Towards information technology for BPMN models quality assessment based on intelligence theory

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Abstract

Nowadays, business process modeling is a core technique that bridges Information Technology and Management domains using graphical diagrams. The de-facto standard for workflow documenting, analyzing, improving, and automating is considered Business Process Model and Notation (BPMN). BPMN models are crucial artifacts in organizational and information systems design. Thus, BPMN models must be of high-quality, to ensure workflows efficiency and reliability. Therefore, this paper considers the development of an information technology based on the intelligence theory, to assess BPMN models quality. The proposed intelligent technology considers feature extraction of BPMN elements from analyzed diagrams, identification of incorrect elements, and calculation of general quality measures using weights of different BPMN elements. The experiments performed with the large set of BPMN models were analyzed and discussed, conclusions and future work are outlined.

Keywords

Business Process Modeling, Quality Assessment, Information Technology, Intelligence Theory

1. Introduction

In the modern dynamic enterprise environment, effective management of internal processes is a key factor in ensuring the competitiveness of organizations. A business process is defined as a sequence of coordinated tasks or actions performed within an organizational or technical context to achieve specific goals and create value for customers [1]. A business process is the sequence of various events, decision-making points, and activities that are part of the overall organizational operations [2].

In order to better understand, analyze, and improve organizational activities, a graphical representation of business processes is widely used by applying the business process modeling technique [3]. Visual diagrams are not only contributing to a deeper understanding of the organizational functioning, but also improve the modeling quality, being valuable assets in the Business Process Management (BPM) life cycle [3]. Overall, BPM is a discipline that combines management and information technology practices to support and improve processes within an organization [4].

Hence, one of the key techniques of BPM is process modeling, which allows to graphically represent the activities, events, and decisions that form business processes [5]. The use of BPM contributes to the achievement of high quality services and products, as well as to the improvement of the overall organizational efficiency [6]. Therefore, Business Process Model and Notation (BPMN) plays an important role, by providing a clear, standardized graphical representation of business

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processes from start to finish events, as well as facilitating clear understanding by both technical and non-technical stakeholders [6].

Using BPMN, business users can effectively communicate with IT specialists responsible for developing and maintaining information systems, by providing a consistent vision of all the workflows and requirements [7]. Thus, business process modeling not only serves as a tool for formalizing organizational activities, but also for increasing organizational flexibility and adaptability in response to constant changes.

Therefore, the research object assumes the procedure of business process models quality assessment. The research subject includes the intelligent information technology of business process models quality assessment. The research work aims to improve the quality of business process models described using BPMN, as well as to prevent possible errors in organizational and information system workflows caused by incorrect BPMN structures.

2. State-of-the-Art

In the business process modeling practice, there are a number of notations and languages used to describe, analyze, and improve the organizational activities. The most common among them include BPMN (Business Process Model and Notation), EPC (Event-driven Process Chain), as well as notations based on the IDEF methodology, in particular IDEF0 and DFD (Data Flow Diagram) [8]. These tools provide formal approaches to visualizing processes, which significantly improves the shared understanding of workflows between different stakeholders.

In recent years, BPMN has largely replaced EPC as the dominant standard in the business process modeling field. Its popularity is caused by its flexibility, unification, and high level of support from both IT professionals and business users [9]. BPMN provides a powerful yet intuitive way to represent the business process logic of in the form of graphical diagrams.

The core set of BPMN elements is demonstrated in Fig. 1.

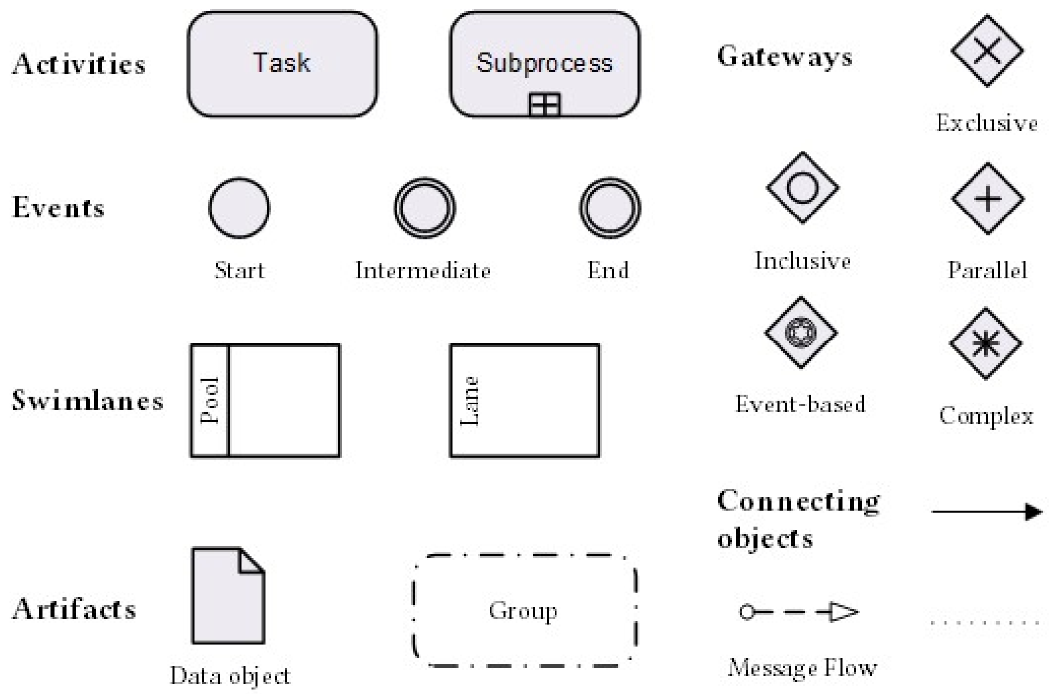

Figure 1: Core set of BPMN elements.

BPMN models are built around the main elements, including events, activities (tasks and sub-processes), gateways, and control flows. Control flows define the sequence of activities and the relationships between process elements [10]. Events show the beginning, end, or intermediate states of a process, and activities represent specific atomic tasks or non-atomic sub-processes performed within a business process. Gateways introduce logical branching, allowing to determine the parallel (AND), inclusive (OR) or exclusive (XOR) scenarios by splitting and joining workflows [10].

Another important feature of BPMN is the ability to model collaborative processes with a clear distribution of involved roles. The concepts of pools and lanes are used to represent the responsibilities of different participants. Pools show the boundaries of a particular business process or organizational unit, while lanes detail the actions performed by individual roles or units [10]. This approach significantly improves the understanding of the participant roles and responsibilities, especially in complex cross-functional processes.

BPMN also supports modeling of repeated and conditional scenarios, allowing to describe both linear and non-linear business processes. This makes BPMN suitable for both simple documentation tasks and complex process analysis and automation [10]. Hence, BPMN has become a key tool in BPM systems (BPMS), where accuracy, transparency, and the ability to integrate with IT solutions are critical characteristics.

3. Related Work

Business process modeling is a critical technique of BPM, as it provides a visual representation of organizational activities, events, and decision-making steps [11]. This visual representation facilitates better processes understanding, documentation, and improvement, which is crucial for bridging the gap between business and IT stakeholders [12]. In particular, BPMN models contribute to increased workflow transparency, monitoring, event tracking, and control, which in turn allows to assess the efficiency of the enterprise [13].

The quality of business process models is essential for achieving BPM goals, as the success of the entire BPM initiative depends on it [14]. Thus, the existing studies pay great attention to the development and use of metrics to assess the quality of business process models. Such metrics cover structural characteristics such as the Number of Activities (NOA), Number of Activities, Joins and Splits (NOAJS), Control-Flows Complexity (CFC), and the other size measures of BPMN models [14]. These measures allow quantifying the size, complexity, and logical structure of BPMN models.

Meanwhile, the qualitative characteristics of BPMN models, such as understandability and maintainability, are also recognized as important factors. Understandability indicates the ease of models perception by users, while maintainability determines the ability to make changes without disrupting the workflow logic [15]. Both user-centric studies and adapted measures from the software engineering field are used to evaluate these criteria [15].

Special attention is paid to modeling standards adherence and compliance with guidelines. For example, frameworks such as SEQUAL or the 7 Process Modeling Guidelines (7PMG) offer structured approaches for checking the models quality, taking into account both syntactic and semantic correctness [16]. Also, measures based on the model structure, such as the number of elements, the longest paths between them, or the degree of connectivity, can indicate the complexity and efficiency of the model architecture [17].

Moreover, the study [18] shows that NOA, NOAJS and CFC can be effectively used to quantify the complexity of BPMN models. NOA and NOAJS measures the amount of activities and gateways, while CFC takes into account the control-flow logic, in particular the use of AND, XOR, and OR gateways. These measures are widely used to detect excessive complexity, which can reduce clarity and increase the risk of errors.

A number of studies have proposed thresholds for quality measures. For example, in [19], the authors used data mining methods to determine thresholds for the NOA, CFC, and other measures, which allows assessing the quality of BPMN models. Similarly, authors of [20] proposed a methodology for BPMN modeling quality assurance with a focus on the same measures. In [21], 50 recommendations are presented along with the corresponding metrics and thresholds to improve BPMN models understandability.

These approaches have been formalized in the form of industry standards and practical guidelines, which allows the automated model quality assessment [22]. Finally, the study [23] demonstrates how the selected metrics can be applied to collect quantitative data on structural complexity, compliance with standards, and other quality attributes of business processes.

4. Formal Problem Statement

Formally, a business process model with its set of elements N and other objects, described using the BPMN notation's symbols, can be denoted as the following tuple:

$$BPrM = \langle E_s, E_e, E_i, E_b, T, SP, G_{and}, G_{or}, G_{xor}, P, SF, MF \rangle, \quad (1)$$

where:

- E_{start} is the set of start events, $E_s^j \in E_s \subseteq N$, $j \in [1, |N|]$;
- E_{end} is the set of end events, $E_e^j \in E_e \subseteq N$, $j \in [1, |N|]$;
- E_{int} is the set of intermediate events, $E_i^j \in E_i \subseteq N$, $j \in [1, |N|]$;
- E_b is the set of boundary events, $E_b^j \in E_b \subseteq N$, $j \in [1, |N|]$;
- T is the set of tasks, $T^j \in T \subseteq N$, $j \in [1, |N|]$;
- SP is the set of sub-processes, $SP^j \in SP \subseteq N$, $j \in [1, |N|]$;
- G_{and} is the set of parallel (AND) gateways, $G_{and}^j \in G_{and} \subseteq N$, $j \in [1, |N|]$;
- G_{or} is the set of inclusive (OR) gateways, $G_{or}^j \in G_{or} \subseteq N$, $j \in [1, |N|]$;
- G_{xor} is the set of exclusive (XOR, Complex, and Event-based) gateways, $G_{xor}^j \in G_{xor} \subseteq N$, $j \in [1, |N|]$;
- P is the set of pools, each of which may contain elements to define business process boundaries within a model, $P = \{P_j \subseteq N \big| P_1 \cap P_2 \cap \ldots \cap P_j = \emptyset, j \in [1, |P|]\}$;
- $SF \subseteq N \times N$ is the binary relationship that represents sequence flows between business process elements;
- $MF \subseteq N \times N$ is the binary relationship that represents message flows between business process elements.

Fig. 2 shows the proposed approach based on the incorrect BPMN elements identification using intelligence theory approach [24].

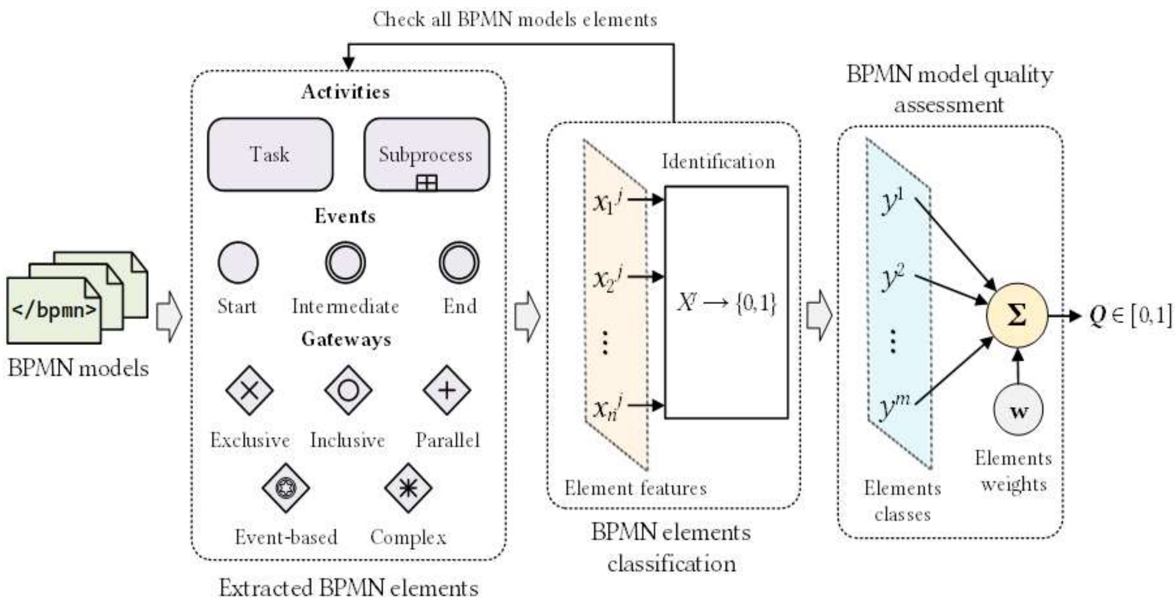

Figure 2: BPMN models quality assessment procedure.

Thus, let us describe each BPMN element using the following vector:

$$X^j = \left(x_1^j, x_2^j, \dots, x_9^j, x_{10}^j, x_{11}^j\right), j \in [1, |N|], \quad (2)$$

where:

- $x_1^j, x_2^j, \dots, x_9^j$ are the binary values $\{0,1\}$ corresponding to the one of business process model element types;
- x_{10}^j is the number of incoming sequence flows of the certain BPMN element;
- x_{11}^j is the number of outgoing sequence flows of the certain BPMN element.

Here in Fig. 2, n is the number of BPMN element features, $n = 1$; m is the size of a certain BPMN model (i.e. the number of its elements), $m = |N|$.

The proposed approach (Fig. 2) assumes:

1. Extraction of BPMN elements features $X^j, j \in [1, |N|]$ by processing BPMN model files as specially organized XML (eXtensible Markup Language) documents.
2. Identification $X^j \to \{0,1\}, j \in [1, |N|]$ of incorrect BPMN elements to describe business process models as binary vectors:

$$y = (y^1, y^2, \dots, y^m), m = |N|. \quad (3)$$

3. Quality assessment of BPMN models $Q \in [0,1]$ using the following expression:

$$Q = \sum_{j=1}^{|N|} w^j \cdot y^j, \quad (4)$$

where W^j is the weight of a certain business process model element, regarding the impact of such element types on the BPMN models correctness:

$$\sum_{j=1}^{|N|} w^j = 1. \quad (5)$$

Therefore, the outlined steps should be implemented as part of the proposed intelligent information technology for BPMN models quality assessment and improvement.

5. Materials and Methods

The algorithmic model AM of the proposed intelligent information technology for BPMN models quality assessment is formalized as:

$$AM = \{M, DF \subseteq M \times M\}, \quad (6)$$

where:

- $M = \{M_1, M_2, M_3, M_4\}$ is the set of interconnected software modules, implemented in Python programming language;
- DF is the set of data flows between the considered software modules.

The interacting software modules include:

- M_1 is responsible for BPMN model files processing as XML documents;
- M_2 is responsible for BPMN elements features extraction;

- M_3 is responsible for incorrect BPMN elements identification based on modeling rules;
- M_4 is responsible for quality assessment using the proposed general measure.

The functional model of the proposed intelligent information technology, which consists of four software modules M_1 – M_4, is demonstrated in Fig. 3.

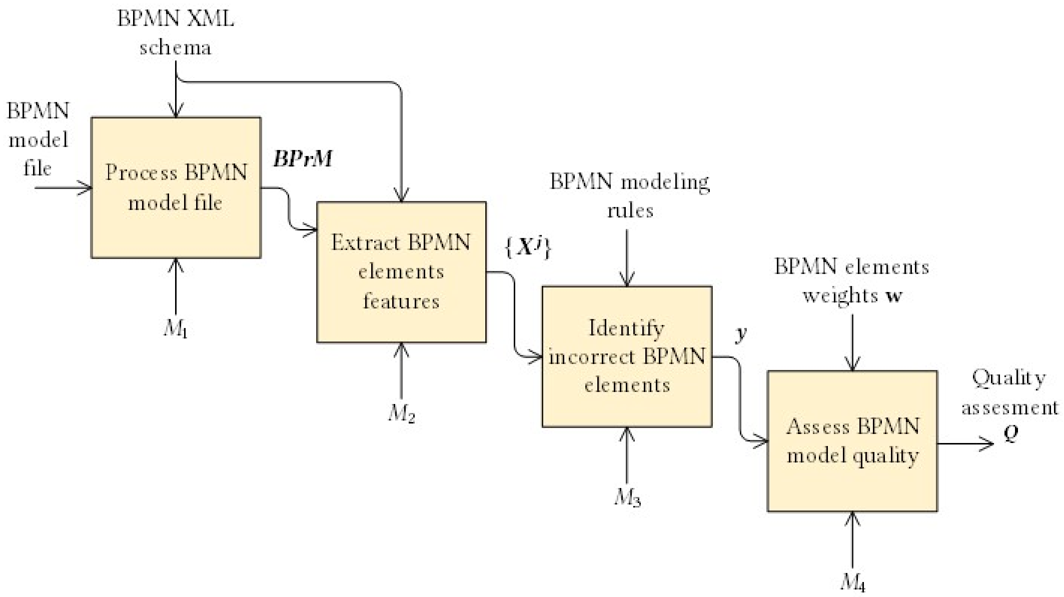

Figure 3: Functional model of the proposed intelligent information technology.

Fig. 4 below outlines the processing of BPMN files as XML parsing and feature extraction for various business process elements, such as type, incoming, and outgoing flows.

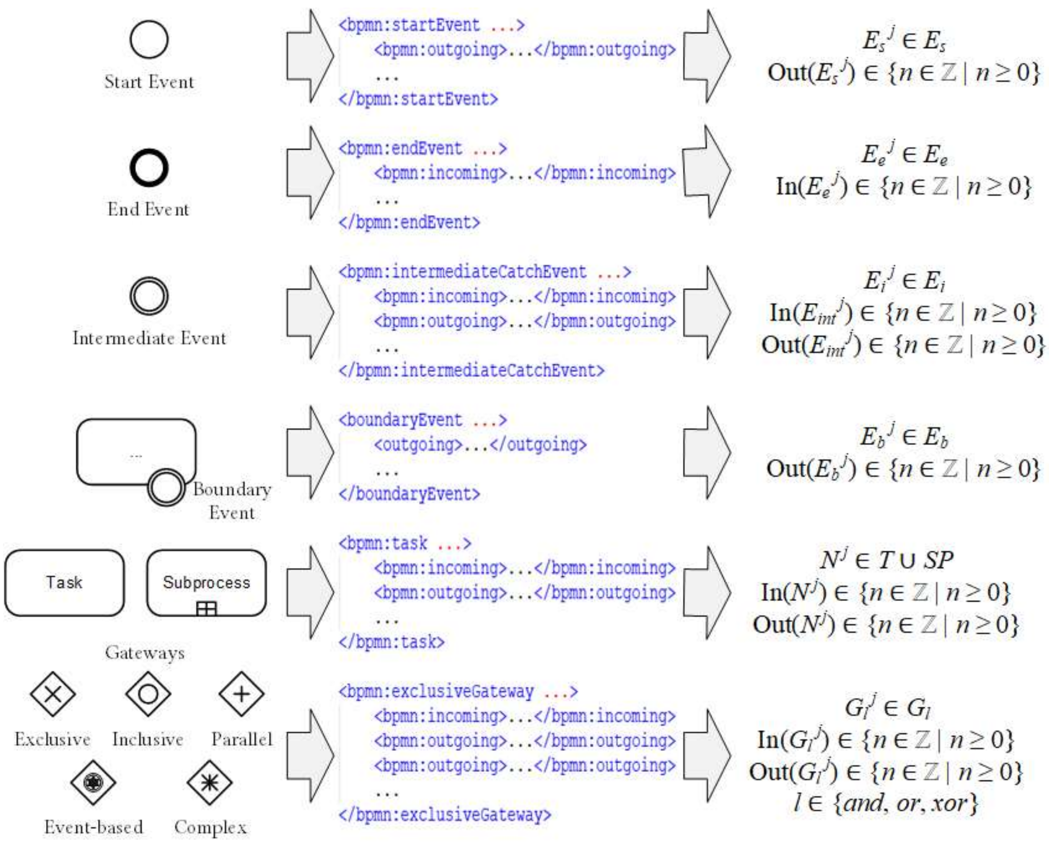

Figure 4: BPMN elements extraction using XML parsing.

The identification of incorrect BPMN elements is performed using the comparison toward the following modeling rules [25]:

- R1: Start events should have one outgoing flow.
- R2: Intermediate events should have one incoming and one outgoing flow.
- R3: Boundary events should have one outgoing flow.
- R4: End events should have one incoming flow.
- R5: Activities (i.e. task or sub-process) should have one incoming and one outgoing flow.
- R6: Gateways should have either one incoming and two outgoing flows (i.e. for splits), or two incoming and one outgoing flow (i.e. for joins).

Table 1 below outlines the formal expressions to validate BPMN elements toward modeling rules R1–R6.

Table 1
Formal representation of business process modeling rules [25]

Business process modeling rule	BPMN elements to check	Formal expression
R1 R3	E_s E_b	$\text{In}(N^j) = 0 \wedge \text{Out}(N^j) = 1$
R4	E_e	$\text{In}(N^j) = 1 \wedge \text{Out}(N^j) = 0$
R2 R5	E_i T, SP	$\text{In}(N^j) = 1 \wedge \text{Out}(N^j) = 1$
R6	G_{and}, G_{or}, G_{xor}	$[\text{In}(N^j) = 1\ \wedge \text{Out}(N^j) = 2] \vee$ $\vee [\text{In}(N^j) = 2\ \wedge \text{Out}(N^j) = 1]$

Here, in Table 1, $\text{In}(N^j)$ is the number of incoming sequence flows, and $\text{Out}(N^j)$ is the number of outgoing sequence flows of the BPMN element N^j, $j \in [1, |N|]$.

The intelligence theory [24], being a one of research directions in the artificial intelligence domain, assumes the formalization of human-centric reasoning. The considered comparator identification method is based on predicate logic, by taking any inputs and producing binary values (either 0 or 1) on output [24]:

$$\text{P}(x_1, x_2, \dots, x_n) = \text{K}\big(y_1 = f(x_1), y_2 = f(x_2), \dots, y_n = f(x_n)\big) = \theta, \tag{7}$$

where:

- $x_1, x_2, \dots, x_n$ are the input signals;
- $y_1 = f(x_1), y_2 = f(x_2), \dots, y_n = f(x_n)$ are the internal signals;
- K is the comparator with n inputs and one boolean output $\theta \in \{0,1\}$.

Hence, let us propose the connectionist system inspired by the computational systems that simulate constitution of living being brains, known as artificial neural networks [26], which structure is demonstrated in Fig. 5.

Since comparator networks improve machine-based "thinking mechanisms" in compare to the classical comparator identification approach, the proposed comparator network is used for BPMN elements classification (Fig. 5).

As given in Fig. 5, the indicator (characteristic) functions $\mathbf{1}_{x_{10}=0}$, $\mathbf{1}_{x_{10}=1}$, $\mathbf{1}_{x_{10}=2}$, $\mathbf{1}_{x_{11}=0}$, $\mathbf{1}_{x_{11}=1}$, $\mathbf{1}_{x_{11}=2}$ are used to compare $\text{In}(N^j)$ and $\text{Out}(N^j)$ values of BPMN elements toward expected by modeling rules, $j \in [1, |N|]$.

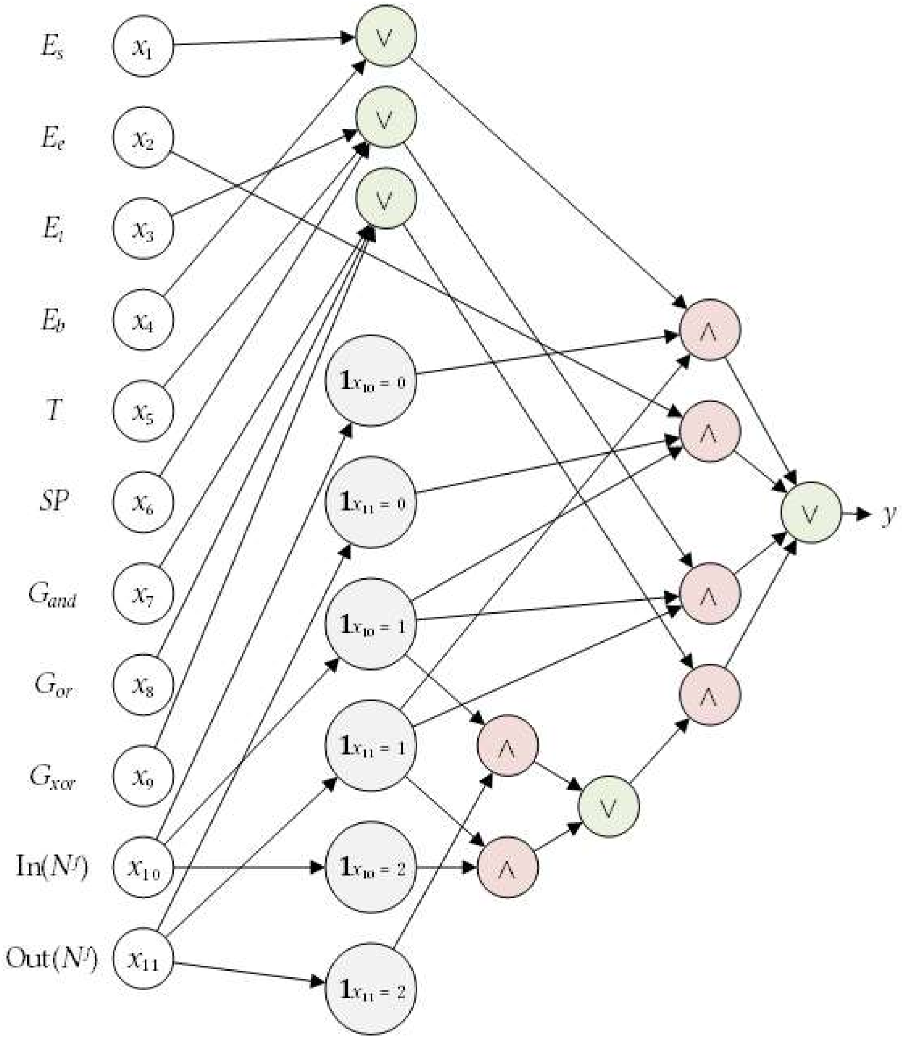

Figure 5: Comparator network for BPMN elements classification.

The indicator function is used to checks whether an element u of some set U belongs to a subset $B \subseteq U$:

$$\mathbf{1}_B(u) = \begin{cases} 1, & u \in B, \\ 0, & u \notin B. \end{cases} \tag{8}$$

Hence, the proposed comparator network (Fig. 5), used for BPMN elements classification, produces $y^j = 1$ for correct elements and $y^j = 0$ – for incorrect elements, $j \in [1, |N|]$.

The weights of business process model elements $w^j, j \in [1, |N|]$ can be defined using the following expression:

$$w^j = \frac{\varepsilon_{t(j)}}{\left|N_{t(j)}\right|}, j \in [1, |N|], \tag{9}$$

where:

- $t(j)$ is the type of a certain BPMN element $j \in [1, |N|]$;
- $\varepsilon_{t(j)}$ is the impact of BPMN elements of the same type t, as the current element j, on the model correctness;
- $N_{t(j)}$ is the sub-set of BPMN elements of the same type t, as the current element j.

The impacts of BPMN element types on the model correctness [27] are outlined in Table 2.

Table 2
Impacts of BPMN element types on model correctness [27]

Element type, t	SP	E_b	G_{and}	G_{or}	G_{xor}	E_i	T	E_e	E_s
Impact, ε	0,19	0,19	0,17	0,17	0,13	0,04	0,04	0,04	0,02

6. Results and Discussion

Fig. 6 below outlines the software implementation of the proposed intelligent information technology in terms of the activity diagram.

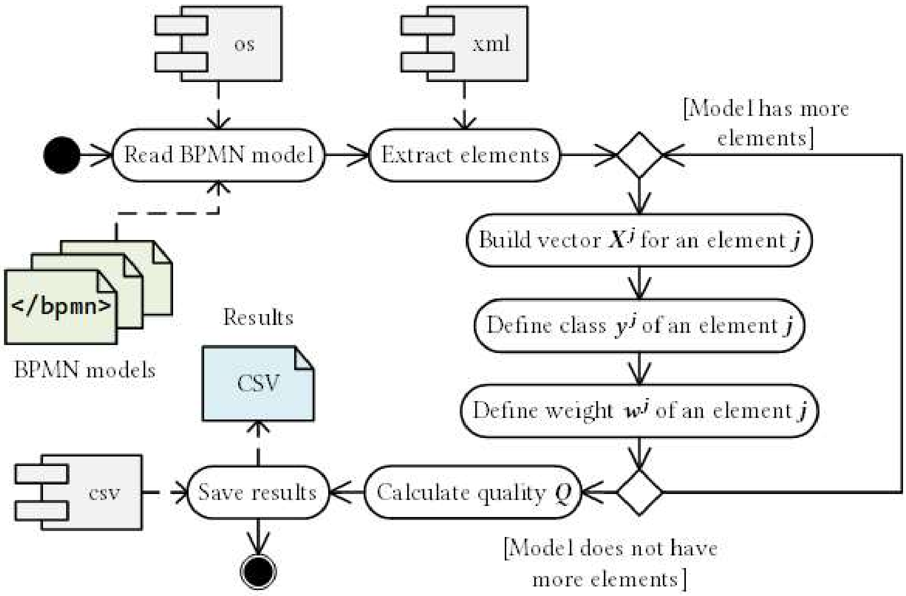

Figure 6: Software implementation of the proposed intelligent information technology.

The software implementation for experiments is developed using the Python programming language and packages to provide:

- BPMN model files reading from the file system using “os” package;
- parsing of BPMN files as XML documents using “xml” package;
- storing BPMN models quality measurement results to Comma-Separated Values (CSV) files using “csv” package.

The proposed intelligent information technology is tested on the large set of real-world BPMN models, freely available for research purposes in the Camunda GitHub repository [28]. Out of 3729 BPMN models, 3722 (about 99.81%) were successfully processed by the proposed software, while the 7 BPMN models failed parsing due to the inconsistent XML markup.

Table 3 below demonstrates the results of exploratory analysis applied to the quality values calculated for processed BPMN models.

Table 3
Exploratory analysis of BPMN models quality assessment results

Exploratory analysis measures	Minimum	Q1	Median	Q3	Maximum
BPMN quality measure, Q	0.49	0.94	0.96	0.99	1.00
Number of corresponding BPMN models	918	639	1227	162	776

Fig. 7 shows that most of processed BPMN models (1227, 33%) have quality value $0.96 \leq Q < 0.99$ and belong to 3rd quartile, 918 (25%) of models have quality value $0.49 \leq Q < 0.94$ and belong to 1st quartile, 776 (21%) of models have maximum quality value of $Q = 1.00$, 639 (17%) of models have quality value $0.94 \leq Q < 0.96$ and belong to 2nd quartile, and only 162 (4%) of models have quality value $0.99 \leq Q < 1.00$ and belong to 4th quartile.

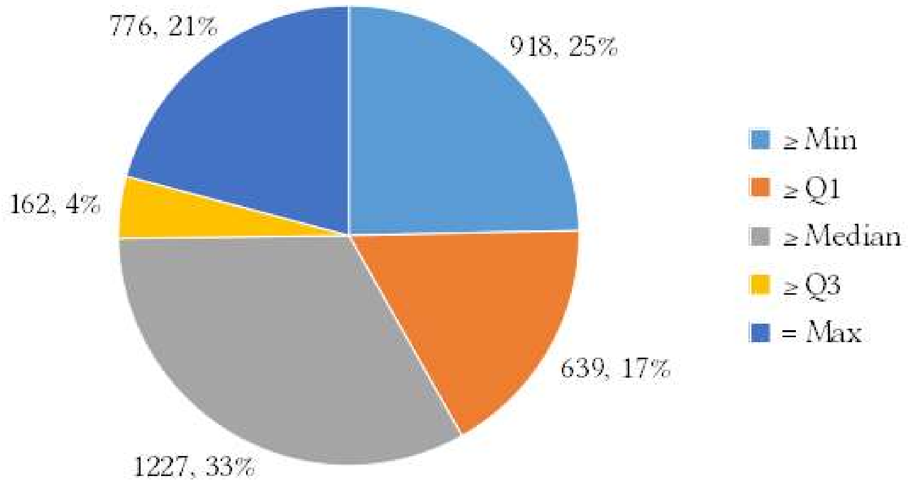

Figure 7: Distribution of obtained quality values of processed BPMN models.

Fig. 8 demonstrates the example BPMN model, describing goods dispatch process in a small hardware store, and the identified incorrect elements E1–E6 on this model.

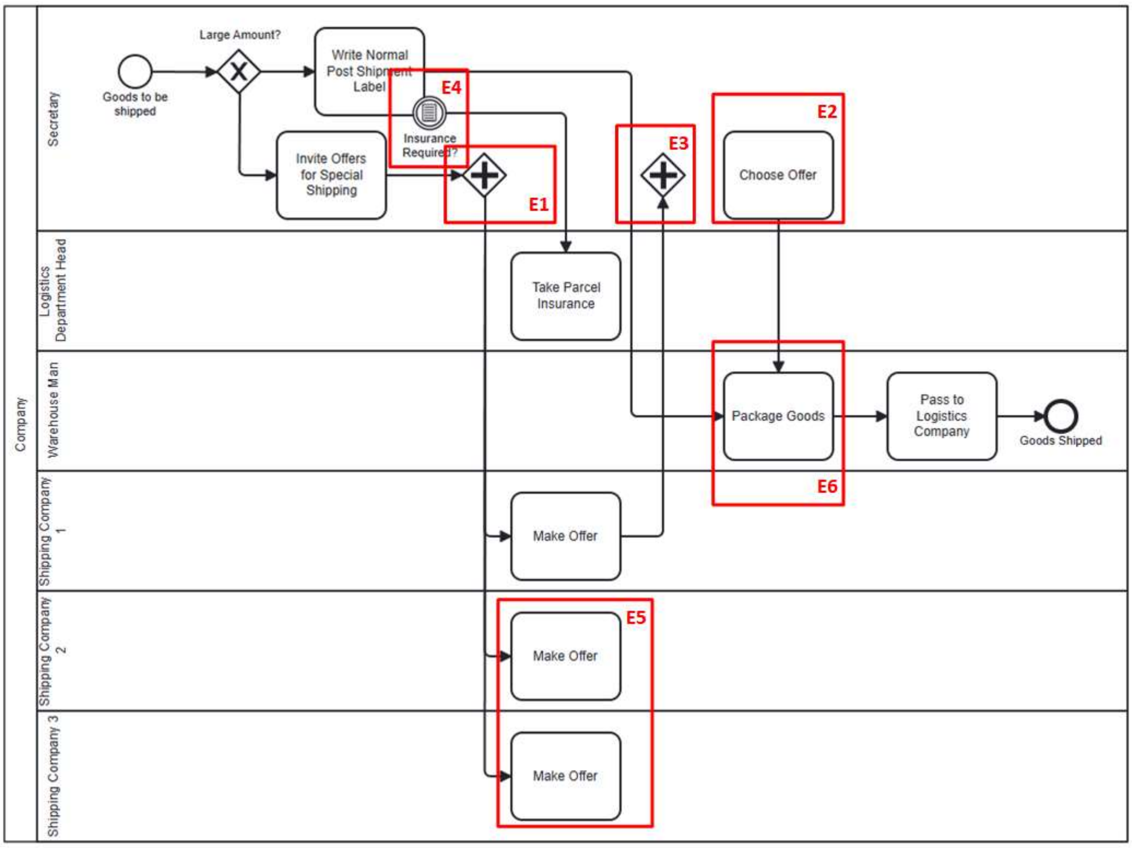

Figure 8: Goods dispatch BPMN model with identified shortcomings.

Using the proposed intelligent technology and its software implementation, the following shortcomings of the presented BPMN model (Fig. 8) were detected:

- E1: the parallel gateway with 1 incoming and 3 outgoing flows – increases the workflow complexity;
- E2: the task "Choose Offer" with 0 incoming and 1 outgoing flows – a start event is missing;
- E3: the parallel Gateway with 1 incoming and 0 outgoing flows – logic is missing;
- E4: the intermediate event "Insurance Required?" with 0 incoming and 1 outgoing flows – incorrectly used instead of a boundary event;
- E5: tasks "Make Offer" with 1 incoming and 0 outgoing flows – end events are missing;
- E6: the task "Package Goods" with 2 incoming and 1 outgoing flows – incorrectly used instead of a join gateway.

The assessed quality value of this BPMN model (Fig. 8) is relatively high, $Q = 0.79$.

7. Conclusion and Future Work

This study addressed the problem of quality analysis and improvement of business process models, represented using the BPMN notation.

The business process modeling technique is used to bridge the gap between information technology and business domains, while BPMN diagrams belong to ones of the core assets in the organizational and information systems design, required to be of high quality to prevent workflow errors and failures caused by modeling shortcomings.

Thus, the proposed information technology based on the intelligence theory is expected to:

- extract BPMN elements from XML documents;
- identify incorrect elements of various types using modeling rules;
- assess BPMN models quality using the proposed measure, given as the weighted sum of elements assessments and impacts of each element's type on the overall business process model correctness.

The experimental results demonstrated that among 3722 processed BPMN diagrams, over 97% (3613) are of very high quality (i.e. $Q \geq 0.79$). The example goods dispatch BPMN model demonstrates possible business process modeling errors detected using the Python-based tool, implementing the proposed intelligent technology.

Future work in this field includes the use of machine learning classification algorithms to predict the quality of BPMN models, as well as the fuzzy logic application to modeling rules in order to assume uncertainty of modeled business process elements. Moreover, it is planned to deeper analyze the syntax and semantics of BPMN models, assume collaborative models, size and complexity constraints and optimization.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

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