Towards a Taxonomy of Business Process and Its Anomalies

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Summary
This paper presents the definition of a business process and a taxonomy of anomalies in BPMN. Graphical modeling is very popular nowadays and is easily understood by various specialists from different fields. Modeling is a graphical representation of processes in an organization using available rules and resources. Therefore, it is important to use a universal and comprehensive standard to describe models of processes, decisions and software. Such a standard is the BPMN notation, which is a precise notation, but unfortunately it is only a descriptive and graphical form that may contain inaccuracies. The aim of this paper is to collect and analyze available literature describing current state of knowledge about BPMN notation and to present problems and shortcomings related to this topic. The paper includes a taxonomy of problems, their definitions and examples of occurrence in real cases.

Key words:
business process, BPMN, Business Process Model and Notation, anomalies, taxonomy

1. Introduction

Nowadays, an approach to modeling based on graphical notations understandable by various specialists has become very popular. Business process models are graphical representations of processes in an organization. These models bridge the gap between technical and business users. They are used to describe sequential, parallel, and alternative workflows in an organization to achieve required goals [2]. Visualizations of processes make them much easier to understand than textual descriptions. Therefore, the Object Management Group (OMG) consortium [3], formed in 1989, is trying to create a universal and comprehensive standard for visualizing process, decision, and software models [4]. OMG's goal was to establish a cross-platform standard in the field of distributed object-oriented programming [5]. This effort resulted in several standards including:

- Unified Modeling Language (UML),
- Business Process Model and Notation (BPMN),
- Decision Model and Notation (DMN),
- Case Management Model and Notation (CMMN).

Business process model and notation (BPMN) [1] is the most common notation for modeling processes. The goal of BPMN was to create a uniform business process notation that could be generally understood- from professional process analysts to managers to ordinary employees [1]. BPMN originated from a synthesis of many business modeling notations. It was originally published by the Business Process Management Initiative (BPMI) in 2004. The BPMN specification was released by the OMG in February 2006. Version 2.0 of BPMN was developed in 2010, and the current version of the specification was released in December 2013. The latest version (BPMN 2.0.2) was formally published by ISO as the 2013 edition standard: ISO/IEC 19510.

According to [1], BPMN is a standard business process model and BPMN notation provides companies with the ability to understand their internal business procedures in graphical form. It enables organizations to be able to communicate in a standardized way. In addition, BPMN notation makes it easier to understand the collaboration of performance and business transactions between different organizations.

Despite many efforts, there are still problems with unambiguous interpretation. This fact is due to the lack of a satisfactory BPMN interpreter. In fact, BPMN processes have not been formally defined and, consequently, the semantics of BPMN components and connections are not given. Therefore, different devices may interpret the same BPMN models differently. The lack of formal semantics can lead to misinterpretations and errors. Most articles in the business process area focus on the use of BPMN's capabilities, but articles analyzing errors and how to eliminate them are in the minority.

BPMN notation is a precise notation, but unfortunately it is only descriptive and graphical. Therefore, this paper is an attempt to analyze the problem of anomalies that may occur in BPMN. An attempt has been made to present possible problems. The research is based on literature analysis and some experience with BPMN models. The paper is organized as follows: the first chapter is an introduction to the topic, the second and third chapters contain business process taxonomies and BPMN notation with gates. The next chapter presents anomaly in business processes with literature analysis. Chapter five contains a taxonomy of problems in BPMN and an example. The last one is the conclusion of this paper.

2. Business Process

In the field of IT and business, the issues related to analysis, modeling and automation of business processes are developing very dynamically. Their foundation is the

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business process, the knowledge of which is necessary for correct and effective use in practice.

Speaking about the business process, it is necessary to define this concept in a proper way, as its components: process and business. The "process" itself is an issue used in many areas of life (e.g. life processes in biology, processes in operating systems- computer science or clinical processes in medicine) and generally expresses a sequence of consecutive activities. The second element is "business", which is an organized activity that uses various resources to achieve a goal (service, product) and deliver them to customers. Having the components of the business process illustrated in this way, we can assume that the business process itself is a set of activities that aim at achieving a certain value in the form of a product. In order to produce this product, resources are required and the rules by which the product is created.

There are various rich definitions of a business process in the literature, selected ones are presented in Table 1. The paper [6] collects various definitions that have been developed over the last 20 years. According to the ARIS (Architecture of Integrated Information Systems) methodology, it is a chain of logically related functions, executed sequentially or in parallel, which, using the available resources, transform inputs into outputs leading to the achievement of the intended goal. The Business Process Model and Notation (BPMN) definition defines that a business process represents a sequence or flow of activities in an organization with a goal in mind. The most accurate definition seems to be the definition according to Rummlen and Brache in 1995: "a business process is a series of steps designed to produce a product or service".

Table 1: Process definitions

author and year	the wording of the definition
Pall (1987)	Business process is the logical organisation of people, materials, energy, equipment and procedures into work activities designed to produce a specified end result.
Davenport and Short (1990)	Business process is a set of logically related tasks performed to achieve a defined business outcome.
Davenport (1993)	Business process is defined as the chain of activities whose final aim is the production of a specific output for a particular customer or market.
Hammer and Champy (1993	A business process is a collection of activities that takes one or more kinds of inputs and creates an output that is of value to the customer. A business process has a goal and is affected by events occurring in the external world or in other processes.
Johanson et al. (1993)	A business process is a set of linked activities that takes an input and it transforms it to create an output. It should add value to the input and create an output that is more useful and effective to the recipient
Jacobson (1995)	The set of internal activities performer to serve a customer.
Rummler and Brache (1995)	A business process is a series of steps designed to produce a product or service.
Soliman (1998)	Business process may be considered as a complex network of activities connected together.
Agerfalk (1999)	A business process consists of activities ordered in a structured way with the purpose of providing valuable results to the customer.
Workflow Management Coalition (1999)	Business process is a set of one or more linked procedures or activities which collectively realise a business objective or policy goal, normally within the context of an organizational structure defining functional roles and relationships.
Eriksson and Pencker (2000)	A business process has an explicit goal, a set of input objects and a set of output objects. The input objects are resources that are transformed or consumed as part of the process, such as raw material in a manufacturing process.
Volkner and Werners (2000)	Business process is defined as a sequence of states, which result from the execution of activities in organisations to reach a certain objective.
Fan (2001)	Business process is a set of one or more linked procedures or activities that collectively realise a business objective or policy goal, normally within the context of an organisational structure defining functional roles and relationships.
Stock and Lambert (2001)	A business process can be viewed as a structure of activities designed for action with focus on the end customer and the dynamic management of flows involving products, information, cash, knowledge and ideas.
Stohr and Zhao (2001)	A business process consists of a sequence of activities. It has distinct inputs and outputs and serves a meaningful purpose within an organisation or between organisations.
Gunasekaran and Kobu (2002)	A group of related tasks that together create value for a customer is called a business process.

Irani et al. (2002)	A business process is a dynamic ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs.
Castellanos et al. (2004)	The term business process is used to denote a set of activities that collectively achieve certain business goal. Examples of these processes are the hiring of a new employee or the processing of an order.
Shen et al. (2004)	Business process is a set of one or more linked procedures or activities that collectively realise a business objective or policy goal, normally within the context of an organisational structure defining functional roles and relationships.
Wang and Wang (2005)	Business process is defined as a set of business rules that control tasks through explicit representation of process knowledge.
OMG: BPMN v. 2.0 (2011)	A defined set of business activities that represent the steps required to achieve a business objective. It includes the flow and use of information and resources.

Technically, a business process is one or more activities that transform an initial set of inputs into one or more outputs that are valued by the organization. In diagrams, a business process is represented as a rectangle with rounded corners with inputs and outputs. A simple BPMN diagram is shown in Figure 1.

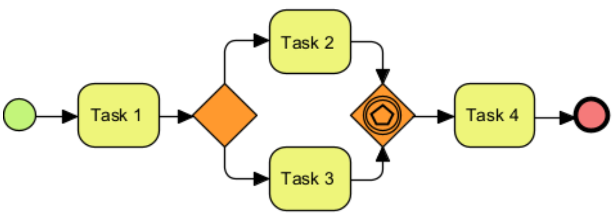


Fig. 1. Example of a BPMN diagram.

3. Business Process Model and Notation

Business Process Model and Notation (BPMN) [1] is the most widely used notation for business process modeling [7]. Since the notation is quite complex it has many application areas which can be found in [5],[8-15]. The purpose of creating the BPMN notation was to create a universal notation for modeling business interactions, understandable not only to people involved in IT operations but also to people unrelated to the subject [1].
BPMN defines more than 100 elements, so that practitioners differentiate them depending on the level of detail in the model. Three levels of models can be distinguished [16]:

- descriptive level, is the basic level using a very intuitive subset of BPMN to reflect the path scenario and all the main activities in the process;
- analytical level, is dedicated to analysts, designers and business architects who use complex structures and elements to design fully characterized processes,
- the executable level for technicians, where the details of execution can be placed in the model.

In addition, many different extensions of BPMN have been proposed to capture other aspects of business processes [17-21]. BPMN notation models are presented in the form of diagrams that use a limited set of graphical elements [1]. BPMN 2.0 specification elements are grouped into four categories (Fig. 2):

- Flow Object (events, activities, gateways),
- Connecting Object (sequence flow, message flow, association),
- Swimlanes (pool, lane),
- Artifacts (data object, group, text annotation).

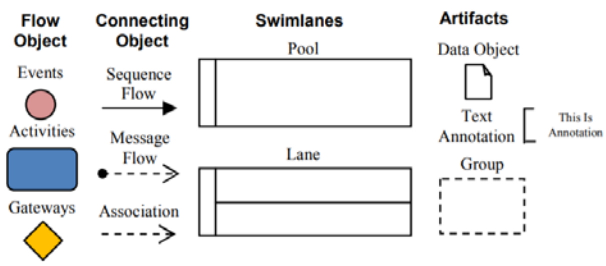


Fig. 2 A core of BPMN elements

3.1 Gateways

In BPMN there are not as many control statements as in programming languages but the equivalent of an if statement has many variations. Logic gates in BPMN (denoted by the rhombus symbol) are used to show which paths a process can take. The following categories of gateways can be categorized:

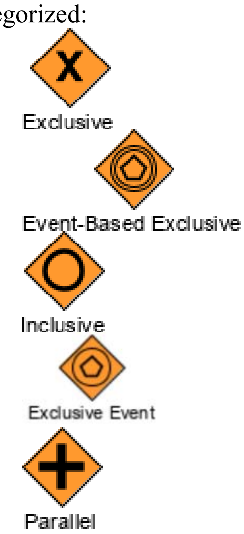
Exclusive

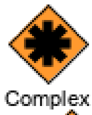
Event-based Exclusive

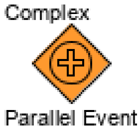
Inclusive

Exclusive Event

Parallel



Complex 

Parallel Event 

Understanding process flow and gate operation is facilitated by the concept of a token. A token is created when an initial event is triggered and a process begins. Starting from the initial event, the token flows along the process flow arrow and activates individual process elements. When it reaches the end of the process (the final event) it is destroyed and the process instance ends.

Exclusive Gateway can be denoted by an empty rhombus symbol or a rhombus with an X. It does not matter which symbol we use. The important thing is consistency. If you choose to label a data-driven exclusion gate with an empty rhombus, you should label it that way throughout the entire process. Do not use a gate with a marker once and a gate without a marker once within a process, as this degrades the readability of the process.

A token, once it reaches a data-driven exclusion gate, can only flow further along one of the paths coming out of the gate. This is a data-driven gate. Therefore, the decision on which path the token will flow is made based on the data it has.

In Figure 1, we have the process of making a selection of a pizza item from the available menu. The initial event is the receipt of the menu card. In the first task of the process (*Menu Analysis*), we verify that a pizza has been selected from the menu. As a result of the check, we get information (data) that a selection was made or not. Having this data, we will lead the process down one of two paths:

- if the selection meets the requirements, the process will take the path marked "*yes*" to the task "*Added to order*"
- if the selection does not meet the requirements, the process will go along the path marked "no" to the task "*No pizza* selected".

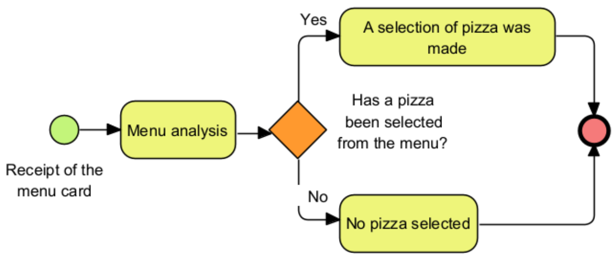


Fig. 3 Example of the Exclusive gateway

A process can branch at a gate into two or more paths. Regardless of the number of paths, in the case of an exclusion gate, the process can continue on only one of the paths. Immediately after the gate, there can be tasks followed by an end event as in example one. Alternatively, a closure gate can be used as shown in Fig. 4. In the second example shown (Fig. 4), a closing gate is used and only after it is the final event.

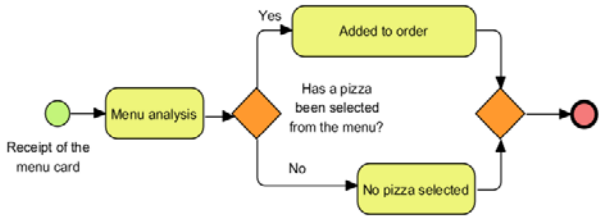


Fig. 4 Example with a closing gate and end event

A gateway is where we branch out a process based on the data we have. It is not a process place where we analyze the data and make a decision. The analysis and decision making occurs in the task before the gateway. One of the paths may be the default. The default path is crossed out. It is implemented if the condition of any of the other paths is not met.

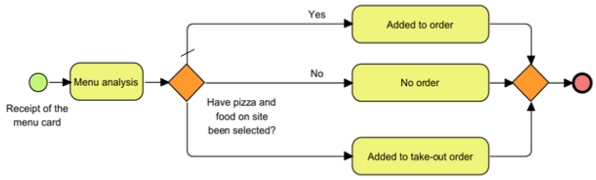


Fig. 5 Default path usage

In the example in Figure 5, the process starts with the initial event "*Receive Menu Card*". The first step of the process is the "*Analyze Menu*" task, where we check to see if the order is placed and if food has been selected on site. Depending on the information we have, the process will flow further along one of the following paths:

- if pizza and takeaway are selected, the token follows the path to the "*Transfer to pack*" task
- if no pizza is selected, the token follows the path to the "*No order*" task
- if none of the above conditions is true, the token follows the default path to the task "*Added to Order*".

Exclusive Event-based gateway-this is where we branch the process based on the event that occurred (Fig. 6). The process can continue along only one of the paths. The event that occurred determines the path that the process will continue.

Fig 6 Example with Exclusive Event-gateway

In the example shown in Figure 6, the process starts with the initial event "*Order received*". Then, the first step of the process is the task "*Request for order confirmation*", which is sent to the customer. The way the process continues depends on which of the following events occurs: the customer's acceptance of the order or expiry of the time in which the confirmation should take place

- if the customer accepts the order (event trigger: message), the token will flow along the path to the "*Order completion*" task.
- if the customer does not confirm the order within 5 minutes (event trigger: timer), the token flows along the path to the task "*Cancel order*".

In BPMN notation, there may be gateways connecting several alternative paths, even if there is no process branching anywhere earlier in the model (Fig. 7).

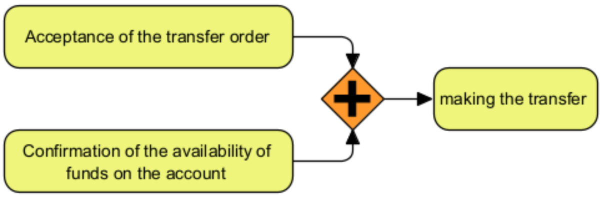


Fig. 7 Parallel Gateway

In the BPMN notation, the gate only symbolizes the branching, while the conditional expressions are specified on the outputs from the gate. Expressions describing individual outputs from a gate according to the BPMN 2.0 standard can be expressed using natural language or formally (pseudo code). According to BPMN 2.0 notation it is possible to omit gates and use conditional sequence flows. The analogy is presented in four variants: with gates and with their omission (Fig. 7).

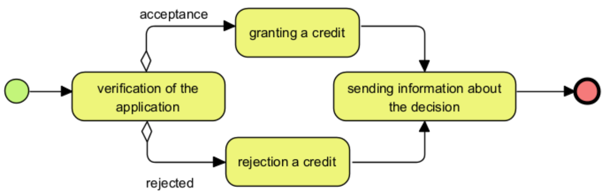


Fig. 7 No gates, only conditional flows

When a user uses several modeling methods at the same time and wants to combine several disconnected paths can cause a problem (Fig. 8, fig. 9).

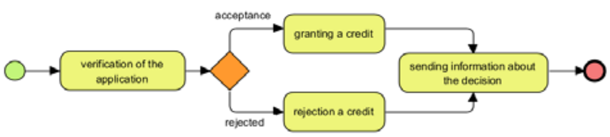


Fig. 8 Dividing gate, no connecting gate

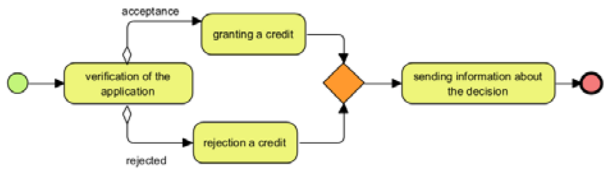


Fig. 9 No dividing gate, connecting gate

To prevent problems with model interpretation, a closing gate can be used for each opening gate after the pair (Fig. 10).

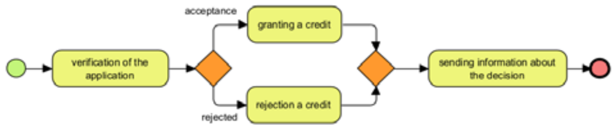


Fig. 10 Dividing and connecting gates

4 Analysis of anomalies in business processes

Anomalies may also occur in the underlying business processes due to the ability to define specifications of inconsistent business logic and its interpretation [26]. Therefore, a mechanism to provide this consistency in detecting defects and irregularities in business processes is desirable [27]. Reliability is the ability of a system to handle defects and errors in such a way that failure does not occur. A failure, in turn, is a situation in which the system (program) is unable to perform its functions due to an error. An error is a situation in which the system is in a state other than the desired (correct) state. An error is a static feature of software and failures are consequences of errors. Note that errors do not necessarily cause system failures. Definitions of anomalies have been presented in numerous works, but the most accurate definition is presented in the IEEE standard classification for software anomalies [28], namely: "*Any condition other than the expected condition is an anomaly*". In business logic, an anomaly can be considered as any negative impact of modeling and models. There is a special kind of anomaly- a defect that blocks the completely correct and efficient flow of objects..

The BPMN standard is very popular due to its versatility, so that it can be used for modeling in different domains. However, despite this advantage, the complexity of BPMN semantics can cause errors during design [29], [30]. Misunderstandings arise because of the use of natural language (sometimes misleading) to define BPMN semantics [31]. This problem is also evident in the differences that can be observed between the available business process management systems [32]. This becomes a more significant problem when using BPMN support tools, i.e., animators, simulators, and enactment tools [33], whose implementation of the execution semantics may not conform to the standard and may differ from each other, thus undermining the portability of the models and the effectiveness of the tools [32]. A taxonomy of anomalies has been developed from the literature, keeping in mind flow control, fundamentals and principles of data verification, and flow accuracy. The taxonomy provides a basis for classification and continued research on anomaly capabilities [29], [34-36]. The anomaly problem in BPMN is to find business logic for specific patterns. In [37], typical controls for anti-patterns are searched using a query language for BPMN. This is confirmed by jamming or misapplication of spinning lock patterns. The same happens in [38] in which typical gate constellations leading to problematic situations in the workflow diagram are presented. An analogous situation also occurs in [39] where an "anomaly pattern" is used. This approach is based on detecting anti-patterns in the data flow. The whole approach is based on timing logic using real model checking. Using different tools, item [40] focuses on different anomalies that are due to formalism or inadequacy of tools.

Anomaly analysis is the process of empirically analyzing values in a data set to find unexpected behavior in order to provide an initial baseline review and is used to reveal potentially flawed data values, data elements, or records. This analysis:

- examines the frequency distributions of values,
- examines the variance of values,
- records the percentage of completed data attributes,
- examines relationships between columns,
- examines relationships between data sets to reveal potentially flawed data values, data elements, or records.

Noted defects are typically documented and can be reported to business customers to determine if each defect has any critical impact on operations.

Business process management literature suggests that more than 60 percent of quality improvement projects fail due to factors related to the lack of predictive quality control and the failure to continually look for anomalies in the quality of performance over time. Quality anomalies indicate extreme performance deviation from quality expectations and requirement. The findings suggest that quality control in BPMN is a scientific method for producing quality anomaly knowledge and signaling capabilities for informed, systematic, and continuous performance improvement. Based on the findings, a predictive framework was proposed in [41]. A path containing was proposed as an activity to define a quality control framework for predicting quality anomalies in BPMN over time:

- Understand the role of quality control and quality improvement in BPMN.
- Understand the analytical method for implementing quality control and quality improvement
- Understand the analytical method for detecting and predicting anomalies in data indexed by time units.

The composition of a BPMN model using a reusable parts repository should always be done in accordance with business process modeling guidelines to avoid common anomalies [34]. Inconsistent business process models can be affected by syntactic anomalies that include incorrect use of actions, gates, object linking, or float lines. Another group are structural anomalies related to improper dynamic process behavior, for example, the presence of jams and infinite loops. Automated process modeling [42] should also include checking if the created model contains any anomalies such as jams, live locks or out of sync [34] [12] or event anomalies [35]. Analysis of the formal aspects of a BPMN model can also be performed using the Alvis Modelling Language [13].

5. A taxonomy of business problems in BPMN

Business process analysis is often challenging not only because of the complex relationships between process activities, but also because of the various sources of errors in activities. Automated detection of potential business process anomalies can tremendously help business analysts and other process participants detect and understand the causes of process errors.

Syntactic anomalies result from incorrect use of BPMN syntax. This results in incorrect business process models [43]. Anomalies of this type have been reported in papers [12], [29], [44-47].

The work [48] proposed an approach to detect time anomalies. Outliers can have different causes; they can be obvious, such as in the case of unusual measurement or execution errors [49], and they can be hidden, such as in the case of latent or propagated errors that do not reveal themselves as such during execution. However, it is often sufficient to detect potential anomalies rather than exact errors. Once such anomalies are presented, expert analysts or other process participants can dig deeper into the problem and fix the current bug. Therefore, detecting potential anomalies can greatly simplify the task of finding potential errors in business processes [50]. The work [48] focuses on timing anomalies, i.e., anomalies regarding the running time of activities within a process. To detect such anomalies, a Bayesian model was used which can be automatically inferred from the representation of a business process as a Petri net. Probabilistic inference on the above model allows the detection of non-obvious and interdependent timing anomalies.

The website dedicated to interoperability

"*interoperability-definition.info*" defines it as a characteristic of a product or system whose interfaces function in full compatibility so as to interoperate with other products or systems that exist, or may exist in the future, without any restriction of access or limited implementability. And according to ISO/IEC 2382-01, Information Technology Vocabulary, Fundamental Terms, interoperability is defined as follows: "The ability to communicate, execute programs, or transfer data between different functional units in a manner that requires little or no user knowledge of the unique characteristics of those units." In BPMN Interoperability and Parallelism is the behavior of processes occurring in complex scenarios and environments that are parallel, inter- and intra-organizational [51]. These scenarios enable interoperability between different systems and services with different formats, both data formats and protocols [52]. Therefore, methods for detecting such anomalies have to deal with a mixture of different execution scenarios of execution environment, process behavior and data. For anomaly detection to work effectively, the process should not only focus on single selected protocols [50]. Existing approaches to process anomaly detection are flexible and methods should be used to account for variable and volatile behavioral data [51].

Another approach is a concept based on UML diagrams in development stages [53]. Control flow anomalies refer to problems related to flow control and gating conditions [53]. The work [54] presents the problem of controlling multiple semantically identical connections between two workflow elements. This diversity complicates workflow changes, which is not desirable [52]. Several types of anomalies can be distinguished in this category, namely:

- Deadlock, an anomaly in which during synchronization of two control flows at least one was not previously activated [12], [29], [34-35], [44] [55-66].
- Dead Activity is an error showing an activity that the control flow never reaches [29], [60].
- Infinite loop error represents an infinite loop. It is caused by the fact that there is no break condition or the condition will never be satisfied [37], [58-62],[67-69].
- Lack of synchronization error what happens in flow control when there is no synchronization is that multiple flows are executed. For example, branching and some loop instructions cause this anomaly [45], [47], [55], [58-67], [69],
- Improper completion error anomaly that forces a process to terminate prematurely [61], [66] ,[70].

Comprehension problems are anomalies that hinder the understanding of business process models and includes the following sub characteristics [71]:

- Language deficit refers to incomplete, inappropriate, or ambiguous text labels or labels that do not conform to naming conventions [44], [47], [58], [72-74].
- Layout deficit refers to anti-patterns relating to the spatial layout of a model [44]. This includes things such as reading direction or placement of model elements (spacing, overlap, etc.) [47].
- Complexity (Complexity): this addresses the problem of overly complex modeling with too large diagrams, too many elements of a certain type, or a missed opportunity to reuse frequently occurring model fragments [44], [46-47], [63], [75-76],

In the works [57], [65], [68], [77] composition anomalies are presented they mainly concern collaboration between actors, e.g. collaboration of actors in groups, departments and institutions.

A process-related defect describes negative characteristics of the actual process (other than problems in the process model). This type considers subordinate characteristics such as:

- Need for process improvements process weakness refers to processes [78] that may lead to higher costs, longer processing times, lower quality, or more errors [73], [79-81]. Examples of such problems may include inefficient or duplicate work, problems related to organizational structure [82-84], or media disruptions,
- Compliance: anomalies that describe violations of rules established by laws, standards, or organizational rules [75], [81], [85].
- Communication defect: are anomalies resulting from communication in the process model [87]. Examples of this type of error include lack of normalization of communication channels and poor quality of transmitted information [79].

Rule-based anomalies have been presented in many works [29], [69], [88-91]. They mainly cover two rule-based problems. The first problem is consistency anomalies. The problems arise from a set of rules that specify conditions but at the same time different outcomes. Rule locks, also known as "circular rules" [91]. Rule locks and rule-based jamming describe a problem with creation rules that are dependent on each other, although they should not be. This type of anomaly suggests that the rule base does not cover the underlying context in which it is used. Scope anomalies refer to rules in which conditions can be satisfied in the underlying context, but inferences are modeled in such a way that no effect will ever be seen.

Another type of anomaly presented in [92] shows anomalies affecting those data elements that can be processed by workflow activities. There are also Data-flow-related anomalies presented in the works: [63], [82], [93], [94], which can be incorrectly created, edited, deleted, or stored [79]. This also includes violations of security and privacy requirements [81].

5.1 Example

The main flow of the Order processing process (Fig. 11) begins after the pizza order is accepted and continues until the ordered item is checked for availability or not. Once the availability is checked and the pizza is shipped to the customer, the financial settlement takes place, which is a collapsed subprocess in this diagram. If an item is not available, it must be purchased by calling the order subprocess.

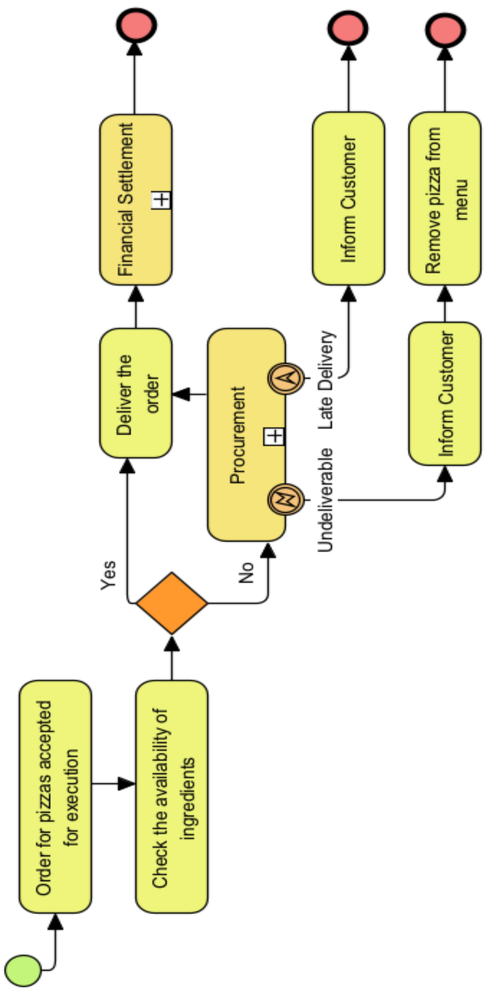


Fig 11. Pizza Order Process

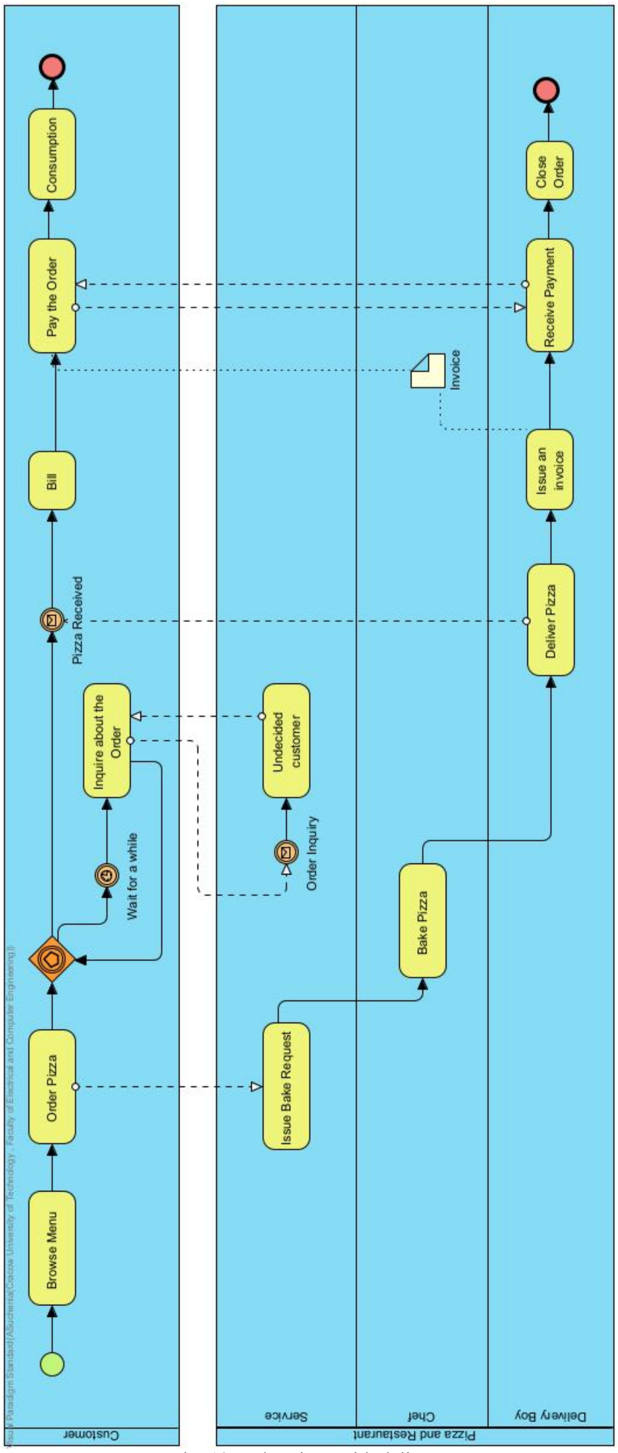


Fig. 12 Order pizza with delivery

The figures (Fig. 13, Fig. 14, Fig 15) are show different variants of parts of the process for a credit card payment for an ordered pizza.

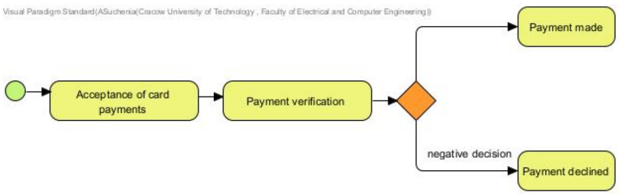


Fig. 13 Fragment of the card payment process

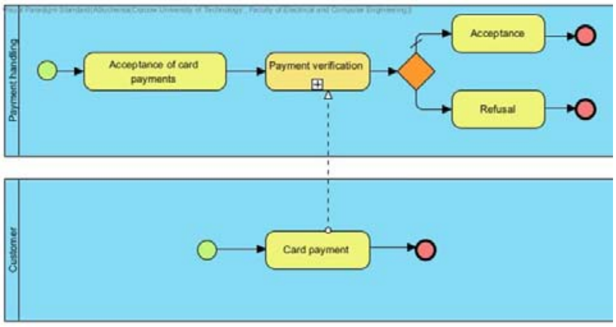


Fig. 14 Fragment of the card payment process with two participants

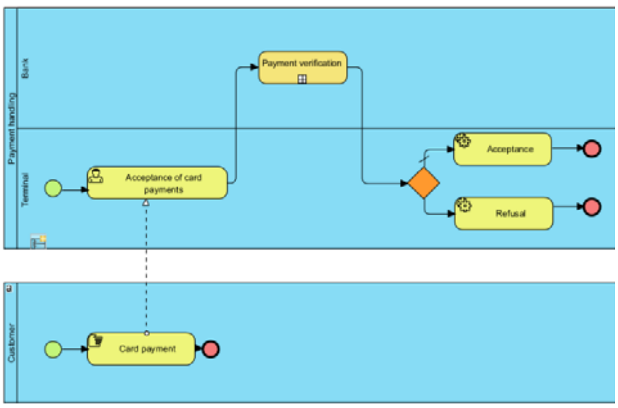


Fig.15 Fragment of the card payment process using pools and swimlanes.

6 Conclusion

Dynamic developing issues related to the analysis, modeling and automation of business processes can lead to inaccuracies. BPMN notation is a graphical representation of business processes that facilitates communication between different users of the business system. BPMN is a modeling stud and one of the important components of a successful business. However, despite the many advantages of BPMN notation, there is still the problem of effective anomaly detection in this solution. The presented work presents an analysis of the available literature in the field of problems and shortcomings related to the topic of errors and anomalies in BPMN notation. The developed drawings were made in the Visual Paradigm environment as part of the Academic Partner Portal. The work is a continuation of research on anomalies and errors in modeling business processes.

References

1. OMG: Business Process Model and Notation (BPMN): Version 2.0 specification. (2011)
2. Kluza, K., Wiśniewski, P., Ligęza, A., Suchenia, A., Wyrobek, J.: Knowledge representation in model driven approach in terms of the zachman framework. Lecture Notes in Artificial Intelligence, Springer (2018) 689–699
3. OMG: https://www.omg.org/marketing/25th/history.htm
4. OMG: https://www.omg.org/about/
5. Kluza K., Kagan M., Wiśniewski P., Adrian W. T., Jemioło P., Suchenia A., Ligęza A.: Using a semantic-based support system for merging knowledge from process participants (2021)
6. bptrends: What is a business process. (2010)
7. Chinosi, M., Trombetta, A.: Bpmn: An introduction to the standard. Computer Standards & Interfaces 34 (2012) 124–134
8. Ligęza, A.: A note on a logical model of an inference process: from ard and rbs to bpmn. Knowledge acquisition and management. Research Papers of Wrocław University of Economics 232 (2011) 41–49
9. Lübke, D., Schneider, K.: Visualizing use case sets as bpmn processes. In: Requirements Engineering Visualization, 2008. REV'08., IEEE (2008) 21–25
10. Weidlich, M., Decker, G., Großkopf, A., Weske, M.: Bpel to bpmn: The myth of a straight-forward mapping. (2008)
11. Lindsay, A., Dawns, D., Lunn, K.: Business processes – attempts to find a definition. Information and Software Technology 45(15) (Dec 2003) 1015–1019 Elsevier.
12. Mroczek, A., Ligęza, A.: A note on bpmn analysis. towards a taxonomy of selected potential anomalies. Number 2 in Annals of Computer Science and Information Systems, Polskie Towarzystwo Informatyczne (2014) 1097–1102
13. Szpyrka, M., Nalepa, G.J., Ligęza, A., Kluza, K.: Proposal of formal verification of selected bpmn models with alvis modeling language. In: Intelligent Distributed Computing V. Springer (2011) 249–255
14. Arevalo, C., Escalona, M., Ramos, I., Domínguez-Muñoz, M.: A metamodel to integrate business processes time perspective in bpmn 2.0. Information and Software Technology 77 (2016) 17–33
15. Trkman, M., Mendling, J., Krisper, M.: Using business process models to better understand the dependencies among user stories. Information and Software Technology 71 (2016) 58–76
16. Silver, B.: BPMN Method and Style, with BPMN Implementer's Guide: A structured approach for business process modeling and implementation using BPMN 2.0. Cody-Cassidy Press Aptos (2011)
17. Yousfi, A., Bauer, C., Saidi, R., Dey, A.K.: ubpmn: A bpmn extension for modeling ubiquitous business processes. Information and Software Technology 74 (2016) 55–68
18. Martinho, R., Domingos, D., Varajão, J.: Cf4bpmn: a bpmn extension for controlled flexibility in business processes. (2015)
19. Pillat, R.M., Oliveira, T.C., Alencar, P.S., Cowan, D.D.: Bpmnt: A bpmn extension for specifying software process tailoring. Information and Software Technology 57 (2015) 95–115
20. Kluza, K., Jobczyk, K., Wiśniewski, P., Ligęza, A.: Overview of time issues with temporal logics for business process models. In: Computer Science and Information Systems (FedCSIS), 2016 Federated Conference on, IEEE (2016) 1115–1123
21. Klimek, R.: Towards formal and deduction-based analysis of business models for soa processes. In: ICAART (2). (2012) 325–330
22. Freund, J.: Praxishandbuch BPMN: [inklusive BPMN 2.0]. (2010)
23. White S., M.D.: BPMN Modeling and Reference Guide. Future Strategies Inc. (2008)
24. Polančič, G.: Understanding BPMN Connections. (2013)
25. Kocbek M., Jošt G., H.M.P.G.: Business process model and notation : the current state of affairs. computer science and information systems. (2015)
26. Mendling, J., Verbeek, H.and van Dongen, B.v.d.A., W.M., Neumann, G.: Detection and prediction of errors in epcs of the sap reference model. Data Knowledge Engineering (64(1)) (2008) 312–329
27. Hallerbach, A., Bauer, T., Reichert, M.: Capturing variability in business proces models: the provop approach. Journal of Software

Maintenance and Evolution: Research and Practice (22(6-7)) (2010) 519–546
28. Group: 1044-2009-ieee standard classification for software anomalies. New York (2010)
29. Suchenia, A., Potempa, T., Ligęza, A., Jobczyk, K., Kluza, K.: Selected approaches towards taxonomy of business process anomalies. In: Advances in business ICT: new ideas from ongoing research. Springer, Cham (2017) 65–85
30. Borger, E.: Approaches to modeling business processes. Soft. Syst. Modeling11 (2012) 305–318
31. Corradini, F., Muzi, C., Re, B., Rossi, L., Tiezzi, F.: Global vs. local semantics ofbpmn 2.0 or-join. SOFSEM. LNCS, vol. 10706 (2018) 321–336
32. Corradini, F., Morichetta, A., Re, B., Tiezzi, F.: Walking through the semantics of exclusive and event-based gateways in bpmn choreographies. The Art of Modelling Computational Systems: A Journey from Logic and Concurrency to Security and Privacy, Essays Dedicated to Catuscia Palamidessi on the Occasion of Her 60th Birthday (2019)
33. Corradini, F., Muzi, C., Re, B., Rossi, L., Tiezzi, F.: Animating multiple instances in bpmn collaborations: from formal semantics to tool support. The Art of Modelling Computational Systems: A Journey from Logic and Concurrency to Security and Privacy, Essays Dedicated to Catuscia Palamidessi on the Occasion of Her 60th Birthday (2018)
34. Suchenia, A., Ligęza, A.: Anomalie w modelowaniu procesów biznesowych. Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska : IAPGOŚ (T. 7, Nr 2) (2017) 88–93
35. Suchenia, A., Ligęza, A.: Event anomalies in modeling with bpmn. International Journal of Computer Technology and Applications : IJCTA (Vol. 6, Iss. 5) (2015) 789–797
36. Suchenia (Mroczek), A., Wiśniewski, P., Ligęza, A.: Overview of verification tools for business process models. In Ganzha, M., ed.: Communication Papers of the 2017 Federated Conference on Computer Science and Information Systems, September 3-6, 2017, Prague, Czech Republic. Number 13 in Annals of Computer Science and Information Systems, Warszawa, Polskie Towarzystwo Informatyczne (2017) 295–302
37. Laue, R., Awad, A.: Visualization of business process modeling anti patterns. Electronic Communications of the EASST (25) (2009)
38. Kühne, S.and Kern, H., Gruhn, V. andLaue, R.: Business process modeling with continuous validation. Journal of Software Maintenance and Evolution: Research and Practice (22(6-7)) (2010) 547–566
39. Trcka, N., Van der Aalst, W., Sidorova, N.: Data-flow anti-patterns: Discovering data-flow errors in workflows. Advanced Information Systems Engineering (2009) 425–439
40. Lohmann, N., Wolf, K.: How to implement a theory of correctness in the area of business processes and services. Business Process Management (2010) 61–77
41. Saab, N., Helms, R., Zoet, M.: Predictive quality performance control in bpm: proposing a framework for predicting quality anomalies. Procedia Computer Science 138 (01 2018) 714–723
42. Wiśniewski, Piotr: Decomposition of business process models into reusable subdiagrams. ITM Web Conf. 15 (2017)
43. Kim, G., Lee, J.H., Son, J.H.: Classification and analyses of business proces anomalies. In: 2009 International Conference on Communication Software and Networks. (2009) 433–437
44. Leopold, H., Mendling, J., Günther, O.: What we can learn from quality issues of bpmn models from industry. IEEE Software 33 (03 2015)
45. Roy, S., Sajeev, A.S.M., Bihary, S., Ranjan, A.: An empirical study of error patterns in industrial business process models. IEEE Transactions on Services Computing 7(2) (2014) 140–153
46. Rozman, T., Horvat, R.: Analysis of most common proces modelling mistakes in bpmn process models. (01 2007)
47. Silingas, D., Mileviciene, E. In: Refactoring BPMN Models: From 'Bad Smells' to Best Practices and Patterns. (01 2007)
48. Rogge-Solti, A., Kasneci, G.: Temporal anomaly detection in business processes. In: BPM. (2014)
49. Mining, W.I.D.: Data mining: Concepts and techniques. Morgan Kaufinann 10 (2006) 559–569
50. Chandola, V., Banerjee, A., Kumar, V.: Anomaly detection: A survey. ACM computing surveys (CSUR) 41(3) (2009) 1–58
51. Böhmer, K., Rinderle-Ma, S.: Anomaly detection in business process runtime behavior - challenges and limitations. ArXiv abs/1705.06659 (2017)
52. Aalst, W.M.V.D., Weske, M.: "to interorganizational workflows". Seminal Contributions to Information Systems Engineering: 25 Years of CAiSE (2013)
53. White, S.: Process modeling notations and workflow patterns. (2004)
54. Olkhovich, L.: Semi-automatic business process performance optimization based on redundant control flow detection. Telecommunications,AICT-ICIW'06, IEEE (2006) 146–146
55. Lin, H., Zhao, Z., Li, H., Chen, Z.: A novel graph reduction algorithm to identify structural conflicts. Proceedings of the 35th Annual Hawaii International Conference on System Sciences (2002) 10 pp.– 56. Awad, A., Puhlmann, F.: Structural detection of deadlocks in business proces models. In: BIS. (2008)
57. Borgert, S., Mühlhäuser, M.: Formal based correctness check for epass-ios 1.1 process models with integrated user support for error correcting. Volume 170. (04 2014)
58. Gruhn, V., Laue, R.: A heuristic method for detecting problems in business proces models. Business Process Management Journal 16 (09 2010) 806–821
59. Han, Z., Gong, P., Zhang, L., Ling, J., Huang, W.: Definition and detection of control-flow anti-patterns in process models. In: 2013 IEEE 37th Annual Computer Software and Applications Conference Workshops. (2013) 433–438
60. Rech, J., Decker, B., Ras, E., Jedlitschka, A., Feldmann, R.L.: The quality of knowledge: Knowledge patterns and knowledge refactorings. IJKM 3 (2007) 74–103
61. Koehler, J., Vanhatalo, J.: Process anti-patterns: How to avoid the common traps of business process modeling. IBM WebSphere Developer Technical Journal 10(2) (2007) 4
62. Laue, R., Awad, A.: Visualization of business process modeling anti patterns. ECEASST 25 (01 2010)
63. Palma, F., Moha, N., Guéhéneuc, Y.G.: Specification and detection of business process antipatterns. Volume 209. (05 2015) 37–52
64. Roa, J., Chiotti, O., Villarreal, P.: Specification of behavioral anti-patterns for the verification of block-structured collaborative business processes. Information and Software Technology 75 (04 2016)
65. Roa, J., Reynares, E., Caliusco, M., Villarreal, P.: Ontology-based heuristics for process behavior: Formalizing false positive scenarios. (05 2017) 106–117
66. Onoda, S., Ikkai, Y., Kobayashi, T., Norihisa, K.: Definition of deadlock patterns for business processes workflow models. (01 1999)
67. Corradini, F., Fornari, F., Muzi, C., Polini, A., Re, B., Tiezzi, F.: On avoiding erroneous synchronization in bpmn processes. (05 2017) 106–119
68. Eid-Sabbagh, R.H., Dijkman, R., Weske, M.: Business process architecture: Use and correctness. (09 2012)
69. Liu, R., Kumar, A.: An analysis and taxonomy of unstructured workflows. Business Process Management, Springer (2005) 268–284
70. Roa, J., Reynares, E., Caliusco, M., Villarreal, P. In: Towards Ontology-Based Anti-patterns for the Verification of Business Process Behavior. (03 2016) 665–673
71. Koschmider, A., Laue, R., Fellmann, M.: Business process model antipatterns: A bibliography and taxonomy of published work. (2019)
72. Leopold, H., Pittke, F., Mendling, J.: Ensuring the canonicity of process models. Data Knowledge Engineering (2017)
73. Laue, R., Koop, W., Gruhn, V.: Indicators for open issues in business proces models. (2016) 102–116
74. Gruhn, V., Laue, R.: Detecting common errors in event-driven process chains by label analysis. Enterprise Modelling and Information Systems Architectures 6 (01 2011) 3–15
75. Becker, J., Weiß, B., Winkelmann, A.: Automatic identification of

structural process weaknesses - experiences with semantic business process modeling in the financial sector. (01 2011) 117
76. Gruhn, V., Laue, R.: Reducing the cognitive complexity of business process models. (06 2009) 339–345
77. Roa, J., Chiotti, O., Villarreal, P.D.: Detection of anti-patterns in the control flow of collaborative business processes. (2015)
78. Becker, J., Bergener, P., Räckers, M., Weiß, B., Winkelmann, A.: Pattern-based semi-automatic analysis of weaknesses in semantic business process models in the banking sector. (01 2010)
79. Eleftheriou, I., Embury, S., Brass, A.: Data journey modelling: Predicting risk for it developments. (2016)
80. Laue, R., Gruhn, V.: Good and bad excuses for unstructured business proces models. (01 2007) 279–290
81. Delfmann, P., Hubers, M.: Towards supporting business process compliance checking with compliance pattern catalogues. Volume Vol. 10, No. 1. (2011)
82. Ramadan, Q., Strüber, D., Salnitri, M., Riediger, V., Jürjens, J.: Detecting conflicts between data-minimization and security requirements in business process models. In: ECMFA@STAF. (2018)
83. Held, M., Blochinger, W.: Structured collaborative workflow design. Future Generation Computer Systems 25 (06 2009) 638–653
84. Breuker, D.: An empirical assessment of the usefulness of weakness patterns in business process redesign. (01 2012)
85. Becker, J., Ahrendt, C., Coners, A., Weiß, B., Winkelmann, A.: Modeling and analysis of business process compliance. Volume 366. (2011) 259–269
86. Lübbecke, P., Goswami, A., Fettke, P.: A method for ecological process optimization based on compliance checking. In: 2018 IEEE 20th Conference on Business Informatics (CBI). Volume 01. (2018) 119–128
87. Höhenberger, S., Delfmann, P.: Supporting business process improvement through business process weakness pattern collections. (2015)
88. Dohring, M., Heublein, S.: Anomalies in rule-adapted workflows-a taxonomy and solutions for vbpmn. Software Maintenance and Reengineering (CSMR), IEEE (2012) 117–126
89. Lig˛eza, A., Nalepa, G.: A study of methodological issues in design and development of rulebased systems: proposal of a new approach. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery (1(2)) (2011) 117–137
90. Xu, D., Xia, K.and Zhang, D., Zhang, H.: Model checking the inconsistency and circularity in rule-based expert systems. Computer and Information Science (2(1)) (2009)
91. Zaidi, A., Levis, A.: Validation and verification of decision making rules. Automatica (33(2)) (1997) 155–169
92. Awad, A., Decker, G., Lohmann, N.: Diagnosing and repairing data anomalies in process models. Business Process Management Workshops, Springer (2009) 5–16
93. von Stackelberg, S., Putze, S., Mülle, J., Böhm, K.: Detecting data-flow errors in bpmn 2.0. Open Journal of Information Systems (OJIS) 1(2) (2014) 1–19
94. Sadiq, S., Orlowska, M., Sadiq, W., Foulger, C.: Data flow and validation in workflow modelling. Proceedings of the 15th Australasian Database Conference (02 2004)

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