Application of bayesian networks in web services: a scoping review

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Research Article

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Abstract

Context. Web services (WSs) are the preferred approach in realizing the service-oriented computing paradigm. However, this comes with challenges like complexity and uncertainty. Bayesian networks (BNs) are one of the techniques used to deal with these challenges.

Objective. This study aims to determine and describe what is known about the use of BNs in WSs research.

Methods. Using the scoping review method, we selected 69 (among the 532 identified) articles published on the subject (2001-2021). These articles were classified by research themes (What), research objectives (Why), and the types of bayesian network used (How).

Results. The research themes explored are, in order of importance, Service composition, Service management, and Service engineering. In terms of research objectives, the articles mainly focused on Prediction, Description, and Prescription. Finally, the types of BNs used are Basic, Combined, and Extended BNs.

Conclusion. This review offers a first structured picture of the use of BNs in WSs. Its results can help researchers and practitioners interested in the subject.

1. Introduction

Web services (WSs) have revolutionized software development practices. Defined as "software components that were self-described, loosely coupled, and easily integrated with one another" (Driss et al., 2022), WSs are present in practically all fields (Bouguettaya et al., 2017; Zhao et al., 2022). This success is fueled, among other things, by the possibilities offered by WSs in terms of cost reduction, ease of reuse and operational efficiency (Papazoglou et al., 2008; Zhao et al., 2022).

However, the dynamic and unpredictable nature of WSs (Papazoglou et al., 2008) leads to various issues, including complexity and uncertainty (Alférez and Pelechano, 2013; Gabarró and Stewart, 2021). All things that make their implementation difficult in practice. One of the ways to address these issues is the use of Machine Learning (ML) techniques (e.g., Purohit and Kumar, 2021; Razian et al, 2022; Song, 2021). Bayesian Networks (BNs), specifically adapted to complex and uncertain situations (Rohmer, 2020), are one of these techniques.

Since their introduction in the 1980s (Pearl, 1986), BNs have become very popular as evidenced by the large number of fields in which they are used (e.g., Bielza and Larrañaga, 2014; Chen et al., 2021; Hosseini and Ivanov, 2020; Kyrimi et al., 2021; Rosário et al., 2022; Xu et al., 2022). Compared to equally popular techniques like the Artificial Neural Network (ANN) or the Support Vector Machine (SVM), BNs have certain advantages that make them unique (Correa et al., 2009; Hosseini and Ivanov, 2020; Kazem et al., 2015; Malekmohamadi et al., 2011; Müller et al., 2020; Weber et al., 2012). For example, with BNs,
incomplete data or data of various kinds from WSs can be integrated into the same model especially during their composition (Larrañaga and Moral, 2011; Weber et al., 2012; Rohmer, 2020). In addition, the structure of this model allows to clearly distinguish the links between its elements (Larrañaga and Moral, 2011). Finally, the use of the model gives results that are explainable (Lacave and Diez, 2002; Müller et al., 2020). These properties make BNs a natural choice in fields such as WSs (Hwang et al., 2007).

Furthermore, several literature reviews on the use of ML techniques in WS research are published (e.g., Batra and Bawa, 2010; Ekie et al., 2021; Purohit and Kumar, 2021; Rodríguez et al., 2016; She et al., 2019), but, to our knowledge, none of these reviews is devoted to BNs. In others words, there is little information on how BNs are effectively used in the WS research. Therefore, and in order to help interested researchers and practitioners, it is necessary and timely to understand how BNs are used to deal with the problems of WSs.

The purpose of this research is to contribute to this understanding. Accordingly, we carried out a scoping review of 69 articles published during the period 2001-2021 in order to:

- Describe the general characteristics of the literature (years, types, and countries of publication);
- Determine the conditions of application of BNs based on a classification framework with three dimensions: (i) research themes examined (What), (ii) objectives pursued (Why), and (iii) types of BN used (How);
- Identify and propose avenues for future research based on this analysis.

The rest of this paper is organized as follows. The basic concepts are briefly defined in section 2. Section 3 describes the methods of the review, the results of which are presented in sections 4 and 5. These results are summarized and discussed in section 6. Section 7 concludes the paper.

2. Background

2.1. Web service

Web services (WSs) are applications developed and deployed on the Web according to the principles of Service-oriented computing (SOC). At the heart of the SOC is the notion of services, i.e., "... self-describing, open components that support rapid, low-cost composition of distributed applications." (Papazoglou and Georgakopoulos, 2003). To concretely translate its principles, SOC is based on the Service Oriented Architecture (SOA) which is "a means of structuring and reorganizing distributed software applications into a set of composed and interactive pre-existing services." (Driss et al., 2022). In addition to these high-level technologies, there are several essential concepts around WSs. These notions are clearly summarized as follows: "... three key features of services are crucial: functionality, behavior, and quality. Functionality is specified by the operations offered by a service; Behavior reflects how the service operations can be invoked and is decided by the dependency constraints between service operations; Quality determines the non-functional properties of a service." (Bouguettaya et al., 2017, p. 70). In
particular, non-functional properties are defined in the form of parameters (Hwang et al., 2007; She et al., 2019) which can be grouped into three categories (Driss et al., 2022): Quality of Service (QoS), Quality of Experience (QoE), and Quality of Business (QoBiz). QoS is "a set of parameters describing the behavior of Web services in terms of performance parameters." (Driss et al., 2022). Among these parameters, we can cite accessibility, availability, reliability, response time, robustness, scalability (Driss et al., 2022; She et al., 2019; Yu et al., 2008). QoE is "a measure of the end-to-end performance of a whole system as both resulting and taken from the user's point of view." (Driss et al., 2022). These parameters can be friendliness, success rate, and reputation. Finally, QoBiz aims to "describe the financial aspects of service provisioning, such as the price of service, the costs of service provisioning, the service provisioning revenue, and the revenue per transaction (comprised of cost per transaction) parameters." (Driss et al., 2022).

### 2.2. Bayesian Network

A BN is a directed acyclic graph which represents in the form of arcs or lines causal dependencies between the variables of the phenomenon studied. At the structural level, a BN is composed of three elements (Kaya and Yet, 2019; Xu et al., 2022): (i) Nodes, which indicate the variables; (ii) Directed arcs/lines with arrows which represent the causal relationship between nodes; (iii) Conditional Probability Table (CPT), which contains the conditional probability of each state of the nodes, to quantify the causal relationship. Elements (i) and (ii) constitute the qualitative part (structure) of the BN, while element (iii) is the quantitative part (parameter). Building a BN therefore comes down to determining these three elements (Kaya and Yet, 2019). In general, the values of the nodes (discrete or continuous) come either from data (real or synthetic) or from expert knowledge or from the combination of both. Additionally, Bayes' formula is used to determine the elements of the CPTs:

$$P(X_i|X_j) = \frac{P(X_j|X_i) \times P(X_i)}{P(X_j)}$$

With

- $P(X_i)$ and $P(X_j)$ are prior (unconditional) probability of $X_i$ and $X_j$ respectively;
- $P(X_i|X_j)$ is the conditional probability of $X_i$, given $X_j$;
- $P(X_j|X_i)$ is the conditional probability of $X_j$, given $X_i$; and
- $P(X_j|X_i) / P(X_j)$ is the Bayes factor.

Finally, the BN model, once constructed, allows inferences to be made, the most important of which are: (i) **Prediction** (forward Inference) which explains the effects of a phenomenon based on its causes; and (ii) **Diagnosis** (backward Inference) which deduces the causes of a phenomenon from its effects.

### 3. Methods
Due to the exploratory nature of this research, we chose to use the scoping review method (Munn et al., 2022). A scoping review allows to identify, classify thematically, and describe the articles devoted to a given subject. Its purpose is to provide an overview of this subject by determining its nature, evolution, and limits (Arksey and O’Malley, 2005; Munn et al., 2022; Petersen et al., 2015). The remainder of this section is organized into the following phases based on (Arksey and O’Malley, 2005; Petersen et al., 2015): (i) Questions definition, (ii) Article identification, (iii) Article selection, and (iv) Article classification.

3.1. Questions definition

Our objective is to provide a snapshot of the published research work on the application of BNs in WSs. To do this, we considered three perspectives: What, Why, and How. Accordingly, this review is organized around the following questions that reflect these perspectives:

- **RQ1 (What)**: What are the main web service themes considered in the literature?
  
  Motivation: This question aims to determine the different aspects of research on WSs covered by the application of BNs. Through this general and structured portrait, the intention is to allow researchers and practitioners to quickly identify the subjects that interest them.

- **RQ2 (Why)**: What are the research objectives pursued in these themes?
  
  Motivation: By answering this question, we want to identify the main reasons that motivate the application of BNs in the identified WSs themes.

- **RQ3 (How)**: What are the types of bayesian network applied in these themes?
  
  Motivation: There are several types of BNs. The intent of this question is to determine which ones are used the identified WSs themes. We also provide some examples of how these BNs models are used and validated.

3.2. Article identification

For researches, we used ACM Digital Library (http://dl.acm.org), Google Scholar (https://scholar.google.com/), and IEEE Xplore (http://ieeexplore.ieee.org). These tools index the main publications on the subject at hand and have been used in similar reviews (e.g., Di Francesco et al., 2019; Rodriguez et al., 2016; She et al., 2019). In particular, we combined two groups of search expressions. The first group refers to terms related to the “web service“ and the second to the “bayesian network“ (see Table 1).
Table 1
Article identification (2022-02-27)

<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACM Digital Library</td>
<td>(&quot;web based service&quot; OR &quot;web based services&quot; OR &quot;web-based service&quot; OR &quot;web-based services&quot;) AND ((&quot;bayes net*&quot; OR &quot;bayes network*&quot; OR &quot;bayesian net*&quot; OR &quot;bayesian network*) OR &quot;bayesian probabilistic model*&quot; OR &quot;belief net*&quot; OR &quot;belief network*&quot; OR &quot;causal net*&quot; OR &quot;causal network*&quot; OR &quot;probabilistic net*&quot; OR &quot;probabilistic network*&quot;) AND NOT (&quot;deep belief&quot; OR &quot;deep learning&quot; OR &quot;meta-analysis&quot; OR &quot;naive bayes*))</td>
<td>159</td>
</tr>
<tr>
<td>Google Scholar</td>
<td>intitle:[&quot;web service</td>
<td>services&quot; &quot;bayes</td>
</tr>
<tr>
<td>IEEE Xplore</td>
<td>(&quot;web based service&quot; OR &quot;web based services&quot; OR &quot;web-based service&quot; OR &quot;web-based services&quot;) AND ((&quot;bayes net*&quot; OR &quot;bayesian net*&quot; OR &quot;bayesian probabilistic model&quot; OR &quot;belief net*&quot; OR &quot;causal net*&quot; OR &quot;probabilistic net&quot;) AND NOT (&quot;deep belief&quot; OR &quot;deep learning&quot; OR &quot;meta-analysis&quot; OR &quot;naive bayes*))</td>
<td>74</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>532</td>
</tr>
</tbody>
</table>

The searches (done on February 27, 2022) produced 523 articles which were saved in EndNote X9 (Thomson Reuters, Philadelphia, USA). After removing duplicates, the remaining 384 articles were submitted for selection.

3.3. Article selection

In addition to the constraints introduced in the search, each article had to meet the following criteria to be selected:

i. Published in English;

ii. Published in refereed journals, international conferences (congresses), or workshops;

iii. Published after 1999;

iv. Focused on BNs application in WS.

This implies that are excluded:

i. Research reports, dissertations or theses, books and book chapters, editorials, opinion pieces, commentaries, reviews, etc.;

ii. Articles not available in full-text;

iii. Conference papers subsequently published in a journal.

These criteria were used to select articles in two stages. First, the examination of the title and the abstract of the articles allows to select 156 articles. Then, the full text of these 156 articles was read to determine their relevance. At the end of this process, 69 articles were selected and classified.

3.4. Article classification
To structure and facilitate the classification of the papers, we developed a framework (Fig. 1) based on the questions of the review. The details of this framework are presented in the following subsections.

### 3.4.1. Web service themes

Based on (Li et al., 2021; Papazoglou et al., 2008) and by iteratively analysing the main focus of the selected papers, we identified three broad research themes, namely Service composition, Service engineering, and Service management.

i. **Service composition.** It "consists of collecting and assembling autonomous Web services to achieve new functionalities by creating complex, value-added service-based applications." (Driss et al., 2022);

ii. **Service engineering.** Also named Service design and development (Papazoglou et al., 2008), it consists of "Managing the entire services lifecycle - including identifying, designing, developing, deploying, finding, applying, evolving, and maintaining services." (Papazoglou and Van den Heuvel, 2006);

iii. **Service management.** "Web service management refers to the control and monitoring of Web service qualities and usage." (Yu et al., 2008, p. 545). These controls and monitorings are made during the execution of the WSs (Papazoglou et al., 2008).

### 3.4.2. Research objectives

Based on (Guerra-Montenegro et al., 2021) and the objective of the selected papers, we categorize the reasons for using BNs for WSs as descriptive (exploratory), predictive, or prescriptive.

i. **Descriptive objective.** To characterize (classify, explain, model, represent, or understand) WS by using BNs;

ii. **Predictive objective.** To appraise (assess, calculate, estimate, evaluate, forecast, measure, prognosis, sizing) WS by using BNs;

iii. **Prescriptive objective.** To define or propose normative approach (framework, method, platform, or procedure) to use BNs in WS.

### 3.4.3. Types of bayesian network

In this review, we distinguished the following types of BNs (e.g., Larrañaga and Moral, 2011; Marcot and Penman, 2019; Weber et al., 2012):

i. **Basic.** Concerns the standard form of BNs in which data contains only discrete variables;

ii. **Extended.** More elaborated forms of BNs such as dynamic BNs, hierarchical BNs, object-oriented BNs, relational BNs, etc. This type of BN also concerns those that contain (i) both continuous and discrete variables (Hybrid BN), (ii) only continuous variables (Continuous BN); and

iii. **Combined.** Joint use of BNs with other techniques such as AHP, Fuzzy logic, neural network, simulation, etc.
These categories were used to manually classify the articles. Even if the categories are not necessarily disjoint, as a general rule, an article is classified in one and only one category. In case an article covers more than one category, we choose the one that best suits the authors' objective.

### 3.5. Limitations

Like any research, our review has limitations. These relate in particular to the identification, selection, and classification of articles. Regarding the identification of articles, it may be that, despite all the rigor we have put into developing them, our search expressions are limited. And, as a result, some relevant articles were not found. However, the number and diversity of the articles finally included in the review ensure that the subject is well represented. As for the selection of articles, we probably eliminated a few by mistake. To reduce this problem, we defined, a priori, eligibility criteria that we applied as rigorously as possible. Finally, when it comes to the classification of articles, another researcher may not obtain exactly the same results as us. Nevertheless, we have defined and used a classification framework whose categories come from both the literature on the subject and the selected articles. We hope that these categories are sufficiently clear and high level to facilitate the reproduction of the classification.

### 4. Bibliographic Analysis Results

The profile and evolution of the selected literature was determined by examining its (i) years of publication, (ii) types of publication, and (iii) geographical distribution (See Table A1 in appendix for details). Figure 2 presents the results of this analysis, the details of which are described in the following subsections.

#### 4.1. Publication by years

As shown in Fig. 2, the 69 selected papers are published between 2001 and 2021. By grouping them into 3 periods of 7 years (2001–2007, 2008–2014, and 2015–2021), we see a double fluctuation in their number. First of all, it should be noted that only 10 papers were published over the period 2001–2007. Then, between 2001–2007 and 2008–2014, we observe a drastic increase in the number of papers which goes from 10 to 38, i.e., nearly 4 times the starting number. However, the following period (2015–2021) is characterized by a decrease in the number of papers, which goes from 38 to 21.

#### 4.2. Publication types and venues

In terms of publication types, Fig. 2 shows that 55.1% of the papers come from conferences, 36.2% from journals, and 8.7% from workshops. According to Table 2, one journal and four conferences published more than one paper. Most publications (78%) are limited to one paper each. Note that the journal Expert Systems with Applications, the International Conference on Web Services and the International Conference on Services Computing are among the best in their respective fields.
Table 2
Papers by publication venues (N = 69)

<table>
<thead>
<tr>
<th>Venue name</th>
<th>Type</th>
<th>Number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>International Conference on Web Services</td>
<td>Conference</td>
<td>6 (8.7%)</td>
</tr>
<tr>
<td>International Conference on Services Computing</td>
<td>Conference</td>
<td>3 (4.3%)</td>
</tr>
<tr>
<td>Expert Systems with Applications</td>
<td>Journal</td>
<td>2 (2.9%)</td>
</tr>
<tr>
<td>International Conference on e-Business Engineering</td>
<td>Conference</td>
<td>2 (2.9%)</td>
</tr>
<tr>
<td>International Congress on Advanced Applied Informatics</td>
<td>Conference</td>
<td>2 (2.9%)</td>
</tr>
<tr>
<td>Others</td>
<td>-</td>
<td>54 (78.3%)</td>
</tr>
</tbody>
</table>

4.3. Publication by continents

Geographically (i.e., the country of affiliation of the main author of each paper), Fig. 2 shows that Asia, with 43 papers (62.4%), largely dominates the list of continents that publish on the subject. The Americas and Europe follow by far with 12 (17.4%) and 8 (11.6%) papers respectively. Finally, Africa and Oceania bring up the rear with 3 (4.3%) papers each. More specifically, the 69 papers originate from 19 countries. China (28 papers), followed by India (8 papers) and the USA (8 papers) are the three countries that contribute the most to the subject.

5. Classification Results

The thematic classification of the 69 papers (Table 3) shows that the theme Service composition comes first with 31 papers (45.0%), followed by Service management with 23 papers (33.3%), and finally, Service engineering with 15 papers (21.7%).

Table 3
Papers on Web service themes (N = 69)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Number (%)</th>
<th>Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service composition</td>
<td>31 (45.0%)</td>
<td>[P01, P02, P03, P04, P05, P06, P07, P08, P09, P10, P17, P50, P51, P52, P53, P54, P55, P56, P57, P58, P59, P60, P61, P62, P63, P64, P65, P66, P67, P68, P69]</td>
</tr>
<tr>
<td>Service engineering</td>
<td>15 (21.7%)</td>
<td>[P11, P12, P13, P14, P15, P16, P18, P19, P20, P21, P22, P24, P25, P26, P27]</td>
</tr>
</tbody>
</table>
The distribution of these themes (and sub-themes) is illustrated in Fig. 3. As can be seen, the theme Service composition is subdivided into three sub-themes: Service selection, Service discovery, and Service recommendation. The theme Service management has two sub-themes: Service monitoring and Service control. The Service engineering is also composed of the following two sub-themes: Service development and Service application.

In the remainder of this section, each of these sub-themes is described and analyzed according to the research objectives and types of BN used. Some illustrative examples of the BNs models are also provided in each case.

### 5.1. Service composition

Table 4 shows the distribution of the 31 papers included in this theme according to the three sub-themes (See Table A2 in appendix for details). The majority of papers (54.8%) concern the Service selection sub-theme. Next comes the Service discovery sub-theme with 9 papers (29.0%), which represents just over half of the papers included in the Service selection. Finally, the Service recommendation sub-theme, with 5 papers (16.2%), accounts for less than a third of the papers included in the Service selection.

Table 4
Papers on Service composition (N = 31)

<table>
<thead>
<tr>
<th>Sub-theme</th>
<th>Number (%)</th>
<th>Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service selection</td>
<td>17 (54.8%)</td>
<td>[P04, P09, P17, P55, P56, P57, P58, P59, P60, P61, P62, P63, P64, P65, P66, P67, P68]</td>
</tr>
<tr>
<td>Service discovery</td>
<td>9 (29.0%)</td>
<td>[P01, P02, P03, P05, P06, P07, P08, P10, P69]</td>
</tr>
<tr>
<td>Service recommendation</td>
<td>5 (16.2%)</td>
<td>[P50, P51, P52, P53, P54]</td>
</tr>
</tbody>
</table>

### 5.1.1. Service selection

Service selection consists of "Choosing the most adequate service among discovered candidates, according to functional or non-functional properties" (Huf and Siqueira, 2019).

- **Overview.** According to our results, the 17 papers of this sub-theme propose BN models based on non-functional requirements such as QoS (12 papers) and QoE (5 papers). For QoS, 8 papers explore QoS in general (P04, P09, P17, P55, P58, P63, P64, P68). The other 4 relate to specific QoS parameters such as Service organization (P67), Data quality (P59), Response time (P65) or Performance (P66). Regarding QoE, the papers explore Trust (P57, P60, P61, P62) and Trust and reputation (P56).
Figure 4 shows that Predictive is the most popular objective with 11 papers (P09, P17, P55, P56, P58, P59, P61, P63, P65, P66, P68). The Descriptive objective follows far with 5 papers (P04, P60, P62, P64, P67), i.e., a little less than half as many papers as before. Finally, 1 paper has a Prescriptive objective (P57). In the latter case, the prescription takes the form of an Approach.

Regarding the types of BN, Fig. 4 indicates that more than three quarters (76.5%) of the papers used Basic BN (P04, P17, P56, P57, P58, P59, P60, P61, P62, P63, P64, P66, P67) and that a little less than a quarter (23.5%) concern the Combined BN (P09, P55, P65, P68). In the case of papers that used the Combined type, the BN is combined with stochastic local search (P09), Fuzzy logic (P55), Hidden Markov Model (P65) and Combined Cuckoo Search Algorithm (P68). Note that no paper used the Extended BN.

In (P57), a trust-aware service selection approach based on Basic BNs has been developed. In particular, the trust was modeled as probability values. Their approach was validated by simulation. In addition, in (P65), authors propose a model for prediction of response time (waiting time, network delay, service execution time) of WSs using a combined model of Hidden Markov Model (HMM) and BNs. The model was experimentally validated using WSDream data set.

5.1.2. Service discovery

Service discovery aims to “[locate] relevant services that offer some desired data or functionality” (Huf and Siqueira, 2019). In general, three approaches are used for Service discovery: Syntactic-aware, Semantic-aware, and Context-aware (Huang and Zhao, 2022; Rodríguez et al., 2016).

According to the results, 7 of the 9 papers of this sub-theme use BN models based on the Semantic-aware approach (P01, P02, P04, P06, P07, P10, P69). The other 2 papers deal with BN models based on the Context-aware approach (P05, P08). In particular, in the paper (P07), the authors used the Semantic-aware mode to explore QoS (“Quality as functionality”).

According to Fig. 5, the objectives covered in this sub-theme are Descriptive with 5 papers (P03, P06, P07, P10, P69), Prescriptive with 3 papers (P01, P02, P05) and, Predictive with 1 paper (P08). Among the 3 papers whose objective is Prescriptive, the contribution is in the form of Approach (P01, P02) and Framework (P05).

Regarding the types of BN, Fig. 5 shows that 7 papers used the Basic BN (P01, P02, P03, P06, P07, P10, P69) and 2 the Extended BN (P05, P08). For these latter papers, the Extended form is a Dynamic BN (DBN). The Combined BN type is not used in this sub-theme.

In (P05), the authors propose a context-aware approach (Framework) in an Internet of Things (IoT) environment. In particular, the IoT context (role and relationships with entities) have been represented in the form of an ontology. In addition, a DBN has been developed to deal with the dynamic aspect (uncertainty and time) of this context. The proposed approach has not been evaluated. Moreover, a semantic-aware model based on the Basic BN, bi-Directional Hybrid Priors Topic Model (bi-HPTM), has been proposed in (P10). In this model, the thematic distribution of each
sentence is determined both by the concepts of the words involved, and also influenced by the preceding and following sentences. The proposed model has been experimentally validated on ProgrammableWeb.

5.1.3. Service recommendation

"Web service recommendation is the process of automatically identifying the usefulness of services and proactively recommending services to end users." (Yao et al., 2015, p. 453). In particular, this can facilitate the service composition (Wu et al., 2015).

- **Overview.** Examination of the papers of this sub-theme suggests that, in general, the Service recommendation is a support task. Thus, the 5 papers included in this sub-theme use the recommendation to support Service discovery (P50, P51) and Service selection (P52, P53, P54). Note that all papers are based on the "QoS-aware recommendation method" (Li et al., 2021).

- **Research objectives.** Figure 6 shows that 4 papers have a Predictive objective (P50, P51, P52, P53) and 1 paper a Prescriptive objective (P54). In this last paper, the prescription is in the form of a Method. No paper has a Descriptive objective.

- **Types of BN.** Regarding the types of BN, Fig. 6 indicates that 4 papers used Basic BN (P50, P51, P52, P54) and 1 paper used Extended BN in the form of Dynamic BN (P53). No paper used Combined BN.

- **Examples.** To support service discovery, the authors proposed in (P50) a WS recommendation model based on Basic BN. Constructed from existing serving sequences, the model was then used to recommend an optimal serving sequence. The robustness and efficiency of the model have been illustrated experimentally. On the other hand, to support service selection, the authors of (P54) introduced a method based on a basic BN which recommends WSs. The BN structure comes from service invocation history records (with service clusters as nodes, and the relationships between services as the edges between nodes). Its parameters are determined using learning methods (MLE and BE). Finally, case study and experiments are used to validate the proposed method.

5.2. Service management

According to the results (Table 5), 23 papers form this theme (See Table A3 in appendix for details). These papers are subdivided almost equally in two sub-themes: Service control (12 papers), and Service monitoring (11 papers).

<table>
<thead>
<tr>
<th>Sub-theme</th>
<th>Number (%)</th>
<th>Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service control</td>
<td>12 (52.2%)</td>
<td>[P23, P28, P29, P31, P32, P34, P36, P38, P39, P40, P43, P44]</td>
</tr>
<tr>
<td>Service monitoring</td>
<td>11 (47.8%)</td>
<td>[P30, P33, P35, P37, P41, P42, P45, P46, P47, P48, P49]</td>
</tr>
</tbody>
</table>

Table 5
Papers on Service management (N = 23)
5.2.1. Service control

In the review, Service control or "Control management aims to improve the service quality through a set of control mechanisms (e.g., transaction, change management, and optimization)." (Yu et al., 2008, p. 538).

- **Overview.** The results indicate that 9 of the 12 papers in this sub-theme are dedicated to exception detection tasks (P36, P38), diagnosis of faults (P23, P28, P32, P34, P44) or the root cause of problems (P29, P31). The other 3 papers focus on optimizing the performance (P40), reliability (P43) and workflow (P39) of WSs.

- **Research objectives.** Figure 7 shows that among the papers of this sub-theme, 7 have a Prescriptive objective (P29, P31, P32, P34, P38, P36, P44), 3 a Predictive objective (P39, P40, P43), and 2 a Descriptive objective (P23, P28). For papers whose objective is Prescriptive, the prescription takes the form of Approach (P29, P32, P38, P44), Framework (P31) and Method (P34, P36).

- **Types of BN.** According to Fig. 7, the types of BN used are the Basic BN in 10 papers (P23, P28, P29, P31, P32, P34, P38, P40, P43, P44), the Combined BN in 1 paper (P36) and the Extended BN in 1 paper (P39). In the paper that used the Combined type, the BN is associated with an Agent and in the one that used the Extended type, the BN is a Dynamic BN.

- **Examples.** In Tunneling (P23), the authors propose a WS that incorporates a basic BN as a module to diagnose machine faults during operation. The BN structure and parameters are built from the diagnostic database used to store fault data. No validation of the model is proposed. Moreover, the authors of (P36) present an exception detection method which uses a WS based on a combination of agent and BN. In the structure of the BN, the nodes are represented by the WSs and the edges by the flow of execution of direct causality between the nodes. The feasibility and the efficiency of the proposed method are demonstrated by an experiment.

5.2.2. Service monitoring

Service monitoring consists of "... calculating the QoWS (Quality of WS) parameter values or assessing a Web service claim in terms of promised QoWS" (Yu et al., 2008, p. 538).

- **Overview.** Among the 11 papers included in this sub-theme, 6 relate to the evaluation of reliability (P35, P41, P45, P47, P48) and QoS (P46). Four other papers concern monitoring of the change (P37) and the performance (P30, P33, P42). Finally, a single paper concerns the process of the WSs (P49).

- **Research objectives.** Figure 8 shows that 8 papers have a Predictive objective (P33, P35, P42, P45, P46, P47, P48, P49) and 3 a Prescriptive objective (P30, P37, P41). For these last papers, the prescription takes the form of Approach (P41), Framework (P37), and Method (P30). No paper has Descriptive objective.

- **Types of BN.** According to Fig. 8, the type of BN used is the Basic BN in 6 papers (P30, P33, P37, P42, P46, P49), the Extended BN in 4 papers (P41, P45, P47, P48) and the Combined BN in 1 paper (P35). In this last paper, the BN is associated with an Ontology. For the Extended BN type, the authors used Dynamic BNs.
• **Examples.** In (P35), the authors propose a WS reliability ontology (WSRO) in order to select better WS for integration. The knowledge resulting from this ontology served as a basis for the construction of the BN model. And the causality reasoning capacity of this model was used to assess the WS reliability. Finally, the applicability and effectiveness of the approach have been demonstrated experimentally. In the same vein, the authors in (P41) propose an approach to predict the QoS (online reliability) of service-oriented system of system (SoS) thanks to DBNs which are built from historical records. The effectiveness of the approach is demonstrated experimentally from real cases.

### 5.3. Service engineering

Table 6 shows the 15 papers of this theme (See Table A4 in appendix for details) distributed according to the two sub-themes: *Service development* (9 papers), and *Service application* (6 papers).

<table>
<thead>
<tr>
<th>Sub-theme</th>
<th>Number (%)</th>
<th>Papers</th>
</tr>
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<tbody>
<tr>
<td>Service development</td>
<td>9 (60.0%)</td>
<td>[P11, P12, P14, P16, P18, P19, P24, P25, P27]</td>
</tr>
<tr>
<td>Service application</td>
<td>6 (40.0%)</td>
<td>[P13, P15, P20, P21, P22, P26]</td>
</tr>
</tbody>
</table>

#### 5.3.1. Service development

In this review, Service development concerns the design and development of WSs.

- **Overview.** The papers of this sub-theme relate to a prototype of WS that supports the daily life (P25) or tourism services (P11). Others focus on web-based online data (dependency) analysis tool (P12), diagnosis service (P18), an ontology-based WS (P19) or WS API which computes learners’ competence and capability assessment (P24). Finally, others explore the field of the supply chain (P14, P16) and intelligent WSs (P27).

- **Research objectives.** According to Fig. 9, the objectives pursued are *Descriptive* in 4 papers (P11, P14, P18, P25), *Predictive* in 4 papers (P12, P16, P24, P27) and *Prescriptive* in 1 paper (P19). For this last paper, the prescription takes the form of *Method*.

- **Types of BN.** Figure 9 also shows that the types of BN used are the *Basic* BN in 7 papers (P11, P12, P14, P16, P18, P24, P25), and the *Combined* BN in 2 papers (P19, P27). Regarding the *Combined* type, one of the papers uses the BN with the *Neural network* and *Ontology* (P19) and the other combines the BN with the *Multi-entity* (P27). No paper used the *Extended* BN.

- **Examples.** The authors of (P25) developed a WS named Mutual Assistance Support System (MASS) to support the daily life of the most vulnerable road users (the elderly). In order to determine the factors that have a strong influence on the use of MASS, a baseline BN is constructed from the responses to the user survey. This model is then used in numerical experiments to analyze the awareness of young people (main providers of skills resources) to MASS. In (P27), the authors...
developed a framework consisting of a smart WS that takes into account the diversity of contexts, the semantic context representation and the capacity to reason with uncertain information. Regarding this last aspect, a multi-entity Bayesian network (MEBN) model is used. To show its reasoning capabilities, the framework is validated with a smart plant watering use case.

5.3.2. Service application

Service application concerns the use of BNs to examine existing WSs integrated in frameworks, prototypes, tools, etc.

- **Overview.** In a prototype called "whereabouts diary", white-pages WSs are used to extract information about locations visited by users and BNs to classify places (P13). In (P15), an intelligent system relying on spatial WS (GIS functions) to provide personalized recommendations for tourist attractions is proposed. In the (P20), a geospatial WS is integrated into Enterprise Business System. Furthermore, a diagnostic functionality is exposed through a web API in (P21), and in (P22), an interactive recommender system based on a WS is used to manage patient information. Finally, in (P26), the authors use BNs to analyze the sensitivity of a prototype of WS.

- **Research objectives.** Figure 10 shows that 3 papers (P13, P21, P22) have a *Descriptive* objective, 2 (P15, P26) a *Predictive* objective and 1 paper (P20) a *Prescriptive* objective. In this last paper, the prescription takes the form of *Framework*.

- **Types of BN.** According to Fig. 10, the types of BN used are the *Basic* BN in 5 papers (P13, P20, P21, P22, P26), and the *Combined* BN in 1 paper (P15). In this last paper, BN is combined with the Analytic hierarchy process (AHP). No paper used the *Extended* BN.

- **Examples.** In (P15), the authors developed a prototype for tourist attractions recommendations. This system integrates a geospatial WS (ESRI ArcWeb Service) and a BN combined with the AHP. The BN structure and parameters are based on the knowledge (literature) in the travel domain. The prototype is validated through an example. Similarly, in (P20), the authors develop a framework composed of an enterprise business system, geospatial WSs, intelligent agents, and BN. In particular, the BN plays the role of QoS reasoning model whose performance is validated in a geospatial data integration project in a tobacco company.

6. Summary And Discussion

This scoping review aims to determine what is known about the application of BNs in WSs. To this end, 69 papers published over the period 2001-2021 were identified and analyzed. From a bibliographic point of view, the results reveal that these papers (i) are published mainly in conferences; (ii) increased sharply in number between 2001-2007 and 2008-2014; and (iii) have authors predominantly from Asia (particularly China). Furthermore, based on the review questions, the results are organized around: (i) the themes of the WSs; (ii) the objectives pursued in these themes; and (iii) the types of BNs used in these themes. The remainder of this section summarizes (Fig. 11) and discusses these findings and suggests avenues for future research where appropriate.
6.1 Web service themes

- Regarding the WS themes explored, Fig. 11 suggests that Service composition is the most popular (45.0%), followed by Service management (33.3%) and finally, Service engineering (21.7%);
- Among the three sub-themes of Service composition (Table 4), Service selection is the most explored with BN models based on QoS and QoE. The Service discovery sub-theme, on the other hand, uses BNs in concert with Semantic-aware and Context-aware approaches. Finally, the results suggest that the BNs developed in the papers of the sub-theme Service recommendation are intended to support Service selection and Service discovery. For Service management, the sub-theme Service control is at the top, followed closely by Service monitoring (Table 5). In these two sub-themes, BNs are mainly used to assess and improve the quality of services. As for the two sub-themes of Service engineering, Service development and Service application, they are equally popular (Table 6);
- Finally, as the Fig. 11 illustrates, there is very little activity over the period 2001-2007 with the number of papers between 3 and 4. The period 2008-2014 is the one that attracts the most attention with 20 papers in Service composition, 11 papers in Service management and 7 papers in Service engineering.

Briefly, in response to question RQ1 (What are the main themes of web services considered in the literature?), our review reveals the predominance of the Service composition. This is hardly surprising considering that service composition is the "raison d’être" of the SOC paradigm (Papazoglou et al., 2008). Recent studies clearly reflect this trend (e.g., Agarwal et al., 2022; Huf and Siqueira, 2021; Razian et al., 2022; Zhao et al., 2022).

Moreover, the review indicates that, of the three elements (Functionality, Behavior, and Quality) considered fundamental for the WSs (Bouguettaya et al., 2017), it is Quality which is mainly studied with the BNs. Among the 69 analyzed papers, 33 (47.8%) deal with one aspect or another of Quality (22 papers on Service composition, and 11 on Service management). Based on these observations, we suggest that researchers pay more attention to the Functionality and Behavior of WSs when studying the use of BNs.

Finally, regarding the Service recommendation, the results show that no paper mentions the type of recommendation approach used. Therefore, it would be important to explore how recommendation approaches (e.g., collaborative filtering, content-based and hybrid) may be used in concert with BNs in a WS context.

6.2 Research objectives pursued

- Concerning research objectives, Fig. 11 highlights that the majority of papers (47.8%) have a Predictive objective. The Descriptive and Prescriptive objectives follow with 27.5% and 24.7% of the papers respectively;
Furthermore, using BNs for a *Prescriptive* objective is equivalent to suggesting ways of doing things. According to our results, these suggestions can take the form of *Approach* (P01, P02, P29, P32, P38, P41, P44, P57), *Framework* (P05, P20, P31, P37) or *Method* (P19, P30, P34, P36, P54);

With respect to the themes explored, the *Predictive* objective is used, by order of importance, in *Service composition, Service management* and *Service engineering*. The *Descriptive* objective is mainly used in *Service composition* and *Service engineering*. Finally, the *Prescriptive* objective is mainly used in *Service management*.

In summary, concerning the question **RQ2** (What are the research objectives pursued in these themes?), the results indicate that the articles relate mainly to predictive objectives that focus on the composition and management of services. These results are quite logical since these two themes contain activities aimed at predicting or evaluating WSs according to predefined criteria.

Furthermore, the results highlight the lack of popularity of the Prescriptive objective, particularly in Services Engineering (only 2 papers are concerned - see Fig. 11). This aligns perfectly with (Bouguettaya et al., 2017, p. 68) who remarked that “Service systems have so far been built without an adequate rigorous basis from which to reason about them”. However, the activities of the Service engineering must be carried out according to precise prescriptions in order to design and develop applications based on the WS. Thus, we suggest that future research should pay more attention to how BNs are used for prescriptive purposes in service engineering. For this, we can rely on models such as those proposed in (Kurniawan et al., 2020; Reyes-Delgado et al., 2022).

### 6.3 Types of bayesian network used

- In terms of types of BN, Fig. 11 shows that, *Basic* is the most used by researchers with 52 of the 69 (75.4%) papers analysed. Then follow, and to a lesser extent, the two other types of BNs, *Combined* and *Extended*, with 9 (13%) and 8 (11.6%) papers respectively;
- The 8 papers devoted to the *Extended* BN are all DBNs (P05, P08, P39, P41, P45, P47, P48, P53);
- As for the *Combined* form, the results show that in Service selection sub-theme, BNs were combined with Stochastic Local Search (P09), Fuzzy logic (P55), Hidden Markov Model (P65), and Cuckoo Search Algorithm (P68). In Service development, BNs were combined with Neural network and Ontology (P19) and Multi-Entity BN (P27). Finally, BNs were combined with AHP (P15) in Service application, with Agent (P36) in Service control, and with Ontology (P35) in Service monitoring;
- With respect to the themes explored, the *Basic* BN are mainly used in *Service composition*, in *Service management* and in *Service engineering*. The *Combined* form is also used in these themes, but in a much lower proportion. Finally, the *Extended* form is only used in *Service composition* and in *Service management*. 
Thus, regarding question RQ3 (What are the types of bayesian network applied in these themes?), the results show that it is the Basic BNs that are the most used, and this, mainly in the Service composition. These results can be explained by the ability of BNs to visually represent the dependencies between the different elements of a WS. Which is a facilitating element (Zhao et al., 2022) in the particular case of Service composition.

At the same time, for complex and dynamic phenomena such as WS (Papazoglou, 2008), “description” alone is not enough. We need slightly more adapted techniques like DBN to better understand these phenomena. Our results suggest that, if this form of BN is actually used, it remains marginal (8 papers). This could be explained by the complexity of DBNs (Bielza and Larrañaga, 2014); which can notably increase their computation time (Hosseini and Ivanov, 2020). The same goes for the Combined BN which, like the Extended BN, concerns only 9 papers. However, as “BNs are limited by the modeling aspects that they can deal with” (Weber et al., 2008), it is necessary to combine them with other techniques in order to correctly model the phenomenon under study. Therefore, these constraints must be taken into account when considering using Combined and Extended BNs in a WS context.

7. Conclusion

This review, the first devoted specifically to the application of BNs in WSs, offers important contributions. In particular, by organizing its results by a framework composed of themes (What), objectives (Why) and types of BNs (How), the review provides interested researchers and practitioners with (i) an accessible and structured source of references on the subject; and (ii) a clear indications of the strengths and weaknesses of each of these elements. These results are therefore likely to help them in the planning of their research or the implementation of BNs in a WS context. Furthermore, the review also reveals that, despite the advent of other forms of services such as cloud, fog, grid, micro, mobile services, "traditional" web services (Razian et al., 2022) remain a very active field of research.

Declarations

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References


Figures

Bayesian networks for web services

<table>
<thead>
<tr>
<th>Web service themes</th>
<th>Research objectives</th>
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Figure 1
Classification framework

Figure 2
Distribution of papers by years, publication types, and continents
Figure 3

Web service themes and sub-themes
Figure 4

Service selection: Research objectives & Types of BN

<table>
<thead>
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Figure 5

Service discovery: Research objectives & Types of BN
Figure 6

Service recommendation: Research objectives & Types of BN
### Figure 7

Service control: Research objectives & Types of BN

<table>
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</table>

**Figure 8**

Service monitoring: Research objectives & Types of BN
Figure 9

Service development: Research objectives & Types of BN
Figure 10

Service application: Research objectives & Types of BN
Figure 11

Summary of results

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- AppendixA1toA4.docx