibliometric analysis and then the studies were assessed
251 according to the content and used methods. The bibliometric analysis describes and analyses up to date
252 research. It aims at summarizing the latest progress in the field by quantitatively investigating the literature.
253 This method provides a vast canvas of knowledge from the micro-level (institutes, researchers, and
254 campuses) to the macro-level (countries and continents) Mryglod et al. (2013).Frequency analysis is used
255 to find the most frequented scientific areas, the most publishing countries, the most common keywords.
256 Science mapping is performed using the VOS viewer, Venn diagram, bar or bubble graph, Van Eck et al.
257 (2010); Cobo et al. (2011).
258   The Venn/Euler diagram graphically represents the relationships of the most massive set of keywords.
259 Euler diagrams are considered to be an effective means of visualizing containment, intersection, and
260 exclusion. The goal of such graphs is to communicate scientific results visually. Leonhard Euler first
261 popularized the principle of labeled closed curves in the paper Euler (1775) Alternative names for Euler
262 diagrams include "Euler circles". They can also be incorrectly called Venn diagrams. Venn diagrams
263 require all possible curve intersections to be present, so can be seen as a subset of Euler diagrams, that
264 is, every Venn diagram is a Euler diagram, but not every Euler diagram is a Venn diagram. John Venn
265 introduced Venn diagrams a hundred years after Euler in the paper Venn (1880). Venn diagram is a
266 schematic graph used in logic theory to depict collections of sets and represent their relationships.

RESULTS

The initial search resulted in 128 articles. After removing duplicates, 107 items underwent title and abstract screening, yielding 61 articles for full-text review. The final number of included papers for information abstraction was 36. Overview of the number of publications according to exclusion criteria is shown in Figure 1.

Eighteen keywords selected from the paper by Lane et al. (1993) were involved in the study. These keywords have been classified according to whether a publication meeting a study condition has been found for them. Only for 13 keywords were found a publication suitable for this study, as can be seen in table 2
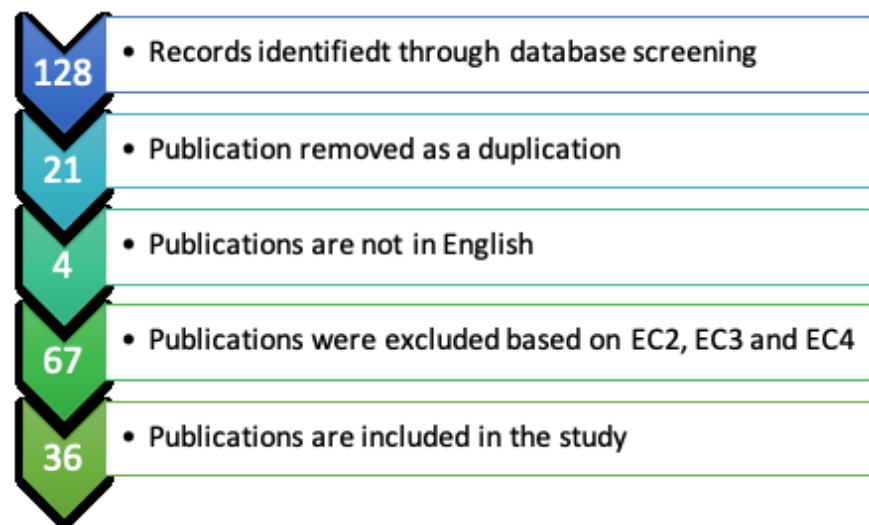
Figure 1. Overview of the systematic review

Categorization of Publications Based on the Clarivate Analytics

Journals and books covered by the Web of Science Core Collection are assigned to at least one Web of Science category. Each Web of Science category is mapped to one research area Clarivate Analytics (2019). Research areas for selected publications are:

- COMPUTER SCIENCE (CS)

- ENGINEERING (En)

- OPERATIONAL RESEARCH MANAGEMENT SCIENCE (OR)

- BUSINESS ECONOMICS (BE)

- ROBOTICS (Ro)

- AUTOMATION CONTROL SYSTEMS (ACS)

- TELECOMMUNICATIONS (Te)

- TRANSPORTATION (Tr)

We selected four main groups, for which we compiled a bar graph and a Venn diagram after analysis. We chose the number of four research areas for representation in the Venn diagram; four sets are still well arranged. Another argument was the number of publications in other areas, where the set "ROBOTICS" contains two documents and the sets "AUTOMATION CONTROL SYSTEMS", "TELECOMMUNICA-TIONS" and "TRANSPORTATION" each one document.

Bar graph on figure 2 is based on frequency analysis and contains the total number of publications in a given research area, their average number of citations, and the corresponding average number of pages per

295 paper. The graph shows the results by type of purpose. The first part shows the frequencies of documents
296 for research areas. The second part focuses on the average number of citations, and the third shows the
297 average number of pages per article.
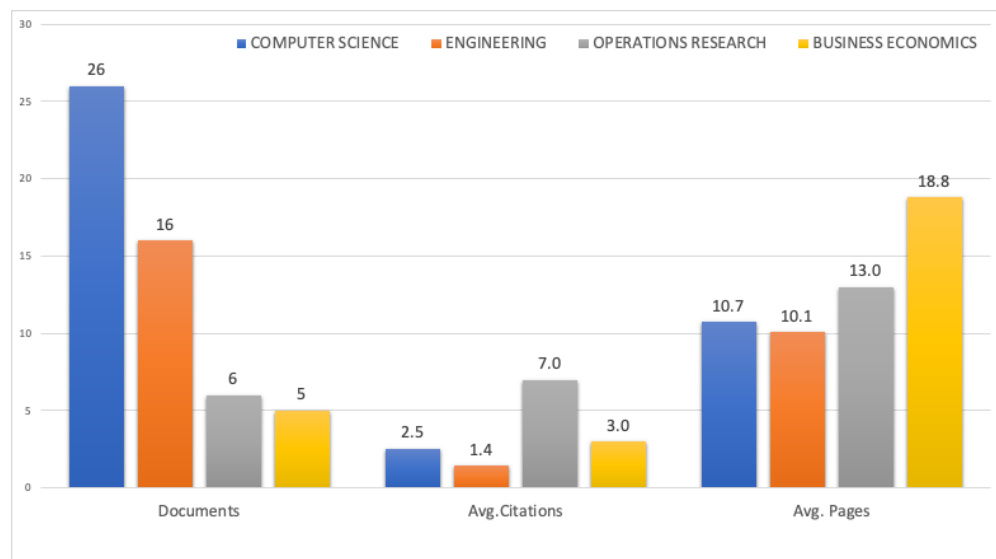
Figure 2. Research areas of selected publications; Documents, Average Citations and Average Pages

298 The Venn diagram, in figure 3, shows selected four research areas as sets, including their intersection
299 areas. In a specific area, we also stated the relevant number of documents and their average number of
300 citations.
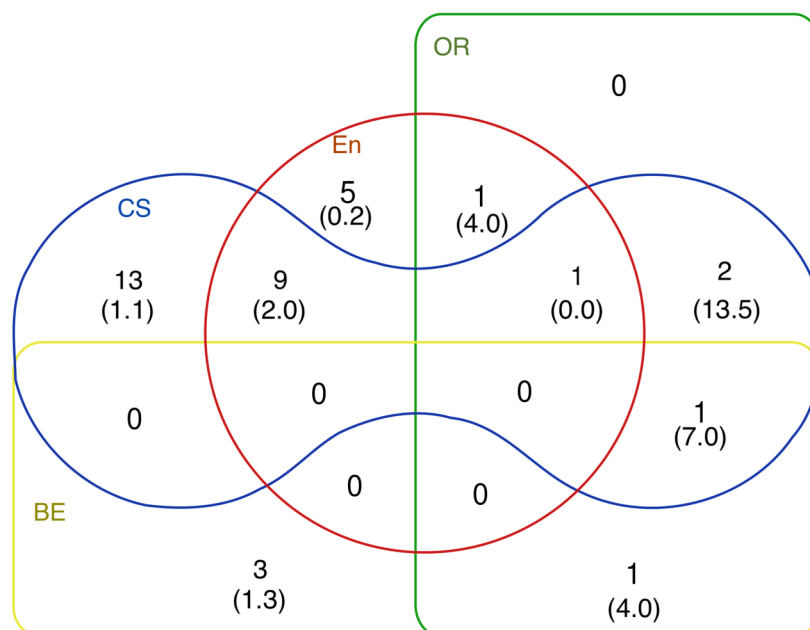
Figure 3. Venn diagram of research areas of selected publications; average citation is listed in the parentheses.

301 This part of the bibliometric analysis showed us the answer to the research question R2. Although
302 BPMN was explicitly designed for corporate analysis and economic analysis, and Operational Research

focuses primarily on addressing managerial decisions, most publications are not in the field of Business Economics. On the contrary, there are the fewest publications in the BE area. Most documents are in the field of Computer Science. Papers in the field of Operational Research received the most citations. The research area "BE" has the lead in the most extended publications, i.e. the number of average pages per paper.

Result1: Research question R2 - not confirmed.

Year of Publication

Figure 4 illustrates the distribution over time of the selected publications with BPMN milestones. The BPMN versions adoption dates, taken from OMG.org (2018), complements this figure.
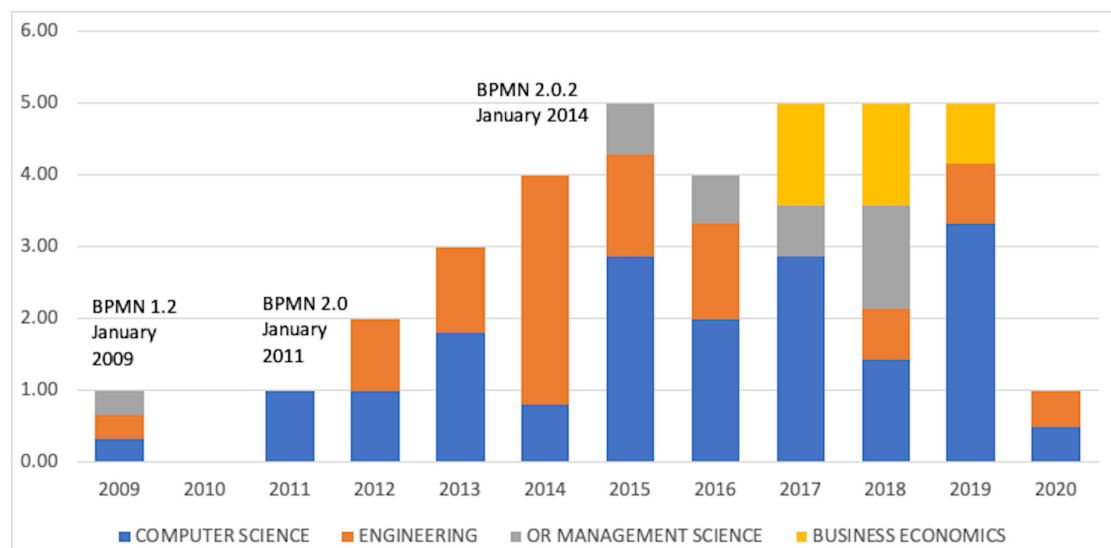
Figure 4. Distribution of the publications by year and their representation in research areas

BPMN versions brought more or fewer changes in notation. While the changes between BPMN 1.0 and BPMN 1.2 were rather cosmetic; for example, renaming "Rule" elements to "Conditional" or slight increasing the number of elements from 48 to 55. The arrival of BPMN 2.0 was a breakthrough. As of BPMN version 2.0, it is possible to create a new "Choreography model", "Collaborations model" and "Conversation model" in BPMN in addition to collaborative processes and internal (private) business processes. Events are now divided into "interrupted" and "non-interrupted" and "catching" and "throwing". The message type is newly introduced, and the data object has three specifications. BPMN 2.0 contains 116 elements. BPMN 2.0 represents the largest revision of BPMN since its inception. BPMN 2.0.2 included only minor modifications in terms of typos.

Given the magnitude of changes between versions of the BPMN notation, the sharp increase in publications following the introduction of the BPMN 2.0 notation can be considered a confirmation of research question R1. It is very interesting that only in 2017 will publications from the field of business economic appear for the first time.

Result: Research question R1 - confirmed.

The average number of citations of analyzed documents is 2.22, where the 1st quartile has a value of 0, 3 quartile is 3.75, Median is equal to one and data variability above the third quartile is limited to 7 citations. We identified two outliers values: 12 citations for Hasic et al. (2018) and 15 citations for paper Wu et al. (2015).

Author analyses

Bibliometric analysis cannot be done without review by the authors. We focused on illustrating co-authorship. The total number of authors of publications selected for this study is 84 : al achhab, m (1), aouina, zk (1), ayani, r (1), aysolmaz, b (1), bahaweres, rb (1), batoulis, k (1), ben ayed, ne (1), ben said, l (1), ben-abdallah, h (3), bisogno, s (1), bocciarelli, p (1), boukadi, k (1), braghetto, kr (1), burattin, a (1), calabrese, a (1), ceballos, hg (2), chien, cf (1), cho, sy (1), creese, s (1), cunha, p (1), d'ambrogio, a (1),

d'ambrogio, sa (1), de lara, j (1), de smedt, j (2), demirors, o (1), duran, f (2), el hichami, o (1), el mohajir, b (1), ferreira, je (1), figl, k (1), fitriyah, a (1), flores-solorio, v (2), fookes, c (1), garcia-vazquez, jp (1), ghiron, nl (1), ghlala, r (1), gomez-martinez, e (1), hansen, z (1), hansen, znl (3), happa, j (1), hasic, f (2), herbert, lt (8), holm, g (1), iren, d (1), jacobsen, p (3), jobczyk, k (1), kamrani, f (1), khlif, w (2), kluza, k (1), ligeza, a (1), manuel vara, j (1), marcos, e (1), mazhar, s (1), mendling, j (1), mendoza morales, le (1), mengersen, k (1), monsalve, c (1), moradi, f (1), naoum, m (1), onggo, bss (1), pablo garcia, j (1), perez-blanco, f (1), pitchforth, j (1), proudlove, nc (1), rekik, m (1), rocha, c (2), rosemann, m (1), rozy, nf (1), salaun, g (2), sharp, r (4), sperduti, a (1), suchenia, a (1), tang, rz (1), tokdemir, g (1), tomaskova, h (1), vanden broucke, sklm (1), vanthienen, j (3), veluscek, m (1), villavicencio, m (1), vincent, jm (1), weske, m (1), wisniewski, p (1), wu, ppy (2), xie, y (1).

These authors form more substantial or smaller groups, as can be seen in Figure 5. We grouped the authors according to their co-author's collaboration into groups where a curve connects the co-authors. The size of the node of this connection corresponds to the number of documents of the given author. The colour distinction of the authors was created using the average year of publication of the author's papers.
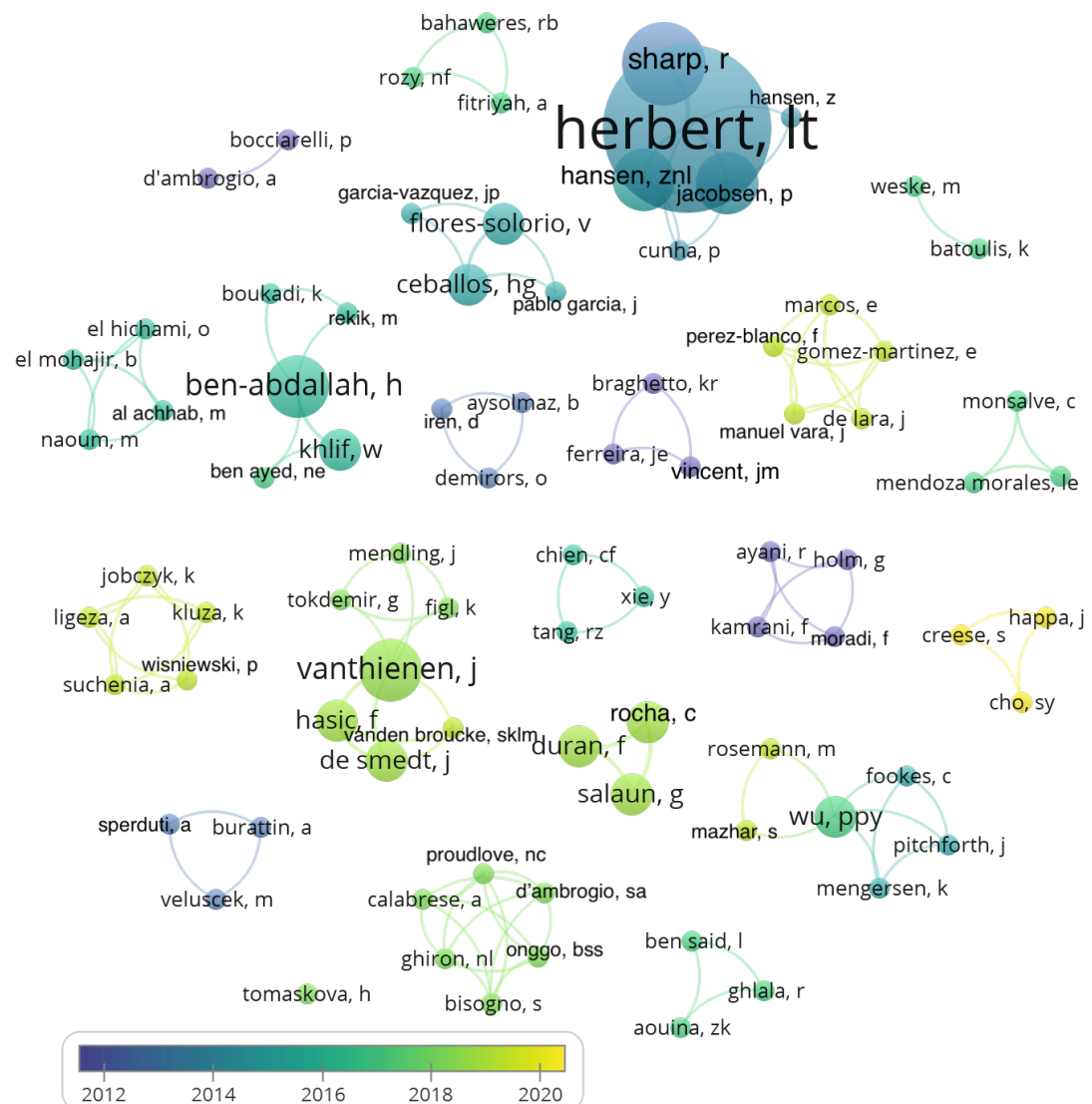
Figure 5. Division of authors into groups according to co-authorship.

For the average values of the author's publications year, we performed analyze showing that the 1st quartile corresponds to 2015, the third quartile 2018.5 and the median is 2017. The variability outside the lower and upper quartiles is given by 2011 and 2020. We identified one outlier value corresponding to the

year 2009.

The most prominent groups are around the authors listed in figure 6. This figure also contains the number of documents of the author, the total number of citations and their average value.
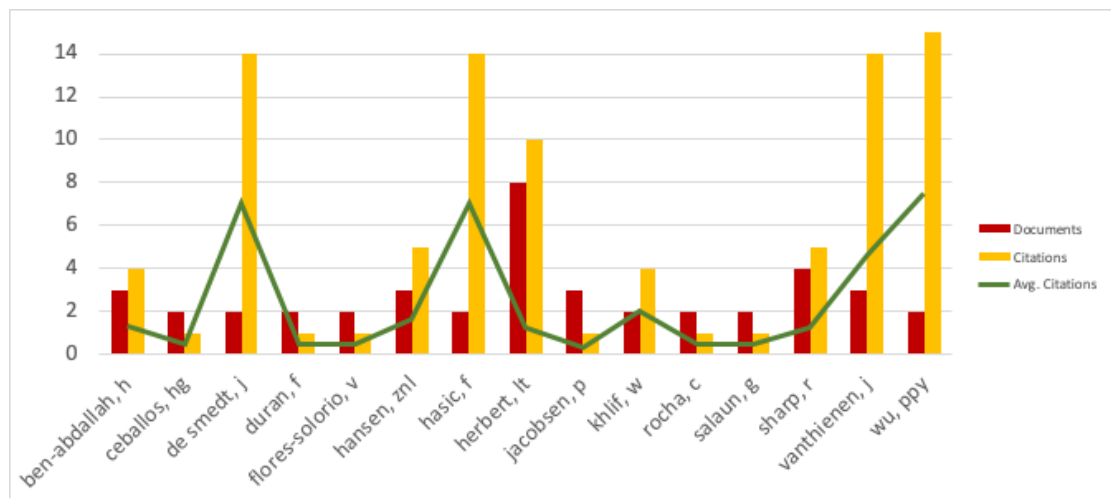
Figure 6. Fifteen most successful authors

From this authors analysis, we can highlight the authors Wu, py, who have the highest average amount of citations (7.5), De Smedt, J. (7) and Hasic, F. (7); Herbert, L.T., who has the most documents (8) and Tomaskova, H., which has no co-author's connection.

The authors were also analyzed in terms of their affiliation to the country or region. A total of 25 countries were identified and their location, including the number of relevant publications, is shown in Figure 7. Most records are identified for Denmark (8), followed by Tunisia (4), three records are for Belgium, France, Saudi Arabia, Italy and Spain.
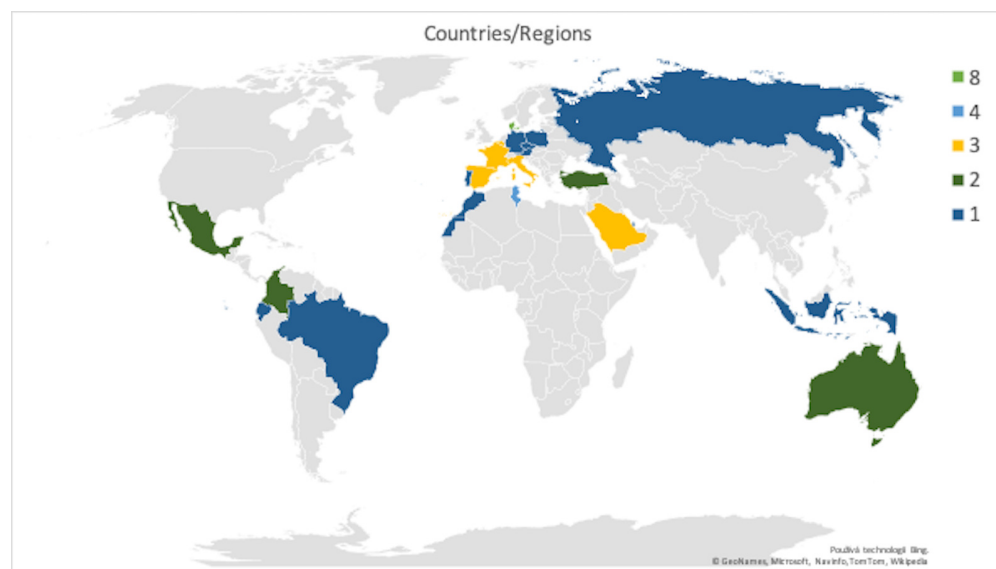
Figure 7. Location of publications in the world, own processing

Keywords analysis

The keywords were categorized according to the keywords identified by the published authors and the keywords PLUS assigned by Clarivate Analytics databases. The data in KeyWords Plus are words or phrases that frequently appear in the titles of an article's references but do not appear in the title of the

367 item itself. Based upon a special algorithm that is unique to Clarivate Analytics databases, KeyWords
368 Plus enhances the power of cited-reference searching by searching across disciplines for all the articles
369 that have cited references in common, more information is on the web link Clarivate Analytics (2018). A
370 total of 130 unique keywords and 46 unique keywords PLUS were found for selected publications.
371   A total of 130 author keywords are mentioned in the publications and a general view of their
372 interconnection can be seen in Figure 8.
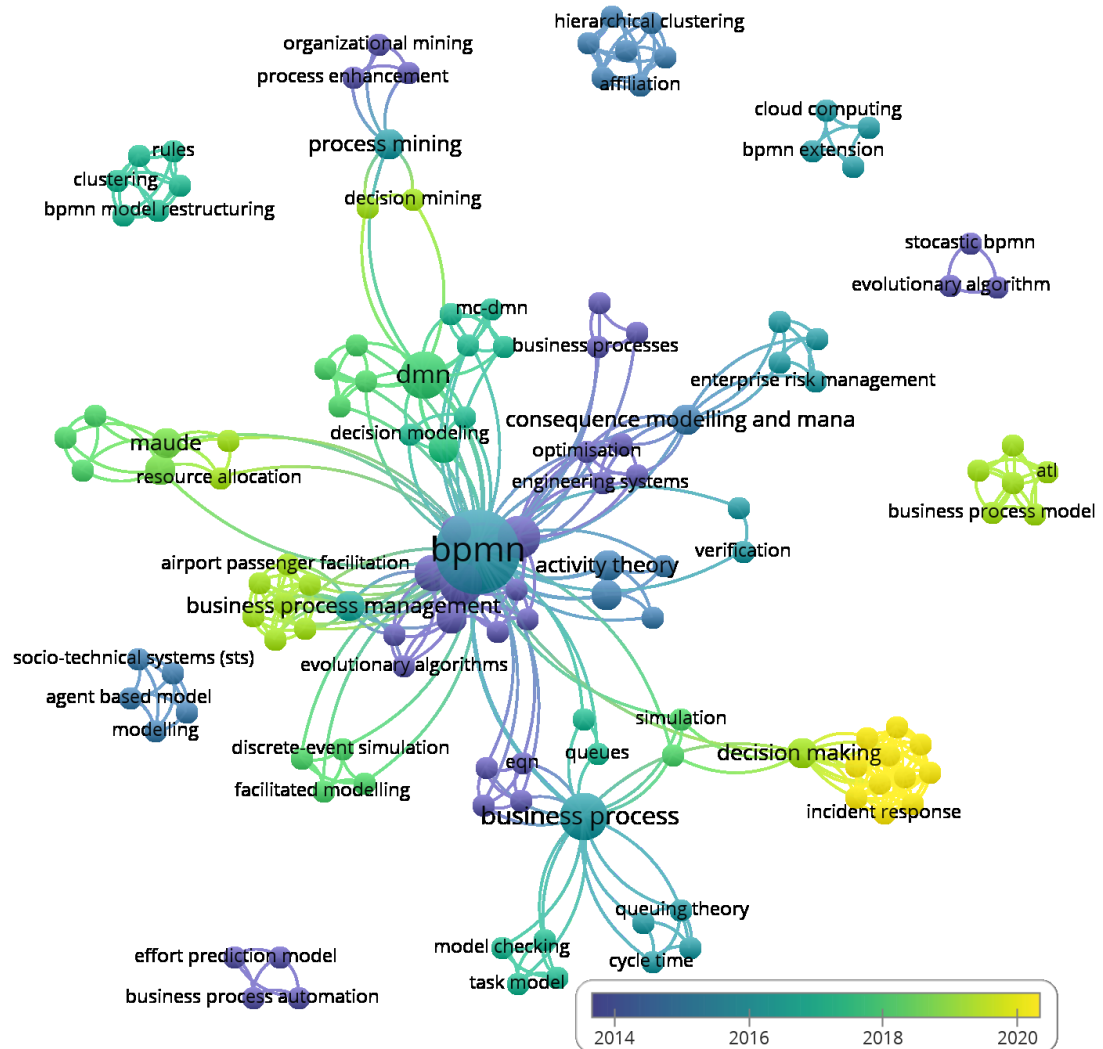
Figure 8. Co-ocurence of Author keywords

373   A list of all authored keywords with weight link to other keywords is: activity theory (4), affiliation (6),
374 agent based model (4), agent-based systems engineering (3), airport passenger facilitation (8), atl (5),
375 automated verification (4), bayesian network (4), bayesian networks (4), bpm (6), bpmn (60), bpmn
376 business processes (4), bpmn extension (3), bpmn model restructuring (5), business process (18), business
377 process automation (3), business process management (13), business process model (5), business process
378 model measures (3), business process modelling notation (4), business process optimisation (5), business
379 process outsourcing (3), business processes (3), cloud computing (3), clustering (5), communication
380 theory (11), configurable reference model (8), consequence modelling and management (10), contextual
381 factors (8), cycle time (4), decision making (15), decision mining (3), decision model and notation (3),
382 decision modeling (4), decision modelling (5), dikw (11), discrete-event simulation (4), dmn (15), effort
383 prediction model (3), engineering agent-based systems (3), engineering systems (6), enterprise risk man-
384 agement (4), eqn (5), evolutionary algorithm (2), evolutionary algorithms (5), facilitated modelling (4),

fault tree analysis (6), fault tree generation (6), flow (8), formal risk analysis (6), genetic algorithm (3), healthcare (4), hierarchical clustering (6), incident response (11), integrated modelling (5), interviews (11), jeqn (5), knowledge discovery (6), knowledge management (11), knowledge rediscovery (6), licenses (11), maude (7), mc-dmn (5), mcdm (5), mda (5), metrics (5), model checking (4), model transformations (5), model-driven architecture (4), model-driven engineering (5), modelling (4), object modeling (4), optimisation (6), organizational mining (3), performance (5), performance evaluation (3), petri nets (5), pproduction optimisation (2), preference to criteria (5), prism (8), probability (2), process configuration (8), process enhancement (3), process chain network (5), process merging (8), process mining (6), process modeling (4), process modelling (5), project management (3), qualitative analysis (4), quantitative model checking (10), quantitative service analysis (6), quantitative workflow analysis (4), queues (3), queuing theory (4), reliability analysis and risk assessment methods (4), resource allocation (4), restructuring (6), rewriting logic (7), rules (5), safety assessment software tools (4), safety management and decision making (4), security (11), security operation center (11), sense-making (11), separation of concerns (5), service engineering (6), scheduling (4), simulation (4), simulations (3), social network (5), social network analysis (3), social network model (6), socio-technical systems (sts) (4), soundness (4), space-sensitive process model (8), statistical model checking (4), stocastic bpmn (2), stochastic automata network (3), stochastic bpmn (11), stochastic model checking (13), stochastic modeling and analysis (4), structural and semantic aspects (5), tacit knowledge (11), task analysis (11), task assignment (4), task model (4), timed automata (4), topsis (5), verification (2).

As you can see in the figure, most of the author's keywords are directly or indirectly linked with the term "BPMN." But there are isolated groups. In the following text, we've listed separate keyword groups. We've added a year of publication, a number of citations, and a specific document to which the keywords belong.

- 2013; 2 Citations; (business process automation; business process model measures; effort prediction model; project management) Aysolmaz et al. (2013),

- 2014; 1 Citations; (evolutionary algorithm; pproduction optimisation; stocastic bpmn) Herbert et al. (2014a),

- 2015; 15 Citations; (agent based model; bayesian network; business process modelling notation; modelling; socio-technical systems (sts)) Wu et al. (2015),

- 2015; 1 Citations; (affiliation; bpm; hierarchical clustering; knowledge discovery; knowledge rediscovery; restructuring; social network model) Khlif and Ben-Abdallah (2015),

- 2016; 0 Citations; (bpmn extension; business process outsourcing; cloud computing; genetic algorithm) Rekik et al. (2016),

- 2017; 3 Citations; (bpmn model restructuring; clustering; metrics; rules; social network; structural and semantic aspects) Khlif et al. (2017),

- 2019; 0 Citations; (atl; business process model; model transformations; model-driven engineering; petri nets; process chain network) Gómez-Martínez et al. (2019).

As mentioned above, there are only 46 keywords PLUS (the number of links to other keywords is given in parentheses after the keyword): accuracy (6), ambiguity (6), automation (3), bpmn (20), business process models (6), checking (6), cognitive effectiveness (7), communities (2), complex (0), confidence (6), context (9), critical path (9), decision-making (7), design (7), dimensions (7), distributed simulation (1), framework (8), functional size (2), group creativity (6), identification (9), implementation (5), information (6), integration (2), model (7), neural-network (7), organizational knowledge (1), patterns (6), performance (9), process execution (9), process models (9), productivity (2), quality (2), reality (2), reference models (2), resources (9), risk (6), science research (2), semantics (9), sensemaking (1), simulation (9), strategy (0), systems (6), tables (7), verification (15), web (1), workflow (9).

As can be seen in Figure 9, they are far more separated than the author's keywords.
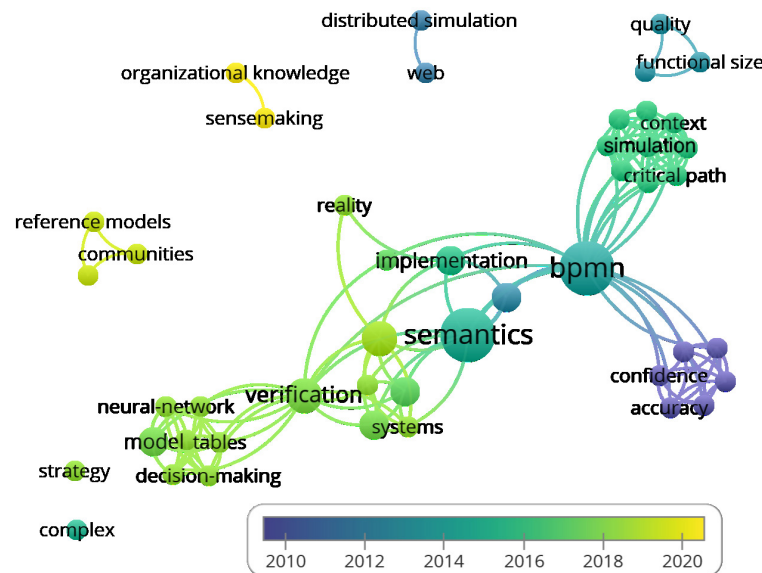
Figure 9. Co-ocurence of KeywordsPlus

Classification of Articles by Methodology

Based on the expert assessment, we examined the documents on the methods and approaches used. We created seven groups: Probabilistic models, DMN, Dynamics task assignment problem, Evolutionary and genetics algorithms, Queuing theory, social networks and Others, into which we divided the documents. Groups correspond to a method or approach that is an essential part of the publication. These groups are also based on keyword analysis, as some separate groups of copyright keywords belong to highly unique articles. We assigned each document to just one group. That is in contradiction to research areas, where one paper can be attributed to more than one research area. The individual documents and their division between research areas and methodological groups can be seen in table 3. We further analyzed the documents in terms of time, i.e. the year of publication. As a result, we plotted using the Buble graph (figure 10); when we assigned the publication year to the X-axis, the Y-axis represents methodological groups. The appropriate number of publications corresponding to the given year and the group is indicated in the respective bubble. This quantity is also graphically represented by the size of the given bubble.
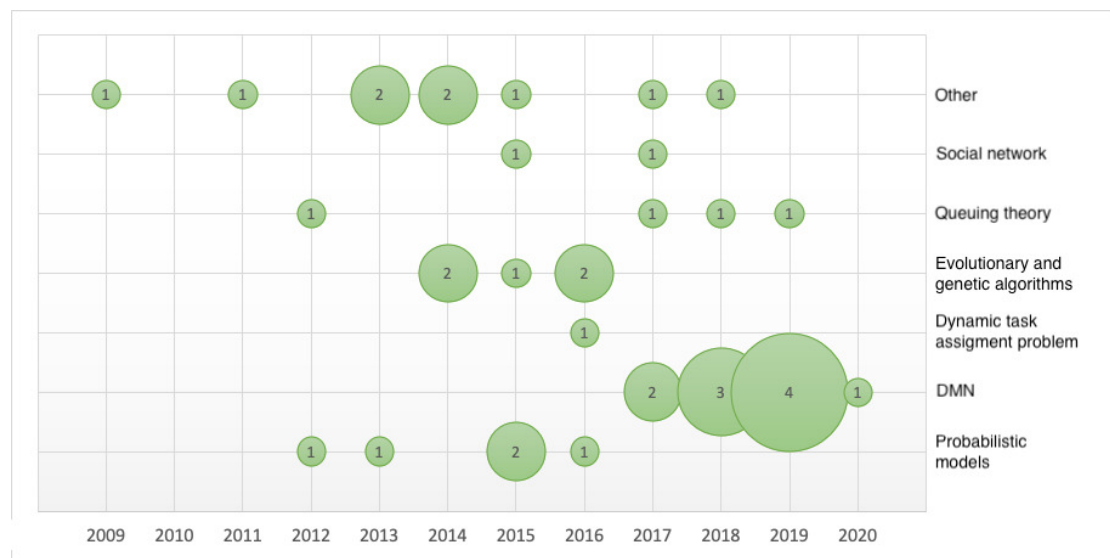
Figure 10. Buble graph - Quantity of papers according to methodological groups and publication year

445   The largest group consists of publications on DMN and BPMN. There are ten documents. Given the
446   initiate year of DMN, this is the most significant approach serving with BPMN. DMN 1.0 came to the
447   public in September 2015; then the OMG group released DMN 1.1 in June 2016, DMN 1.2 in January
448   2019 and the latest version of DMN 1.3 was released in March 2020. The latest version did not affect this
449   systematic search. While the growth of publications since 2017, as seen in figure 10, for example, will
450   undoubtedly be affected by the update of the DMN notation.

451   We assigned only four documents to the methodological group focused on queue theory. That can
452   be seen in table 3, in figure 10, and the specific papers are listed in the following section under the
453   appropriate heading. The largest group is the DMN group with ten documents; we can thus rule out
454   research question R3.

455   Result: Research question R3 - not confirmed.

	Computer Science (26)	Engineering(16)	Operational Research (6)	Business Economics (5)
Probabilistic models (5)	Herbert and Sharp (2012, 2013); Ceballos et al. (2015a,b); Naoum et al. (2016)	Herbert and Sharp (2012, 2013); Ceballos et al. (2015a)		
DMN (10)	Batoulis and Weske (2017); Ghlala et al. (2017); Hasic et al. (2018); De Smedt et al. (2019); Durán et al. (2019); Suchenia et al. (2019); Cho et al. (2020)	Figl et al. (2018); Suchenia et al. (2019); Cho et al. (2020)	Batoulis and Weske (2017); Hasic et al. (2018)	Batoulis and Weske (2017); Tomaskova (2018); Mazhar et al. (2018)
Dynamic task assignment problem (1)	Xie et al. (2016)	Xie et al. (2016)		
Evolutionary and genetic algorithms (5)	Herbert and Sharp (2014b); Rekik et al. (2016)	Herbert and Sharp (2014b); Herbert et al. (2014a, 2015); Herbert and Hansen (2016)	Herbert and Hansen (2016)	
Queuing theory (4)	Bocciarelli and D'Ambrogio (2012); Bahaweres et al. (2017); Gómez-Martínez et al. (2019)	Bocciarelli and D'Ambrogio (2012)	Onggo et al. (2018)	Onggo et al. (2018)
Social network (2)	Khlif and Ben-Abdallah (2015)			Khlif et al. (2017)
Other (9)	Kamrani et al. (2009); Braghetto et al. (2011); Aysolmaz et al. (2013); Burattin et al. (2013); Wu et al. (2015); Mendoza Morales et al. (2017); Duran et al. (2018)	Kamrani et al. (2009); Burattin et al. (2013); Herbert and Sharp (2014a); Herbert et al. (2014b)	Kamrani et al. (2009); Wu et al. (2015)	

Table 3. Documents division into research areas and methodological groups

456   In the following section, the particular methods, techniques and approaches and their use in included
457   publications are listed.

458 ***Probabilistic models***

459 The probabilistic model can be used for decision making when the activity reaches an exclusive splitting
460 gateway and the activity's subject must decide between alternative actions and can be used for predicting
461 or determining between alternative works based on desirable outcomes. Probabilistic models have been
462 presented in the following publications:

463   • Herbert and Sharp (2012): Quantitative analysis of probabilistic BPMN workflows;

464   • Herbert and Sharp (2013): Precise quantitative analysis of probabilistic business process model and
465   notation workflows;

466   • Ceballos et al. (2015a): Towards Probabilistic Decision Making on Human Activities modeled with
467   Business Process Diagrams;

468   • Ceballos et al. (2015b): A Probabilistic BPMN Normal Form to Model and Advise Human
469   Activities;

470   • Naoum et al. (2016): A probabilistic method for business process verification: Reachability,
471   Liveness and deadlock detection,

472 where the (Causal) Bayesian Network or Markov Decision processes were used.

473 ***DMN and Decision analysis***

474 Decision Model and Notation (DMN) is an industry standard for modeling and executing decisions that
475 are determined by business rules. The association of DMN and BPMN is now common practice:

476   • Batoulis and Weske (2017): Soundness of decision-aware business processes,

477   • De Smedt et al. (2019): Holistic discovery of decision models from process execution data,

478   • Durán et al. (2019): A rewriting logic approach to resource allocation analysis in business process
479   models,

480   • Figl et al. (2018): What we know and what we do not know about DMN,

481   • Ghlala et al. (2017): MC-DMN: Meeting MCDM with DMN Involving Multi-criteria Decision-
482   Making in Business Process

483   • Hasic et al. (2018): Augmenting processes with decision intelligence: Principles for integrated
484   modelling

485   • Cho et al. (2020): Capturing Tacit Knowledge in Security Operation Centers,

486   • Mazhar et al. (2018): Designing complex socio-technical process systems - the airport example,

487   • Suchenia et al. (2019): Towards knowledge interoperability between the UML, DMN, BPMN and
488   CMMN models

489   • Tomaskova (2018): Modeling Business Processes for Decision-Making.

490 Both standards fall under OMG.

491 ***Dynamic task assignment approach***

492 The study Xie, Y., Chien, C. F., & Tang, R. Z. (2016). A dynamic task assignment approach based on
493 individual worklists for minimizing the cycle time of business processes by Xie et al. (2016) develop a
494 dynamic task assignment approach for minimizing the cycle time of business processes. The contribution
495 of this paper lies in developing a dynamic task assignment approach based on queuing theory, individual
496 worklist model, and stochastic theory.

497 ***Evolutionary and genetic algorithms***

498 The evolutionary algorithm is applied in these publications:

499   • Herbert and Sharp (2014b): Optimisation of BPMN business models via model checking;

500   • Herbert et al. (2014a): Evolutionary optimization of production materials workflow processes;

501   • Herbert et al. (2015): Using quantitative stochastic model checking tool to increase safety and
502   improve efficiency in production processes;

503 • Herbert and Hansen (2016): Restructuring of workflows to minimise errors via stochastic model
504 checking: An automated evolutionary approach;

505 to optimize the BP diagram, thus looking for a more efficient process. Especially this publication:
506 Rekik, M., Boukadi, K., & Ben-Abdallah, H. (2016). Specifying business process outsourcing require-
507 ments, Rekik et al. (2016), presented a genetic algorithm to identify most appropriate activities of a
508 business process to be outsourced.

Queuing theory

510 In the papers, Bahaweres, R. B., Fitriyah, A., & Rozy, N. F. (2017). Comparative analysis of business
511 process litigation using queue theory and simulation (case study: Religious courts of South Jakarta) Ba-
512 haweres et al. (2017), Onggo, B. S., Proudlove, N. C., D'Ambrogio, S. A., Calabrese, A., Bisogno, S.,
513 & Levialdi Ghiron, N. (2018). A BPMN extension to support discrete-event simulation for healthcare
514 applications: an explicit representation of queues, attributes and data-driven decision points Onggo et al.
515 (2018) and Gomez-Martinez, E; Perez-Blanco, F; de Lara, J; Vara, JM; Marcos, E.(2019).Formal Support
516 of Process Chain Networks using Model-driven Engineering and Petri nets Gómez-Martínez et al. (2019),
517 the authors use queuing theory and simulation to compare processes modeled in BPMN. In the paper,
518 Bocciarelli, P., & D'Ambrogio, A. (2012). Automated performance analysis of business processes Boccia-
519 relli and D'Ambrogio (2012), authors presented a BP performance model of EQN (Extended Queueing
520 Network) type.

Social network

522 The publications below focus on the application of social network analysis metrics (SNA) to studies of
523 biological interaction networks in informatics.

524 • Khlif and Ben-Abdallah (2015): Semantic and structural performer clustering in BPMN models
525 transformed into social network models;

526 • Khlif et al. (2017): A methodology for the semantic and structural restructuring of BPMN models.

Other approaches

528 The following publications were unique in their approaches. We can mention for example Herbert, L. T.,
529 & Sharp, R. (2014). Workflow fault tree generation through model checking Herbert and Sharp (2014a)
530 with FMEA analysis, Aysolmaz, B., İren, D., & Demirörs, O. (2013). An effort prediction model based on
531 BPM measures for process automation Aysolmaz et al. (2013) with Linear multiple regression analysis,
532 Braghetto, K. R., Ferreira, J. E., & Vincent, J. M. (2011). Performance evaluation of business processes
533 through a formal transformation to SAN Braghetto et al. (2011) using Stochastic Automata Network,
534 Kamrani, F., Ayani, R., Moradi, F., & Holm, G. (2009). Estimating performance of a business process
535 model Kamrani et al. (2009) using a Task assignment approach, Morales, L. E. M., Monsalve, C., &
536 Villavicencio, M. (2017). Formal verification of business processes as timed automata Mendoza Morales
537 et al. (2017) convert BPMN to Timed Automata and then perform standard Queuing analysis, Burattin, A.,
538 Sperduti, A., & Veluscek, M. (2013). Business models enhancement through discovery of roles Burattin
539 et al. (2013) the authors have extended the process model to roles, specifically designed role-sharing
540 algorithm, Duran, F; Rocha, C; Salaun, G.(2018).Stochastic analysis of BPMN with time in rewriting
541 logic Duran et al. (2018) presents a rewriting logic executable specification of BPMN with time and
542 extended with probabilities, Herbert, LT; Hansen, Z; Jacobsen, P. (2014). SBAT: A STOCHASTIC
543 BPMN ANALYSIS TOOL Herbert et al. (2014b) presents SBAT, a tool framework for the modelling and
544 analysis of complex business workflows and Wu, PPY; Fookes, C; Pitchforth, J; Mengersen, K.(2015)
545 A framework for model integration and holistic modelling of socio-technical systems Wu et al. (2015)
546 presents a layered framework for the purposes of integrating different socio-technical systems (STS)
547 models and perspectives into a whole-of-systems model.

DISCUSSION

549 We have identified several gaps and issues for future research. The main gaps concern the research area of
550 business economics. We assumed that this area would be the main and most frequent for the combination
551 of BPMN and OR methods. However, we found that this area could be affected by the absence of specific
552 notation. The relevant publications were created only after the release of version DMN 1.1. The effect of
553 DMN notation will be part of future research.

An unexpected gap is a solution to finance and human resources management through operational research. We would like to introduce publications Savku and Weber (2018) and Graczyk-Kucharska et al. (2020) as the pioneering works. The first article added the problem of optimal consumption problem from cash flow with delay and regimes. Authors developed the general analytic model setting and methods for the solution by study a stochastic optimal control problem by the tools of the maximum principle. They proved the necessary and sufficient maximum principles for a delayed jump-diffusion with regimes under full and partial information. The second publication focuses on transversal competencies. These competencies are a set of knowledge, skills and attitudes required for different positions and in different professions. The authors used the method of multivariate additive regression spline together with artificial neural networks to create a model describing the influence of various variables on the acceleration of the acquisition of transverse competencies.

We assume that future research will be influenced by simulation and prediction methods. This study showed the use of Agent-based modelling methods and discrete-event simulations, or probabilistic models and social networks, but neural networks or artificial intelligence methods appeared in any publication. Based on this study, we further expect the use of more sophisticated approaches and the effect of new techniques. At the same time, it is possible to extend process modelling to inaccurate data using Fuzzy methods.

CONCLUSION

The paper presented a systematic overview of publications using the Business Process Model and Notation and operational research methods in process analysis. We analyzed one hundred and twenty-eight selected articles. We chose these articles according to the appropriate strings that we applied to the advanced search in the WOS database. Papers that met the conditions of the study were subjected to various analyzes and briefly described.

The review shows that the processes modelled by BPMN can be extended or analyzed as probabilistic processes, queue theory, or role and task assignments. Alternatively, processes can be optimized using evolutionary or genetic algorithms. Research has also shown the need to identify keywords in publications correctly. For example, only less than two-thirds of the selected articles contained the keyword BPMN, although all documents used this notation. Most of the papers are so-called one-off publications. Only a small number of author teams develop their topic into other continuing publications. Due to that, the average citation is relatively low. Due to the average number of citations to the total number of publications in all research areas, documents falling into the field of operational research are outstanding; there is an average of 7 citations per paper.

We analyzed the publications by research area and found that there is great potential for the research area of business economics (BE), where only a few papers are identified (five in total) but are cited above average. The first document we included in this research area was published in 2017, i.e. only in the last quarter of the examined publication years. The focus of publications on business economics may be affected or caused by the introduction of DMN notation.

Among the authors, smaller collaborating groups around the world have been identified. That groups co-work within the framework of co-authorship and co-citations. We have identified only one single-author publication.

The analysis of keywords showed a significant difference between the keywords assigned by the authors and the so-called PLUS keywords. While the first keywords are almost entirely connectable across publications, Keywords PLUS are significantly diversified.

We have pointed out that the introduction of BPMN 2.0 meant a consequent increase in publishing with this notation.

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627 Birge, J. R. and Louveaux, F. (2011). *Introduction to stochastic programming*. Springer Science &
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