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Measurement in business processes: a systematic review

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Abstract

Purpose – The purpose of this paper is to analyze the current state of the art and trends with regard to business process measurement by means of a systematic review of literature.

Design/methodology/approach – The results are obtained through a systematic review carried out according to existing relevant guidelines. Additionally, a specific methodology through which to systematically obtain all the most important journals is followed. In total, 19 relevant articles are selected and later analyzed. A subsequent critical analysis of the data obtained is applied to identify the gaps in the current literature.

Findings – A considerable effort has been made by researchers in the field of business process measurement, particularly in recent years. Many of the defined measures for business processes have been applied to models (approximately 77 per cent). Most of the initiatives concerning business measurement have been adapted from the software engineering field. A small percentage of the existing business process measures has been empirically validated.

Originality/value – The results presented contribute towards providing an updated overview of the current state of research into business process measurement, in order to identify existing research gaps and concerns on which ongoing and future research efforts on this topic can be focused.

Keywords Business process re-engineering, Measurement, Process management, Research work

Paper type Literature review

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1. Introduction

Measurement has a long tradition and is a fundamental discipline in any type of engineering. Engineers must be skilled in estimation and measurement (Laird and Brennan, 2006), which implies:

- understanding the activities and risks involved in process development;
- predicting and controlling the activities;
- managing the risks;
- a reliable delivery; and
- proactive management in order to avoid crises.

The use of measurement information makes it possible for these organizations to learn from the past in order to improve performance and achieve better predictability over time. Measurement activities, therefore, provide a good means through which to obtain this information and also help us to plan and track improvement efforts, communicate goals and convey reasons for improving (Park *et al.*, 1996). The main goal of a software measurement process is to satisfy certain information needs by collecting quantifiable indicators. This implies to identify the entities and the attributes of these entities, which are quantified by means of the definition of measures (García *et al.*, 2005). Measures are, therefore, applied to these attributes and entities and objective information concerning the state of processes and products is eventually obtained. In our case, measurable entities are business processes since they generate most of the cost of any business. Improving efficiency in any organization therefore generally necessitates improving its processes. Business processes also strongly influence the quality of the product and customer satisfaction, both of which are of fundamental importance in the marketplace. Any well-engineered business process is one in which management establishes the measurements of process performance, and influences process performance in a desired direction by using these measurements to control the process (Powell *et al.*, 2001). These measurements are essential in organizations which intend to attain a high level in the capacity of their processes. It is, therefore, important to integrate measurement as a fundamental part in their business objectives in order to obtain more mature organizations (Sanchez *et al.*, 2009).

The relevant literature contains various interesting initiatives relating to business process measures, but each document proposes the measurement of different attributes of a business process. For instance, some authors propose understandability as the principal factor to be measured, while others propose complexity, and yet others reliability. This lack of consensus among authors with regard to measurable concepts is a disadvantage, and this systematic review will help to collect all existing initiatives in order to facilitate the ongoing and future research efforts on this topic which is currently not sufficiently mature. All the existing measurement initiatives must be classified if they are to be managed. In order to obtain the best classification, it is necessary to view a business process as a complex entity and to understand that developing one necessitates following certain stages. The most important aspects are the design and execution stages and these have, therefore, been classified into measures for business process modelling and execution. The first group has become highly significant in recent years, since high-quality conceptual-modelling plays an important role, making it possible to detect errors at an early stage and thus correct them (Wand and Weber, 2002). Furthermore, since the manipulation and redesign process is carried out in the design phase (Smith and Fingar, 2003), it would appear to be extremely important to collect objective information as it is possible that quality characteristics of process models could affect execution and, eventually, the product obtained. The second group (measures for business process execution) seeks customer satisfaction, and is, therefore, studied in depth by other sciences. In addition, other authors have classified these measures into measures based on software engineering and new approaches, owing to the similarities between a software application and a business process.

This systematic review has been carried out in order to classify the discovered measures into selected documents. Our objective is to discuss the significant issues concerning this topic and to provide an updated state-of-the-art overview, which can then be used to propose innovative research activities. A research methodology (explained in Section 2) is used for this purpose. Once the process had been completed, certain statistical information was obtained, which is shown in Section 3. Finally, the conclusions of this work are presented in Section 4.

2. A systematic review of business process measures

A systematic review is a research methodology which is developed to gather, evaluate and analyze all the available research relevant to a particular *RQ* or area of interest (Kitchenham and Charters, 2007). In contrast to a conventional review of literature, a systematic review follows a list of specific steps to ensure that we can obtain the most relevant studies with regard to a specific topic are obtained in an unbiased manner. This eventually ensures the fidelity, completeness and rigorous nature of the review. The principal disadvantage in carrying out this kind of review is the special effort which must be made to follow all the necessary steps. This is the price that must be paid for in-depth and complete research in an area of interest. We have followed the guidelines presented in Kitchenham and Charters (2007) and the protocol template presented in Biolchini *et al.* (2005, 2007). The following sections give a detailed description of these steps.

2.1 Question formulation

The *RQ* is:

RQ. What are the most current and useful initiatives with which to measure business processes?

The list of keywords used to find an answer to the *RQ* was: "business process", "business process model", "business process modelling", "business process enactment", "business process execution", "measure", "measurement", "metric" and "indicator".

This list of words has been collected by studying the advice of certain experts with regard to business process measurements. It is important to note that there are two groups of words. The first group describes words related to the elements to be measured, in this case business processes. The second group is concerned with terms related to measures, since not all researchers use the same terms to refer to techniques which quantify the goodness of measurable objects.

The expected result of this systematic review is the discovery of how many business process measures exist, what they consist of and whether or not these measures have been validated. Furthermore, we shall attempt to classify those measures with common characteristics. The population group observed was a set of proposals concerning measures in any given stage of the business process lifecycle.

2.2 Sources selection

A string search was obtained by taking the list of keywords shown above and making combinations with logical connectors such as AND, OR and NOT. This search string had to be adapted to each search engine of the respective sources:

> [. . .] ("business process" OR "business process model" OR "business process modelling" OR "business process enactment" OR "business process execution") AND ("measure" OR "measurement" OR "metric" OR "indicator").

The majority of the documents used to answer the *RQ*, and therefore carry out the systematic review, were found in the following list of sources:

- Science@Direct, on the subject of computer science;
- Wiley InterScience, on the subject of computer science;
- IEEE Digital Library;
- ACM Digital Library;
- Scopus, on the subject of computer science;
- Citeseer; and
- as grey literature, all the proceedings of the business process management conferences.

Some of these resources include important journals which deal extensively with our research area, such as: *Information Systems*, the *Journal of System and Software*, *Computers in Industry*, *International Journal of Software Engineering and Knowledge Engineering*, among others. Moreover, not every search engine allows the searcher to introduce the search string in its original form, and might at times return a very high number of relevant studies. These keywords should be included in the title, abstract or keywords of the paper.

2.3 Selection of studies

We propose that the criterion for carrying out this systematic review be based on Pino *et al.* (2008) who propose an iterative and incremental procedure: iterative because of the repetition of one or more activities such as looking for new articles, applying inclusion/exclusion criteria, etc. and incremental since, from the implementation of an initial subset of the sources, more and more complete subsets are added, until the whole review is completed. Each iteration leads to the growth and evolution of the definitive systematic review. Our inclusion criterion is based on the concept of only taking into consideration those studies whose principal subject is that of measurements through which to improve the quality of business processes. This implies that there are some measures which quantify the similarity between two models or the conformance between log files and models, among others. We are solely concerned with quality measures whose results describe the goodness of a business process as a means to improve organizations. The exclusion criterion is the non-inclusion of those studies

As Figure 1 shows, complexity is usually the most measurable concept used by authors (44 per cent). However, is important to remark that measurable concepts of Figure 1 have been reproduced exactly as authors stated them in their articles. However, the authors describe measures according to what they believe their measures quantify, and the majority of them do not follow any standard, or have previously performed a theoretical validation of the measures, which may lead to confusion. For example, some authors propose measures of complexity, but it would appear that they are actually quantifying understandability and/or changeability.

Other quality models exist, such as those proposed by Heravizadeh *et al.* (2008) or Guceglioglu and Demirors (2005). In our opinion, the most suitable is ISO 9126 since its proposed characteristics and sub-characteristics are closer to those proposed by authors of this paper. Membership to each subgroup of ISO 9126 is determined by following the detailed description of measures in the selected sources provided by authors. Table III shows the result of this classification, and Figure 3 shows the most measurable concepts used in defining measures for business processes, specifically, understandability and changeability. For more details, see Section 4.

Certain of these measures are independent of the modelling languages because they use only high-level information from the business process models. Other authors, i.e. Rolón *et al.* (2006), propose measures related to specific standard languages such as business process modeling notation (BPMN), and Mendling (2008) or Vanderfeesten *et al.* (2008b) use the event-driven process chain (EPC) language for business process representation. Researchers into business process measurement usually work with certain specific notations, such as those shown in Figure 4. These measures are those which are most widely used in the measurement research community.

A further important classification concerns new and measurement initiatives based on software engineering. Most of the measures concerning software applications could be applied to business processes (approximately 89 per cent) owing to the parallelism that exists between them. Some authors have discovered these similarities and have been able to adapt measures for software applications to a business process. Other initiatives are created exclusively for business processes (exactly 11 per cent).

However, as was mentioned in Section 1 measurement in business processes is a relatively new topic of research. After analyzing all the selected documents, we discovered that its study is very recent, especially in the last three years. Measures for business process models have also been studied in recent years. For more specific information, see Figure 5 which shows the number of initiatives and the year of their publication.

Further extracted information is based on validation, since this is one of the most important aspects in describing a measure owing to the fact that experimentation helps to determine the effectiveness of proposed theories and methods (Zelkowitz and Wallace, 1998). It is possible to validate measures theoretically and/or empirically. The main objective of a theoretical validation is to demonstrate that the specific measure quantifies the attribute that it wishes to measure (Briand *et al.*, 1996). This means that the measurable attribute is reflected in the measure. Empirical validation, however, verifies the practical utility of the proposed measures. Empirical validation takes place through the use of experiments, case studies or surveys in a real context.

In this systematic review, it was considered key to examine if related works with measures proposals also included theoretical or empirical validation. Tables AI-AIII show the absence or presence of validation in the studied sources. However, some which are not focused on describing measures in detail, i.e. certain initiatives which present the measure but do not describe how to calculate it.

The application of the defined search protocol led to the discovery of various studies in the first phase of the search. The results obtained are shown in Table I. This table describes search engines by date of search, years covered by search, number of documents discovered, number of relevant documents, how many relevant documents are not repeated and, finally, primary studies. We consider repeated documents to be those which belong to the same line of research and do not contribute new ideas.

It is possible that certain papers of interest were not obtained from our principal sources (ACM, Citeseer, etc.) as a result of the limitations of the search string, since the studies were not directly related to our principal topic or because they were not indexed in the most used sources. To complete the search, in the second phase, we have included some studies from the references of those papers obtained in the first phase. This is shown in Table II.

2.4 Study quality assessment checklist

Having obtaining certain documents regarding business process measures, quality information was then extracted from them, i.e. a "detailed description" of a business process measures in inclusion criteria. The software measurement ontology (SMO) by García *et al.* (2005) was used to define the detailed description structure of a business process measure. This ontology establishes all the terms, their definitions and the relationships between them in order to avoid ambiguity which may lead to errors,

Name	Date of search	Years covered by search	Discovered	Relevant	Relevant not repeated	Primaries
Science@ Direct	15 September 2008	1998-2008	37	1	1	1
ACM	16 September 2008	1947-2008	7	2	2	2
Scopus	17 September 2008	1960-2008	30	6	3	3
Wiley InterScience	18 September 2008	1799-2008	7	0	0	0
Citeseer	18 September 2008	Unknown	10	6	4	4
Google Scholar	18 September 2008	Unknown	11	1	1	0
IEEE	19 September 2008	1960-2008	200	4	2	2
BPM Congress	19 September 2008	2000-2008	4	4	4	3
Results			306	23	17	15

Table I.
Distribution of studies by source in the first phase

Table II.
List of studies obtained from references in the second phase

ID source document	New articles discovered	Not repeated	Primaries
S18 (Ghani *et al.*, 2008)	2	2	2

a lack of understanding and unproductive efforts caused by the diversity of the terminology concerning measurement in software engineering. The SMO is composed of four sub-ontologies:

(1) *Characterization and objectives.* The main goal is to satisfy certain information needs by identifying entities and the attributes of those entities.

(2) *Software measures.* These aim to establish and clarify the key elements in the definition of a measure.

(3) *Measurement approaches.* These introduce the concept of the measurement approach to generalize the three different approaches in order to obtain a result: measurement method, a measurement function and an analysis model.

(4) *Measurement.* This establishes the terminology related to the act of measuring, and includes the result of performing measurements.

In accordance with the SMO, in order to extract and structure the most useful information concerning business process measures proposals, the following questions were stated:

- *Q1.* What is the measurable concept?
- *Q2.* What attribute of the entity class business process is measured?
- *Q3.* What kind of measure is it?
- *Q4.* Are measures empirically validated?
- *Q5.* What is the measurement approach?

2.5 Data-extraction process

The previous questions assisted us in our attempts to discover what kinds of measures exist. Elements of the SMO attempt to describe all the necessary attributes that all the measures must have. Tables in Section 4 show all the initiatives that were selected after following the review protocol, along with answers to questions with which to prove the correct quality of measures.

These tables show only the primary studies since it was not possible to obtain new information from the secondary studies. The primary studies are identified with the letter "P" and a number and the secondary studies with the letter "S".

3. Results and discussion

The information in which we were interested was extracted from the business process measure sources. The business process measure initiatives were then classified in two different categories: measures for business process models and execution. This classification is related to the research of Tjaden (1999). We believe that measures are usually applied to basically two aspects of a business process model: the business process design or the results that it produces when executed. Design measures deal with the static properties of business processes and are defined upon the business process model at the time of its design. Measures in the design stage can be used to improve a business process in the early stages of its lifecycle, thus facilitating the correction of possible errors. Execution measures quantify how the process is executed over time and are directly related to the dynamic properties of business processes. Measures concerning this execution can be used to compare these results with the expected results and thus improve the business process in order to achieve customer satisfaction. Approximately, 77 per cent of the initiatives studied concern business process model measures. The principal reason for this could be the usefulness of models. As Dufresne and Martin (2003) state, business process modelling eases the understanding of the key mechanism of an existing business, serves as the basis for the creation of appropriate information systems that support the business, improves the current business structure and operation, shows the structure of an innovated business, identifies outsourcing opportunities and facilitates the alignment of business specifications with the technical framework that information technology (IT) development needs. This classification in two groups (modelling and execution) was the first step towards organizing all the measures found. The following step was to classify the measures according to the measurable concept they are related to. Figures 1 and 2 show the measurable concepts for business process models and execution based on author criteria.

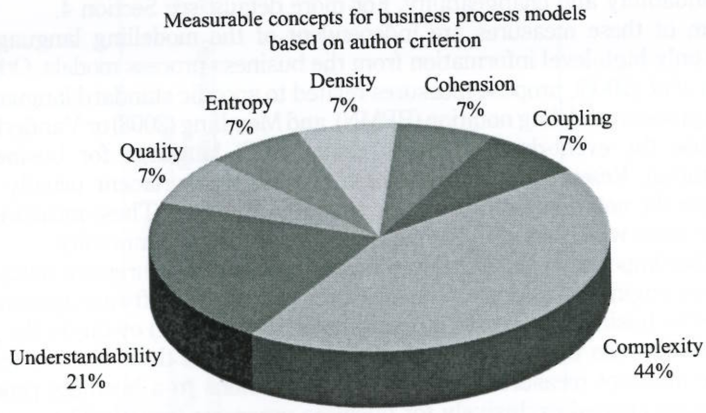

Figure 1.
Measurable concepts of business process models

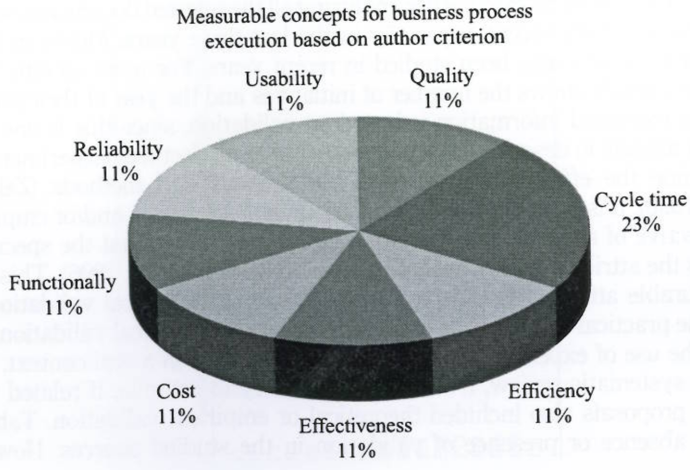

Figure 2.
Measurable concepts of business process execution

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Table III.
Measurable concepts by ISO 9126 related with selected sources

	ISO 9126																
	Functionality					Reliability			Usability			Efficiency		Maintainability			
P	Suitability	Accuracy	Interoper-ability	Compliance	Security	Maturity	Fault tolerance	Recover-ability	Understand-ability	Learn-ability	Operability	Time behavior	Resource behavior	Analyzability	Change-ability	Stability	Test-ability
P1									X						X		
P2												X	X				
P3									X						X		
P4									X								
P5									X						X		
P6		X									X		X				
P7									X						X		
P8									X						X		
P9									X								
P10												X	X				
P11									X								
P12	X																
P13									X						X		
P14									X								
P15									X						X		
P16	X						X	X	X								
P5		X														X	

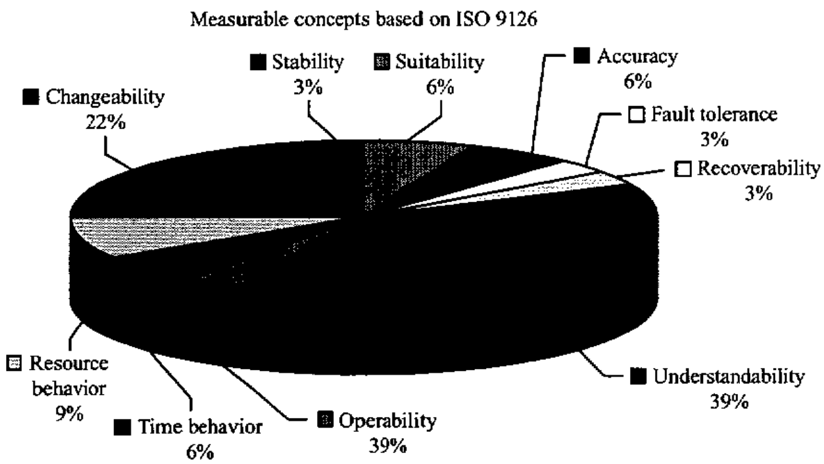

Figure 3.

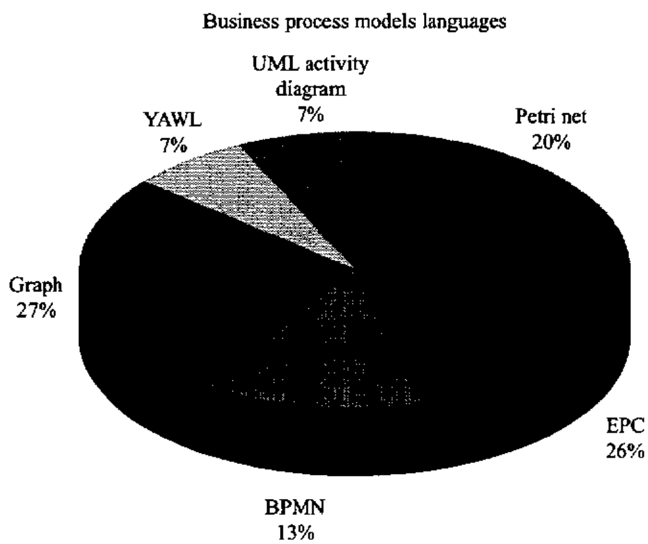

Figure 4.
Most used languages in measurement researching community

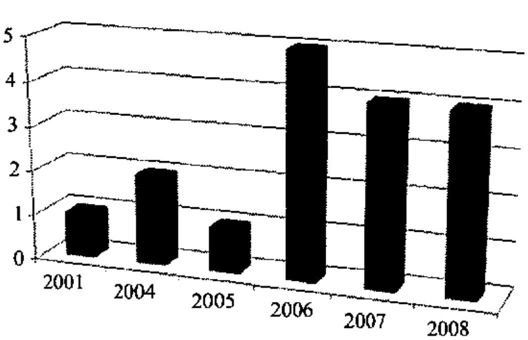

Figure 5.
Number of initiatives for business process measurement and year of publication

important principles must be considered when theoretical or empirical validation of measures is conducted, specially a clear and right specification of the hypotheses and/or prediction systems (Fenton, 1994). The analysis of these principles fulfilment in selected studies was beyond the scope of the current systematic review.

Most of the sources found do not make any specific reference to validity, so we do not consider that any validation activity has been carried out. An empirical or theoretical validation has only been considered when it is explicitly specified in the selected work or in other referenced work when the scope of the selected work does not permit more details. After analyzing all the sources found concerning validation, we reached the following conclusions, which are shown in Table IV.

As Table IV shows, there is a relatively low percentage of empirical validation of the proposed measures (only 35 per cent of the initiatives). However, in the majority of those initiatives which included empirical results validation was not even mention as a task to be carried out in order to build the measures. Of the authors, 24 per cent discuss validation as a future work, but do not provide any empirical results (more details are provided in the Appendix).

This leads us to the conclusion that there is a significant tendency to create measures without any empirical support and that these measures are probably not used in organizations. According to these results, more future research efforts should be made in the empirical validation of existing proposals rather than in defining new measures without empirical support which will be more prone to failure.

4. Conclusions

Business process measures are of great importance in business process management because they help to control, estimate and improve processes and therefore organizations. This systematic review attempts to provide the state-of-the-art in business process measurement in a controlled search process and has led to the following results:

- In recent years, measures for business processes have been applied to models because they are easier to maintain and help to avoid the appearance of certain errors in early stages of the lifecycle.
- Most of the initiatives concerning business measures are based on software engineering. This is as a result of the high number of similarities that exist between software applications and business processes, which has led the majority of researchers to adapt software measures to business processes.
- According to author opinion, the subject which is most researched in the measurement community is measurable concept complexity. This concept

Table IV. Information concerning validation of business processes

Validity	%
No validated	59
No sign of validating	35
Validation in future works	24
Validated	41
Theoretically	6
Empirically	35

appears to be the most important because it is directly connected with understandability or changeability. These are the basic activities to ensure that models are useful for communication between stakeholders and that business processes are in a state of continuous improvement. Moreover, according to the ISO 9126 classification, these two characteristics are those which are most frequently used to define measures.

- No important measurable concept for business process execution measures exists and very few initiatives concerning these measures exist either. This may be because the results of business process execution have been studied in other sciences which are more closely related to business, although they have not been studied in computer sciences.
- A recent growth has taken place in the research related to business process measures because researchers have discovered the importance of measuring processes in order to improve the entire organization. In recent years, many papers concerning business process design measures have been published.
- We believe that lack of measurement validation is important. Most authors do not place importance upon validating activities and do not even mention them in their documents. This indicates that there is no real use of the measures in organizations, since most of the initiatives are theoretical and have never been used in a real environment.

Finally, for future work, it would be interesting to offer support to all of the measures analyzed through the use of an integrated framework which would allow organizations to apply them in a real context. The aim is to use validated measures by following the measurement guidelines of maturity models in order to obtain more mature organizations.

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Appendix

The extracted information from selected sources is shown in Tables AI-AIII.

About the authors

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Table AI. Measures for business process modeling

Measurable concept by ISO 9126	Q2	Q3	Q4	Q5
P1 (Vanderfeesten et al., 2008a)				
Changeability and understandability	Operations of activities in a business process model	Derived measure	This measure has been applied to some examples, but there is no empirical/ theoretical validation	Cohesion measures are calculated as follows: activity cohesion $c(T) = \lambda(T) \times \mu(T)$ where $T = (t, e)$ on operation structure (D, W, O). $t = (p_1, w_1, cs_1)\cdots(p_n, w_n, cs_n)$ and e is a resource that allows the activity to be executed: $\lambda(T) = \begin{cases} (\lvert((p_1, cs_1), (p_2, cs_2))\varepsilon\lvert T \times T\lvert((p_1 v cs_1) \cap (p_2 v cs_2)) \neq \emptyset \wedge p_1 \neq p_2\rvert)/\lvert T\rvert, & \text{for } \lvert T\rvert 1 \\ 0, & \text{for } \lvert T\rvert < 1 \end{cases}$ (1) $\mu(T) = \{ (\lvert d\varepsilon D\rvert \exists((p_1, cs_1), (p_2, cs_2))\varepsilon T)(d\varepsilon((p_1 v cs_1) \cap (p_2 v cs_2)) \wedge (p_1 \neq p_2))\rvert)/\lvert T\rvert \quad \text{for } \lvert T\rvert > 0$ (2) Process cohesion is defined as follows, where a process consists of a set of activities (S): $\text{ch} = (\sum_{(t\varepsilon S)} c(t))/\lvert S\rvert$
Changeability and understandability	Information between activities in a business process model	Derived measure	This measure has been applied to some examples, but there is no empirical/ theoretical validation	Coupling measures are calculated as follows: for a process that consists of a set of activities (S) on the operations structure (D, W, O): $\text{cp} = \begin{cases} (\lvert(T_1, T_2)\varepsilon S \times S\lvert T_1 \neq T_2\rvert \wedge (T_1 v T_2) \neq \emptyset\rvert)/(\lvert S\rvert \times (\lvert S\rvert - 1)), & \text{for } \lvert S\rvert > 1 \\ 0, & \text{for } \lvert S\rvert \leq 1 \end{cases}$ (3)
P3 (Rolón et al., 2006)				
Changeability and understandability	All the elements of which a business process model expressed in BPMN can be composed	46 base measures and (37 counting flow objects, two connecting objects, two swimlane objects, and two artifact objects) and 14 derived measures	These measures are validated based on Briand *et al.* (1996) theoretical framework and empirically based on Ciolkowski *et al.* (2002), Perry *et al.* (2000), Wohlin *et al.* (2000), Juristo and Moreno (2001) and Briand *et al.* (1995)	To illustrate the proposed measures in this study, let us consider some to them. See also, Rolón *et al.* (2006) for more detail. For example, total number of tasks (TNT) = NT + NTL + NTMI + NTC, where NT is the number of tasks, NTL is the number of loop task looping, NTMI is the number of task multiple instances and NTC is the number of task compensation

(continued)

Table AI.

Measurable concept by ISO 9126	Q2	Q3	Q4	Q5
P4 (Vanderfeesten et al., 2008b)				
Understandability	Relationships between elements of a business process model	Derived measure	This measure has been empirically validated using experiments with statistical techniques, as a multivariate regression model	Cross-connectivity measures are calculated as follows: let a process model be given by a set of nodes (N) and a set of directed arcs (A), then $CC = (\sum(n_1, n_2 \varepsilon N) V(n_1, n_2))/(\lvert N\rvert \times (\lvert N\rvert - 1))$
P5 (Cardoso, 2007)				
Understandability and changeability	Elements of a business process described as workflow patterns	Derived measure	There is no evidence of validation	Calculating log-based complexity depends on the workflow pattern. This measure is divided into four parts: measure for sequence pattern, for exclusive choice and deferred choice, interleaved parallel routing and, finally, for arbitrary cycles loops. More details in Cardoso (2007)
P15 (Cardoso, 2006)				
Understandability and changeability	XOR-split, OR-split and AND-split structures of a business process model	Derived measure	The proposed measure is empirically validated with experiments based on Perry *et al.* (2000)	$CFC(P) = \sum_{i \varepsilon XOR-split of P} CFC_{XORsplit}(i) + \sum_{i \varepsilon OR-split of P} CFC_{ORsplit}(i) + \sum_{i \varepsilon AND-split of P} CFC_{ANDsplit}(i)$
P7 (Latva-Koivisto, 2001)				
Understandability and changeability	Elements of a business process represented as a graph	Derived measures	Authors say that in future works they will work on validation of their measures. Since 2001, there have been no publications concerning this	There are some measures concerning complexity in a graph: (a) coefficient of network complexity as Kaiman. A is number of arcs and N number of nodes: $CNC_k = (A^2/N)$; (b) coefficient of network complexity as Pascoe $CNC_p = (A/N)$; (c) cyclomatic number as Temperley $S = A - N + 1$; (d) restrictiveness estimator, where r_{ij} is an element of reachability matrix $\mathbf{RT} = (2 \times \sum r_{ij} - 6(N-1))/((N-2)(N-3))$; and (e) number of trees in a graph, where D_{ij} is the elements of the adjacency matrix of the graph $T = \sum(i \varepsilon \text{Sinknodes}) D_{ij}$

Measurable concept by ISO 9126	Q2	Q3	Q4	Q5
P17 (Jung, 2008)				
Accuracy and stability	All the elements in a business process models	Derived measures	The proposed measures have not been validated	Entropy measures the uncertainty or variability of workflow process models. It is measured as follows: $H(x) = -K\sum_{i=1^n} p(x_i)\log_2 p(x_i)$, where x is a discrete random variable taking possible states $x_1, x_2, \ldots, x_n$ with probabilities $p(x_1), p(x_1), \ldots, p(x_n)$, the constant K is merely the choice of measurement unit
P8 (Gruhn and Laue, 2006b)				
Understandability and changeability	Graphic elements of a business process independent of the notation	Derived measures	Validation of the proposed metrics in a case study is beyond of the scope of the document and must be carried out in future research	The adapted measures were: (a) number of activities; (b) max/mean nesting depth, which provides information about structure; (c) number of handles, which measures well-structureness; (d) antipatterns, which counting the usage of antipatterns for detecting a poor model; and (e) fan-in/fan-out, which indicates poor modularization
P9 (Neumann and Mendling, 2007)				
Understandability	Elements of a business process model	Derived measures	The proposed measure will be validated in future works. A book about validation has been published in 2008 (Mendling, 2008)	It is divided into six measures: (a) size is $S_N(G) = \|N\|$, where N is number of nodes; (b) separability is $\Pi(G) = (\|n \epsilon N \| n - \text{is} - \text{cut} - \text{vertex}\|)/(\|N\| - 2)$; (c) sequentiality is $\Xi(G) = (\|a \epsilon A \| a \epsilon (T \times T)\|)/\|A\|$; (d) structureness is $\Phi_N = 1 - (S_N(G'))/(S_N(G))$; (e) cyclicity is $CYC_N = \|N_C\|/\|N\|$, where N_C represents nodes on a divided cycle; and (f) parallelism is $TS(G) = \sum(c \epsilon C_{or} v C_{and})d(out)(n) - 1$ where C_{or} and C_{and} represent new threads of control as "and" and "or" splits, and d(out) is number of the output degree
P10 (Vitolins, 2004)				
Time behavior	Results in time of the execution of the process	Base measure	This research is not continued and the selected document does not speak about validation	It is calculated by counting the number of seconds the process takes to finish its execution
Resource behavior	Cost related with the prize of the execution of the process	Derived measure	This research is not continued and the selected document does not speak about validation	Cost = 2 EUR/hour × processingTime

(continued)

Table AII.
Measures for business process modeling

Table AII.

Measurable concept by ISO 9126	Q2	Q3	Q4	Q5
P11 (Mendling et al., 2007)				
Understandability	Elements of a business process model independently of the notation	Derived measure is density, the remaining measures are base measures	In this selected documents, the authors speak about empirical validation using one experiment, without replication and using some statistical techniques, as a multivariate regression model	Density = (n arcs/nodes), average connector degree: number of input/output arcs of a routing element, mismatch: degree and summed up per routing element, and connector heterogenity: degree to which routing elements of different types appear in a model
P12 (Huan and Kumar, 2008b)				
Suitability	Badness score of the business process model	Derived measure	Validation of this measure is explained in another referenced document (Huan and Kumar, 2008a). Initial results are quite promising	Badness score is calculated as follows: $$B(n) = \begin{cases} (1 + W_1 \times \mathrm{op}(n) + W_2 \times \mathrm{sl}(n)) \times (B(n_1) + B(n_2)), & n \text{ is a block} \\ (1 + W_1 \times \mathrm{op}(n) + W_2 \times \mathrm{sl}(n)), & n \text{ is a task} \end{cases} \quad (4)$$
P13 (Mendling, 2006)				
Understandability and changeability	Density of elements in a workflow net, in a yawl net and in an EPC model	Derived measures	Authors comment on an experiment, but no details are given	Density is calculated as follows: (a) for a workflow net, where P is a set of places, T is a set of transitions, and A is a set of arcs $\mathrm{d}w = \lvert A\rvert/(\lvert P\rvert \times \lvert T\rvert + \lvert T\rvert \times \lvert P\rvert)$; (b) for a yawl net, where C is a set of conditions, T a set of tasks and A is a set of arcs $\mathrm{d}y = \lvert A\rvert/(\lvert C\rvert \times \lvert T\rvert + \lvert T\rvert \times \lvert C\rvert + \lvert T\rvert \times \lvert T\rvert)$; and (c) for a EPC, where E is a set of events, F is a set of functions, C is a set of connectors, $a_{\min} = n - 1$, $c_{\max\ \mathrm{even}} = ((c/2) + 1)^2$, $c_{\max\ \mathrm{odd}} = (((c-2)/2) + 1)^2 + ((c-1)/2) + 1$ then $d_{\mathrm{even}} = (a - a_{\min})/(c_{\max\ \mathrm{even}} + 2 \times (e + f) - a_{\min})$ and $d_{\mathrm{odd}} = (a - a_{\min})/(c_{\max\ \mathrm{odd}} + 2 \times (e + f) - a_{\min})$
P14 (Gruhn and Laue, 2006a)				
Understandability	Elements of a business process model	Base measure	The proposed measures will be validated in future works	The cognitive complexity is calculated as follows: $\mathrm{CC} = \sum \mathrm{cw}_i$, where cw_i is the cognitive weight of all the elements of a business process model

Table AIII. Measures for business process execution

Measurable concept by ISO 9126	Q2	Q3	Q4	Q5
P2 (Korherr and List, 2007)				
Time behavior and resource behavior	Time of execution of a business process	Base measure	There is no evidence of validation	Waiting time is the time the process instance has to wait for further processing and working time represents the actual time a business process instance is being executed by a role
P6 (Aversano et al., 2004)				
Resource behavior	Total cost of execution, cost of resources and final productivity of the execution of the process	Derived measures	The proposed measures have been empirical validation using a case study applied in a department of public Administration in Bevento (Italy)	Efficiency is divided into cost and productivity. It is measured as follows: total cost of the process is $C = \sum j = 1(n^A)C_j^H + C_j^{SW} + C_j^{HW} + C_j^{Or}$, where $C_j^H = \sum i = 1 (n_j^H) c_{ij}^H n_{ij}^H t_{ij}^H$, $C_j^{SW} = \sum i = 1(n_j^{SW} c_{ij}^{SW} n_j^{SW} t_{ij}^{SW})$, $C_j^{HW} = \sum i = 1(n_j^{HW}) \times (c_{ij}^{Or} n_{ij}^{Or} t_{ij}^{Or})$, and H is "human", SW is "software", HW is "hardware", C is cost, n is number and t is allocation time. On the other hand, productivity of the process is calculated as $P = (\sum j = 1(n^A)P_j)/n^A$, where $P_j = (\sum i = 1(n_{out})P_{ij})/nout_j$, $P_{ij} = (nout_{ij}/tout_{ij}) \times complout_{ij}$. $nout_{ij}$ is number of output categories produced by activity j, $tout_{ij}$ is production time of the output of category i produced by activity j, and $complout_{ij}$ is complexity of the output of category i produced by activity j
Accuracy and operability	User satisfaction, staff satisfaction, process adequacy from the staff point of view, and quality from the point of view of the end-user	Base measures	The proposed measures have been empirically validated using a case study applied in a department of public Administration in Bevento (Italy)	User satisfaction is measured according to five dimensions: tangibility, reliability, responsiveness, assurance and empathy (Zeithalm, 1990). Process adequacy from the staff point of view is measured by verifying the existence of standard rules and guides of applications of the process activities and quality from the point of view of the end-user is based on the ISO quality model

(continued)

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  Harrow, R. (2005), *No Place to Hide*, Simon & Schuster, New York, NY.
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