Towards the Software Solution for Complexity Minimization of Business Process Models to Improve Understandability

Andrii Kopp and Dmytro Orlovskyi

National Technical University "Kharkiv Polytechnic Institute", Kyrpychova str. 2, Kharkiv, 61002, Ukraine

Abstract

Business process modeling is a core technique of Business Process Management (BPM). The goal of business process modeling is to graphically describe sequences of events, tasks, and decisions on diagrams. Business process models are created on the first step of the BPM lifecycle when processes are identified for further improvement. Hence, designed models must be of high quality to be understandable by all of the involved stakeholders. It was found that many quantitative techniques for the quality evaluation of business process models are based on complexity metrics originating from software engineering. Therefore, we analyzed existing metrics and proposed a model to minimize the complexity of business process models given as an optimization problem. The proposed model takes into account rules of business process modeling using Business Process Model and Notation (BPMN), which is a de-facto standard for process modeling nowadays. An algorithm and a software tool for the evaluation of business process model understandability are developed. It utilizes the proposed optimization model to produce recommendations on BPMN diagrams re-design to reduce complexity and achieve better understandability by all readers.

Keywords

Business Process Model, Understandability, Complexity, Optimization Model, Software Tool

1. Introduction

Business processes are sequences of events, activities, and decision-making points that bring value to the organization's customers [1]. Other definitions given by different sources consider a business process as a sequence of coordinated tasks carried out in a technical or organizational context at a specific time [2] or as a collection of activities or logically related tasks that are cross-functional and can be implemented inside a unit or organization [3]. Business Process Management (BPM) is a multidisciplinary approach that integrates operational capabilities and technology to develop and manage business processes [4]. According to [5], BPM is a traditional approach to achieving process excellence, which is critical for the success of digitalization initiatives. BPMN promotes strategic alignment by optimizing business processes and integrating the business and Information Technology (IT) domains [5]. Among the phases of the BPM lifecycle are business process design, implementation, execution, monitoring, and improvement [6]. Also, Business Process Management enables better monitoring and traceability of events and information control, as well as evaluating organizational performance [7]. Business process modeling is an essential BPM technique that can be used to graphically represent an organization's processes to elaborate and improve them [8].

According to [9], business process modeling is a difficult but important task in which a process analyst studies an enterprise's business processes to create a visual representation of its activities, events, and control flow logic. The expected result is a process model that may be utilized as a tool for business process learning, improvement, and communication [9].

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EMAIL: kopp93@gmail.com (A. Kopp); orlovskyi.dm@gmail.com (D. Orlovskyi)
ORCID: 0000-0002-3189-5623 (A. Kopp); 0000-0002-8261-2988 (D. Orlovskyi)

Business process models can be seen as a form of knowledge representation that is widely used in many sectors of the economy and industry [10]. They depict both manual workflows performed by people and automated sequences of tasks performed by computer software [10]. According to [11], business process models are critical objects throughout the BPM lifecycle. Thus, the intended target audience for these models must comprehend the models accurately and on time [11].

The quality of business process models is critical for any purpose within the BPM lifecycle [12]. Authors of [12] emphasize that process analysts should design understandable, explicit, unambiguous, and error-free models. Therefore, when a process is well-defined, the created models can be used for business process analysis and optimization [12].

Authors of [13] stress that business process models, like any other conceptual models, should be easily understandable. Hence, one of the most significant quality criteria for business process models is understandability [13]. The goal of the quality evaluation is to indicate if a business process model is well-structured and easy to understand [14]. The structural complexity without a doubt affects quality characteristics of business process models, such as understandability and maintainability. Therefore, authors of [14] address complexity metrics adapted from software engineering to evaluate process models.

Thus, let us adopt the idea suggested in [14] and assume that the less a business process model is complex, the more it is easy to understand this model and vice versa. Therefore, in this study, we aim at the understandability improvement of business process models by minimizing their complexity.

The rest of this paper is structured in the following way. Section 2 outlines the state-of-the-art in the field of business process model quality analysis. Section 3 describes the formal statement of the problem of business process model complexity minimization using the optimization model. Section 4 proposes materials and methods to provide recommendations for the understandability improvement of business process models by minimizing their complexity. Section 5 shows experimental results and outlines corresponding discussions.

2. Related Work

In [14], the authors emphasize that the high complexity of business process models may have undesirable effects on maintainability of business process models. Therefore, they suggest using the following complexity metrics adopted from the software engineering field [14]:

- Number of Activities (NOA) and Number of Activities, Joins, and Splits (NOAJS) – these metrics are based on the Lines of Code (LOC) metric;
- Control Flow Complexity (CFC) – this metric allows to assess the complexity of a process by assessing AND (parallel), XOR (exclusive), and OR (inclusive) split gateways:

$$\begin{gathered} CFC = \sum_{g \in XOR-Gateway} CFC_{XOR-Split}(g) + \sum_{g \in OR-Gateway} CFC_{OR-Split}(g) + \sum_{g \in AND-Gateway} CFC_{AND-Split}(g), \\ CFC_{XOR-Split}(g) = fan-out(g), \\ CFC_{OR-Split}(g) = 2^{fan-out(g)} - 1, \\ CFC_{AND-Split}(g) = 1, \end{gathered} \tag{1}$$

where g is a gateway; $fan-out(g)$ is the number of outgoing sequence flows from the gateway g;

- Halsted-based Process Complexity (HPC) – these metrics can predict the error rate and the maintenance effort:

$$\begin{gathered} HPC_N = n_1 \cdot \log_2(n_1) + n_2 \cdot \log_2(n_2), \\ HPC_V = (N_1 + N_2) \cdot \log_2(n_1 + n_2), \\ HPC_D = (n_1/2) \cdot (N_2/n_2), \end{gathered} \tag{2}$$

where n_1 is the number of unique control-flow elements (activities, events, gateways, etc.); n_2 is the number of unique data variables manipulated by process activities; N_1 and N_2 are total numbers of the control-flow and data elements derived from n_1 and n_2;

- Interface Complexity (IC) – this metric also can be used to evaluate the process complexity:

$$IC = length \cdot \left(n_{inputs} \cdot n_{outputs}\right)^2, \tag{3}$$

where n_{inputs} is the number of incoming data flows of an activity; $n_{outputs}$ is the number of outgoing data flows of an activity; $length$ is the coefficient equal to 1 for tasks and 3 for sub-processes;

- Cognitive Complexity (CC) – this metric is used to estimate the effort to understand a model;
- Modularity (M) – this metric is used to estimate the degree of decomposition of a model (i.e., the division into sub-processes), which makes business process models easier to understand, reuse, and maintain:

$$M = \left(fan-in \cdot fan-out\right)^2, \tag{4}$$

where $fan-in$ is the number of modules calling a module; $fan-out$ is the number of modules called by a module.

In paper [15], the authors propose the approach to assess the quality of business process models based on fuzzy logic. According to the authors, the HPC metric should be used for maintainability evaluation rather than understandability. As the understandability metrics, study [15] proposes CFC, IC, NOA, NOAJS, and CC. However, few more metrics were considered in [15] as comprehensibility metrics:

- Coupling (CP) – this metric helps to assess the number of interconnections between activities in a model [14]:

$$CP = \frac{1}{|T| \cdot (|T|-1)} \sum_{t_1, t_2 \in T} Connected(t_1, t_2), \tag{5}$$

where t_1 and t_2 are two connected activities of a process model; T is the set of activities of a process model;

- Coefficient of Network Connectivity (CNC) – this metric is used to quantify the structural complexity of a process model as the ratio of arcs to nodes [16]:

$$CNC = \frac{Arcs}{Nodes}, \tag{6}$$

where $Arcs$ is the number of control flows depicted in a model; $Nodes$ is the number of process elements depicted in a model;

- Density (D) – this metric is used to quantify the structural complexity of a process model as the ratio of arcs to the maximum possible number of arcs for the same number of nodes [16]:

$$D = \frac{Arcs}{Nodes \cdot (Nodes-1)}, \tag{7}$$

where $Arcs$ is the number of control flows depicted in a model; $Nodes$ is the number of process elements depicted in a model.

Authors of [17] name complexity as a critical characteristic of business process models, which reflects their understandability and maintainability. They outline the definition of the business process model complexity as the degree to which a model has a design that is difficult for understanding and analysis [17]. In [17] authors stress that a business process model must be evaluated using multiple complexity metrics using not only simple ones (e.g., NOA and NOAJS) but also more complex ones that reflect structural heterogeneity of models (e.g., CNC or CFC) despite the computational efforts.

Also, authors of [17] consider the eligibility of BPMN models for business process redesign [18]. In this paper, Tsakalidis et al. selected NOA, NOAJS, and CFC complexity metrics with the following evaluation thresholds (Table 1) [18].

Table 1
Thresholds of business process model complexity metrics

Metric/Complexity	Low	Moderate	High
NOA	$NOA \le 12$	$12 < NOA \le 26$	$NOA > 26$
NOAJS	$NOAJS \le 17$	$17 < NOAJS \le 33$	$NOAJS > 33$
CNC	$CFC \le 3$	$3 < CFC \le 9$	$CFC > 9$

Size metrics (NOA and NOAJS) and Control-Flow Complexity (CFC) metrics were also proposed in [19] as logical (NOA and NOAJS) and structural (CFC) complexity metrics. However, the inverse of the density (D) metric is suggested to measure the structural flexibility of business processes [19]. In addition, the authors of [19] proposed the diameter (d) metric (i.e., the longest path in a graph) to evaluate the size and complexity of a business process model's graph. The overall complexity metric proposed in [19] is the following:

$$Complexity = \frac{1}{2}\left[CFC + \frac{s+d}{2}\right], \quad (8)$$

where s is the size (i.e. NOA or NOAJS) of a process model; d is the diameter of a process model.

Another overall complexity metric is proposed by Fotoglou et al. in [16]. They propose a weighted sum measure to assign priority to selected metrics (NOAJS, CFC, and CNC) [16]:

$$WS = \sum_{i=1}^{3} w_i v_i, \quad (9)$$

where w_i is the weight of a particular complexity metric; v_i is the value of a particular complexity metric.

Therefore, according to [16], the weights $w_1 = 0.0625$, $w_2 = 0.625$, and $w_3 = 0.3125$ mean a low priority of NOAJS (v_1), a high priority of CFC (v_2), and a moderate priority of CNC (v_3) [16].

In [20], the authors emphasize that understandability is a basic quality characteristic, which needs to be taken into account for business process modeling, and propose a set of 50 guidelines, respective metrics, and thresholds that can be used to improve the understandability of business process models. This paper [20] and the remaining reviewed papers [14] – [19] consider process models developed using Business Process Model and Notation 2.0 (BPMN 2.0). BPMN 2.0 is the widely-used Object Management Group (OMG) standard for business process modeling [20].

BPMN 2.0 models represent business processes as sequences of Activities (Task or Sub-Process) and Events connected using Sequence Flows (or control flows) [21]. Complex process branching can be shown using Parallel (AND), Inclusive (OR), and Exclusive (XOR) gateways. Swimlanes, such as Pools, describe business process boundaries, while Lanes represent process participants. Basic BPMN 2.0 elements are demonstrated in Fig. 1 [21].

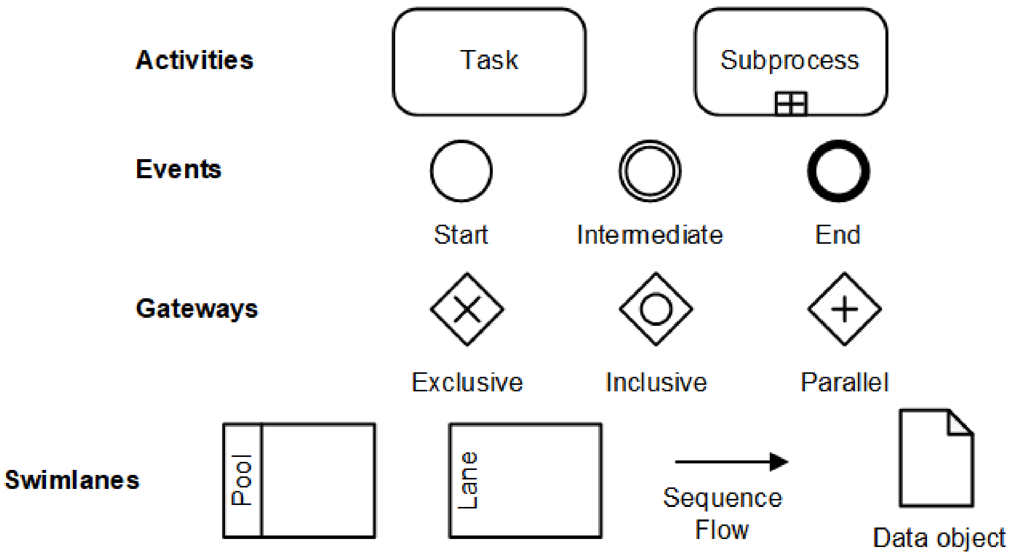

Figure 1: Basic element of the BPMN 2.0 standard [21]

Therefore, reviewed studies [14] – [20] propose different metrics to evaluate the complexity of business process models (NOA, NOAJS, CFC, HPC, IC, CC, M, CP, CNC, D, etc.) and improve their understandability. However, existing studies in this field do not propose techniques for process model improvement, e.g. which recommendations should be followed to minimize model complexity.

3. Formal Problem Statement

Let us consider NOAJS, CFC, and CNC metrics already explored in [16]. However, to make the complexity analysis more precise, let us consider CFC metrics for exclusive (XOR), inclusive (OR), and parallel (AND) gateways separately. We propose to use the priorities of these complexity metrics defined in [16]:

- low priority for NOAJS;
- medium priority for CNC;
- high priority for CFC.

Since we propose to split CFC by gateway types, let us consider equal priorities of separate CFC metrics. Therefore the priorities of complexity metrics and their respective weights look as follows:

- for NOAJS: $p_1 = 1, w_1 = 0.028$;
- for XOR-splits CFC: $p_2 = 10, w_2 = 0.278$;
- for OR-splits CFC: $p_3 = 10, w_3 = 0.278$;
- for AND-splits CFC: $p_4 = 10, w_4 = 0.278$;
- for CNC: $p_5 = 5, w_2 = 0.139$.

Therefore, let us formulate the following linear programming model for complexity minimization of business process models:

$$\begin{gathered}
w_1 x_1 NOAJS + w_2 x_2 \sum_{g \in XOR-Gateway} CFC_{XOR-Split}(g) + w_3 x_3 \sum_{g \in OR-Gateway} CFC_{OR-Split}(g) + \\
+ w_4 x_4 \sum_{g \in AND-Gateway} CFC_{AND-Split}(g) + w_5 x_5 CNC \to \min_{x_i, i=\overline{1,5}}, \\
17 \le x_1 NOAJS \le 33, \\
1 \le x_2 \sum_{g \in XOR-Gateway} CFC_{XOR-Split}(g) \le 3, \\
1 \le x_3 \sum_{g \in OR-Gateway} CFC_{OR-Split}(g) \le 3, \\
1 \le x_4 \sum_{g \in AND-Gateway} CFC_{AND-Split}(g) \le 3, \\
0.4 \le x_5 CNC \le 1.1, \\
0 \le x_i \le 1, i = \overline{1,5},
\end{gathered} \tag{10}$$

where x_1 is the size-based comprehensibility coefficient; x_2 is the XOR-logic comprehensibility coefficient; x_3 is the OR-logic comprehensibility coefficient; x_4 is the AND-logic comprehensibility coefficient; x_5 is the network-based comprehensibility coefficient.

This model can be interpreted as the minimization of a weighted sum that represents the overall complexity of a process model, by finding comprehensibility coefficients x_i, $i = \overline{1,5}$, which can be used to identify complexity drivers of a business process.

Complexity drivers point at specific complexity properties (i.e., logical for NOAJS, structural for CFC, and network for CNC) and help to understand the impact of these properties on the overall understandability of a process model to make necessary re-design of a BPMN diagram:

$$\delta_i = \frac{1 - x_i}{\sum_{i=1}^{5} 1 - x_i}, i = \overline{1,5}. \tag{11}$$

Lower and upper boundaries (10) for each of the complexity metrics (NOAJS, CFC, and CNC) are based on thresholds proposed in [18] (see Table 1). However, we split the threshold values proposed for the CFC metric into equal parts for each of the CFC components (XOR-, OR-, and AND-based). Threshold values for CNC are based on respective values for “very efficient” and “rather inefficient” understandability levels by Sánchez-González et al. referred in [22].

4. Materials and Methods

The linear programming model proposed in equation (10) can be solved using the simplex method. However, in our particular problem, the minimum value of the weighted sum is achieved when the variables (i.e., comprehensibility coefficients x_i, $i=\overline{1,5}$) take their lower bounds.

The complexity drivers now demonstrate the "distances" between lower bounds of NOAJS, CFC, and CNC metrics that correspond to the moderate complexity of process models (see Table 1). Thus, to prove this statement, let us re-formulate the initially proposed linear optimization model (10) into the non-linear programming problem, specifically, the least squares optimization:

$$\begin{gathered} w_1(17-x_1 NOAJS)^2 + w_2\left(1-x_2\sum_{g\in XOR-Gateway} CFC_{XOR-Split}(g)\right)^2 + \\ + w_3\left(1-x_3\sum_{g\in OR-Gateway} CFC_{OR-Split}(g)\right)^2 + w_4\left(1-x_4\sum_{g\in AND-Gateway} CFC_{AND-Split}(g)\right)^2 + \\ + w_5(0.4-x_5 CNC)^2 \to \min_{x_i, i=\overline{1,5}}, \\ 0\le x_i \le 1, i=\overline{1,5}. \end{gathered} \tag{12}$$

This model can be interpreted as the minimization of weighted squares of distances between actual complexity metric values and lower bounds that correspond to the moderate understandability of process models (Table 1). Hence, the minimum of the quadratic loss function described by (13) can be found by setting the gradients to zero values [23]:

$$\begin{gathered} \frac{\partial}{\partial x_i}\left[w_1(17-x_1 NOAJS)^2 + w_2\left(1-x_2\sum_{g\in XOR-Gateway} CFC_{XOR-Split}(g)\right)^2 + \right. \\ + w_3\left(1-x_3\sum_{g\in OR-Gateway} CFC_{OR-Split}(g)\right)^2 + \\ \left. + w_4\left(1-x_4\sum_{g\in AND-Gateway} CFC_{AND-Split}(g)\right)^2 + w_5(0.4-x_5 CNC)^2 \right] = 0, i=\overline{1,5}. \end{gathered} \tag{13}$$

Therefore, the comprehensibility coefficients of a process model will take the following values:

$$\begin{cases} \dfrac{\partial}{\partial x_1} = 0 \Rightarrow x_1 = \min\left\{\dfrac{17}{NOAJS}, 1\right\}, \\ \dfrac{\partial}{\partial x_2} = 0 \Rightarrow x_2 = \min\left\{\dfrac{1}{\sum\limits_{g\in XOR-Gateway} CFC_{XOR-Split}(g)}, 1\right\}, \\ \dfrac{\partial}{\partial x_3} = 0 \Rightarrow x_3 = \min\left\{\dfrac{1}{\sum\limits_{g\in OR-Gateway} CFC_{OR-Split}(g)}, 1\right\}, \\ \dfrac{\partial}{\partial x_4} = 0 \Rightarrow x_4 = \min\left\{\dfrac{1}{\sum\limits_{g\in AND-Gateway} CFC_{g\in AND-Gateway}(g)}, 1\right\}, \\ \dfrac{\partial}{\partial x_5} = 0 \Rightarrow x_5 = \min\left\{\dfrac{0.4}{CNC}, 1\right\}. \end{cases} \tag{14}$$

Therefore, we propose the algorithm (Fig. 2) to evaluate the process model understandability by processing BPMN 2.0 files as XML (eXtensible Markup Language) documents [24].

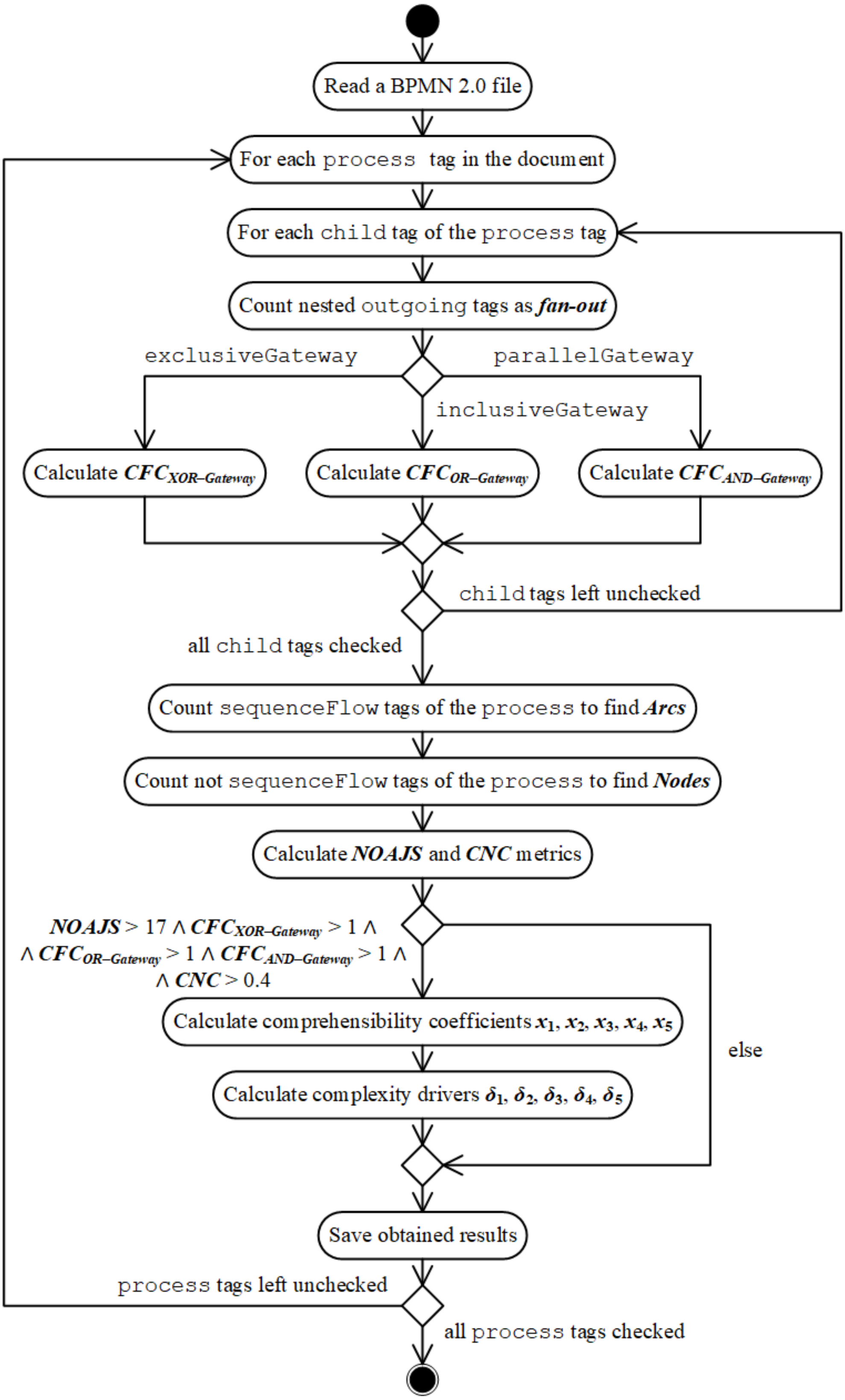

Figure 2: The algorithm for the evaluation of business process model understandability

As shown in Fig. 2, complexity drivers are calculated only for models of moderate complexity.

5. Results and Discussion

The software implementation of the proposed algorithm (see Fig. 2) is done as the Python [25] tool, which processes a collection of BPMN 2.0 files. This software tool reads XML-like documents [25] and stores the obtained results into a CSV (Comma-Separated Values) file for further analytical processing. The analytical processing is done using the Microsoft Power BI tool [26].

The generic workflow of the proposed software solution is demonstrated in Fig. 3 below.

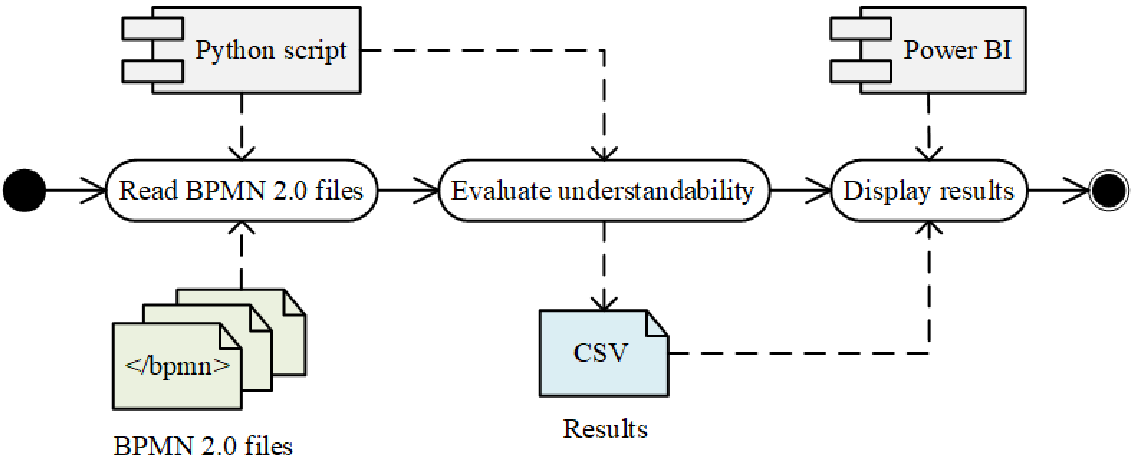

Figure 3: The software solution for the evaluation of business process model understandability

The first portion of obtained results based on input BPMN files [27] is demonstrated in Fig. 4.

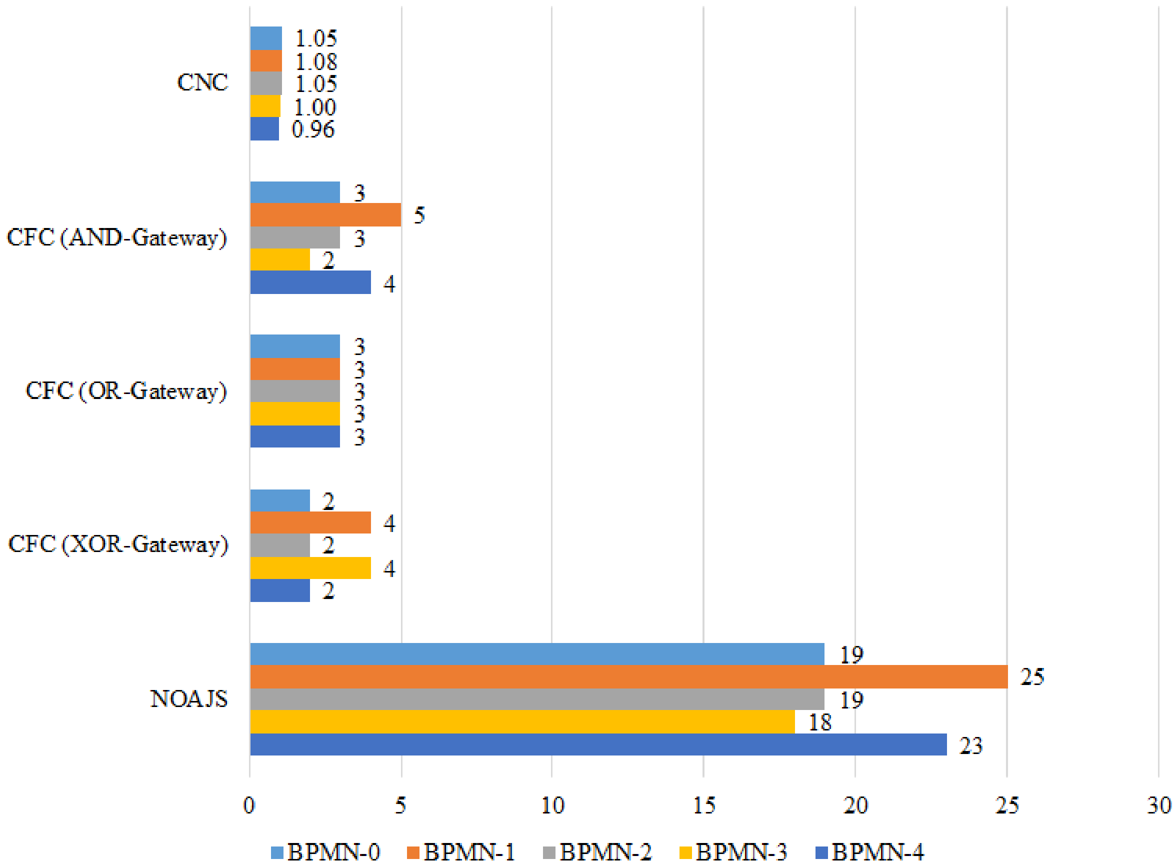

Figure 4: The first portion of processed BPMN 2.0 models and obtained metric values

Fig. 4 above demonstrates the results obtained for the first five BPMN 2.0 files taken from [27] – a large collection of BPMN models provided for research by Camunda. In total, we took for experiments ten BPMN 2.0 models that demonstrate moderate comprehensibility by their NOAJS, CFC, and CNC metric values (see Fig. 4). These ten models are demonstrated in bar chart diagrams in Fig. 4 and 5 as BPMN-0, BPMN-1, …, BPMN-9 items.

Fig. 5 below demonstrates the second portion of another five BPMN 2.0 files processed and the corresponding NOAJS, CFC, and CNC metrics calculated for these BPMN models as well.

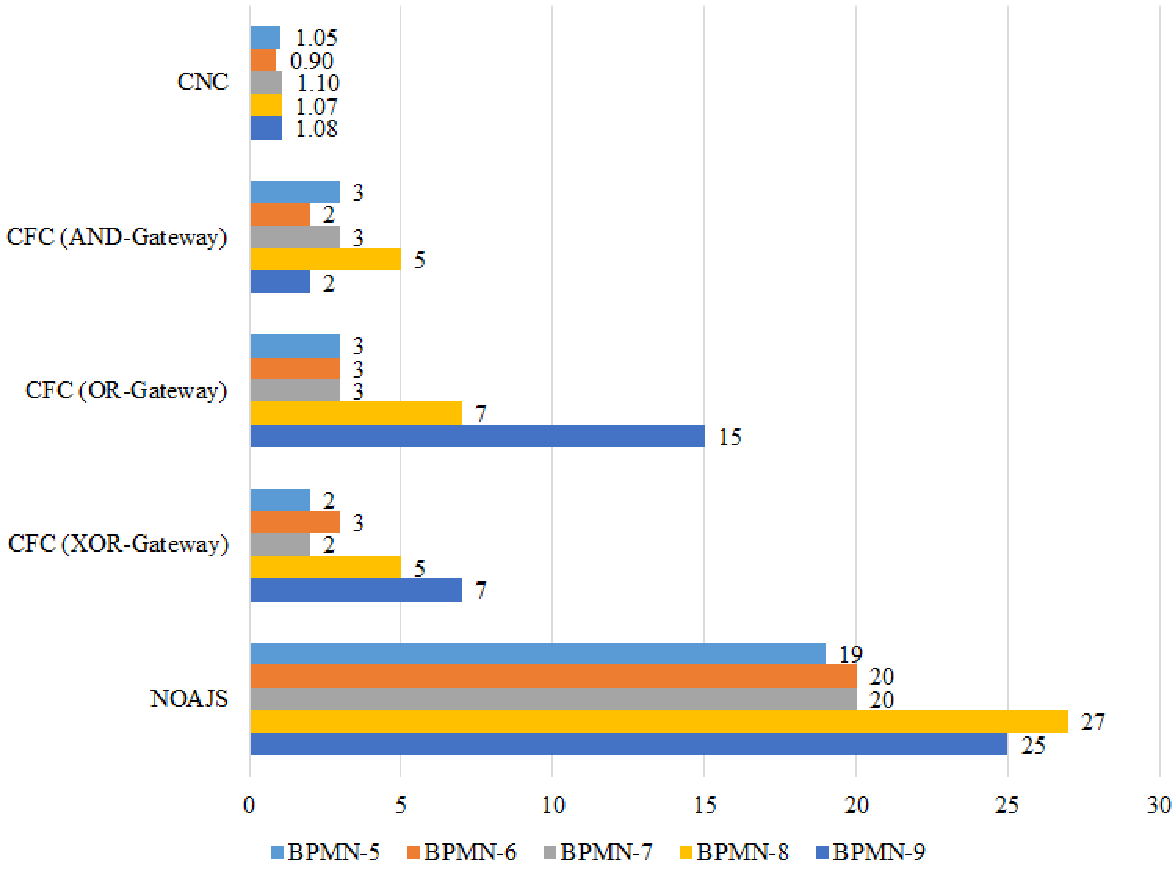

Figure 5: The second portion of processed BPMN 2.0 models and obtained metric values

As can be seen from the obtained results:

- the most hard for comprehension BPMN 2.0 diagrams from the size-based point, are BPMN-9 (25), BPMN-8 (27), BPMN-4 (23), and BPMN-1 (25);
- the most hard for comprehension BPMN 2.0 diagrams from the XOR-gateway complexity point, are BPMN-9 (7). BPMN-8 (5), BPMN-3 (4), and BPMN-1 (4);
- the most hard for comprehension BPMN 2.0 diagrams from the OR-gateway complexity point, are BPMN-9 (15) and BPMN-8 (7);
- the most hard for comprehension BPMN 2.0 diagrams from the AND-gateway complexity point, are BPMN-8 (5), BPMN-4 (4), and BPMN-1 (5);
- and all of the processed BPMN 2.0 diagrams demonstrate relatively similar CNC values in the range from 0.90 (for BPMN-6) to 1.10 (for BPMN-7).

Let us consider one of the most complex BPMN 2.0 models among the processed ones. This is the BPMN-8 diagram, which has the following complexity properties:

- $NOAJS = 27$;
- $\sum_{g \in XOR-Gateway} CFC_{XOR-Split}(g) = 5$;

- $$\sum_{g \in OR-Gateway} CFC_{OR-Split}(g) = 7;$$
- $$\sum_{g \in AND-Gateway} CFC_{AND-Split}(g) = 5;$$
- $CNC = 1.07$.

This business process model (BPMN-8) is demonstrated in Fig. 6 below. This model describes a goods dispatch business process, which happens in a small hardware store [27].

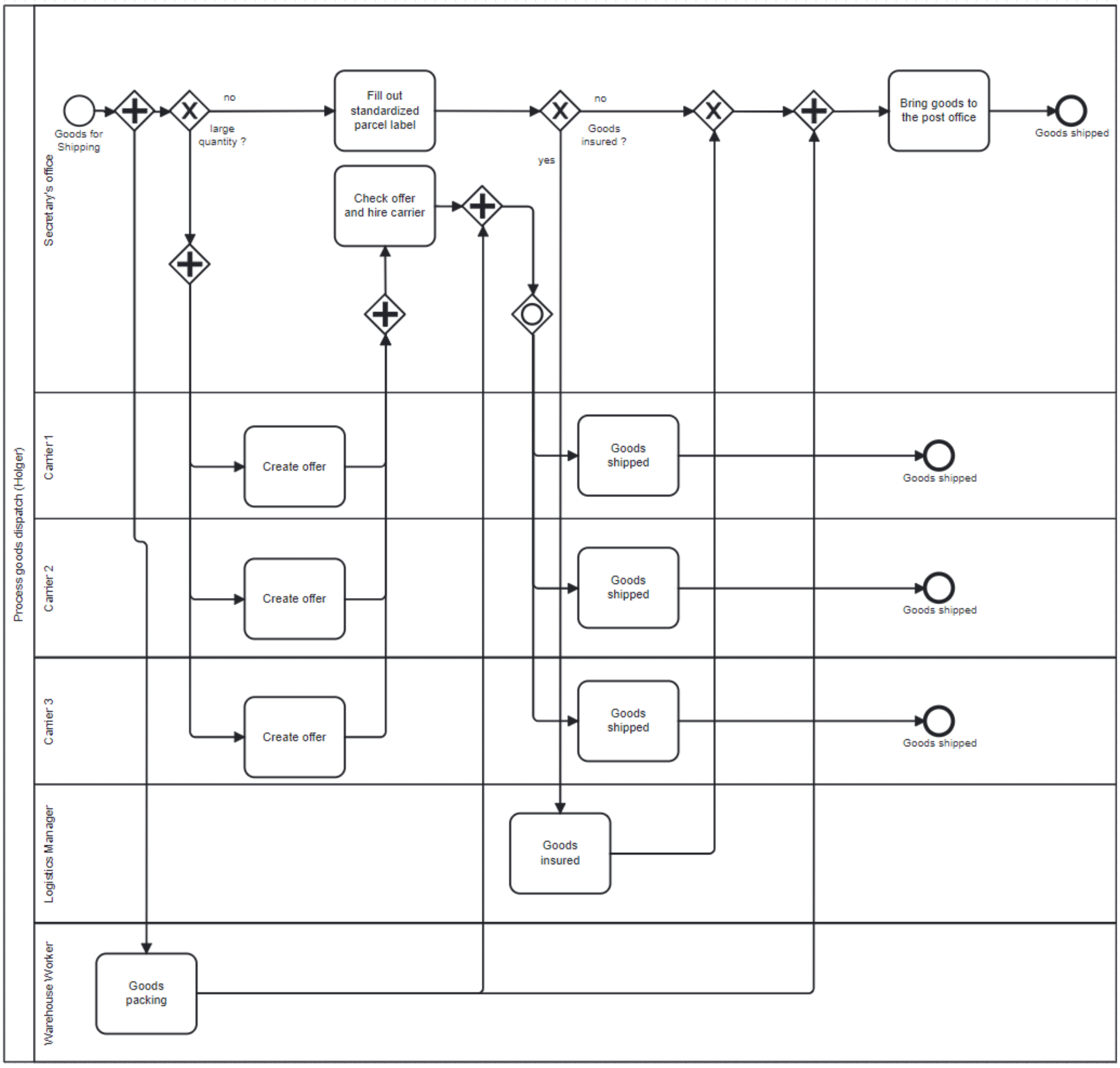

Figure 6: The goods dispatch process BPMN 2.0 model used for experiments

Taking into account the calculated metrics for the BPMN-8 diagram (see Fig. 6), the algorithm and software tool (Fig. 3) were used to define comprehensibility coefficients given by equation (14):

- size-based, $x_1 = 0.63$;
- XOR-logic, $x_2 = 0.20$;
- OR-logic, $x_3 = 0.14$;
- AND-logic, $x_4 = 0.20$;
- network-based, $x_5 = 0.37$.

Let us present the obtained comprehensibility coefficients on a column chart, depicted in Fig. 7.

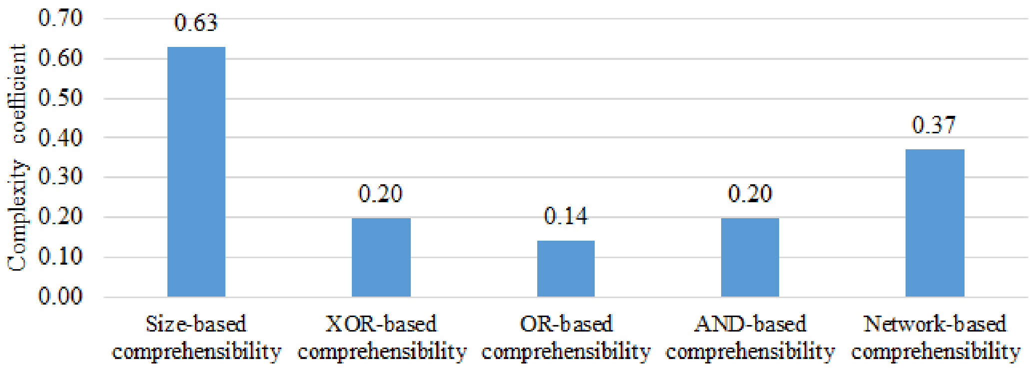

Figure 7: Obtained comprehensibility coefficients

Fig. 7 demonstrates the highest comprehensibility property of the considered BPMN 2.0 goods dispatch process model (see Fig. 6) is size-based (0.63), the medium comprehensibility property is network-based (0.37), and the lowest comprehensibility properties are gateway-based (0.20 for XOR- and AND-logic, 0.14 for OR-logic).

Therefore, let us calculate the complexity drivers given by equation (11):

- size-based, $\delta_1 = 0.11$;
- XOR-logic, $\delta_2 = 0.23$;
- OR-logic, $\delta_3 = 0.25$;
- AND-logic, $\delta_4 = 0.23$;
- network-based, $\delta_5 = 0.18$.

The impact of complexity drivers (i.e., size, XOR-logic, OR-logic, AND-logic, network structure) on the overall understandability of the goods dispatch BPMN 2.0 process model (see Fig. 6) is shown using the pie chart in Fig. 8 below.

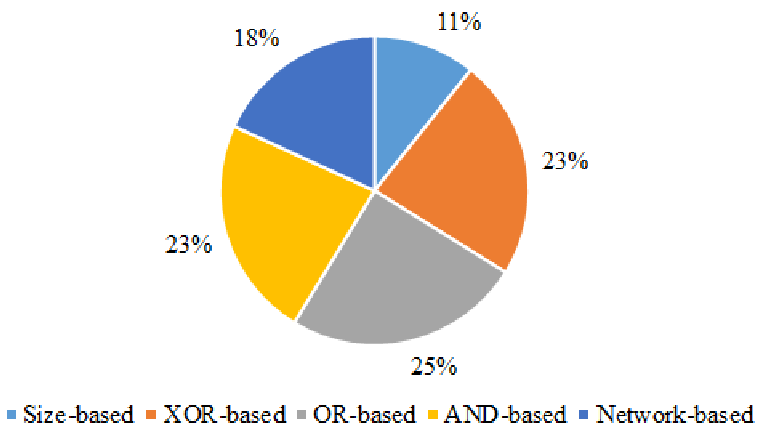

Figure 8: The impact of complexity drivers on the overall understandability of the process model

Thus, using the proposed optimization model, developed algorithm (Fig. 2), and software (Fig. 3), BPMN 2.0 business process models can be automatically evaluated and special recommendations can be provided to reduce complexity and improve the understandability of business process models, making them efficient communication tools available and comprehensible by all of the involved stakeholders.

For, example, the obtained complexity drivers can be interpreted as the following suggestions for a process modeler:

- re-design OR-gateways – they reduce the model's understandability by 25%;
- re-design XOR- and AND-gateways – they reduce the model's understandability by 23%.

While size- and network-based drivers do not exceed 20% and may not be included in suggestions.

6. Conclusion and Future Work

In this paper, existing business process model complexity metrics were analyzed and a model to minimize the complexity of BPMN 2.0 process models, formulated as the optimization problem, is proposed. To apply the proposed model and perform experiments, the algorithm and software for the evaluation of business process model comprehensibility are proposed. This software can be used to produce recommendations to reduce complexity and achieve better understandability of BPMN 2.0 models. There are the following findings that could be summarized after validation of the proposed solution through the performed experiments:

- business process models given as BPMN 2.0 files are easily processed as machine-readable XML documents to extract their structure;
- with the relatively close CNC values, values of NOAJS and CFC metrics of business process models could significantly vary, causing negative effects on the understandability;
- found comprehensibility coefficients and related complexity drivers reveal “weak” sides of business process models and could be used as subjects of improvement recommendations.

In the future, the proposed technique of business process model analysis should be extended with the automatic correction of BPMN 2.0 files, by manipulating the structure of XML documents. This can be achieved by using intelligent technologies, such as machine learning classification algorithms for finding the best suitable solutions for detected structural issues in process models.

Also, in the future, the software tool should be elaborated to become available for daily usage by business process model designers, business analysts, and other persons creating BPMN diagrams. The software also should be extended with Big Data Analytics and Business Intelligence capabilities to efficiently collect, store, and process large volumes of business process data.

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