A concept to develop and operationalize a ranking of business process model metrics in the context of predictive process monitoring

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***Abstract* —** Predictive process monitoring is a subject of a growing interest in academic research and industry. The current status is a poor comparability and comprehensibility due to a high complexity in this research area. To tackle this issue, the paper at hand proposes a concept to establish a benchmark using a ranking of business process model metrics. The aim is to reduce the lack of understanding and further increase the probability of a positive prediction outcome. In order to address the issues, the concept has to identify and categorize business process model metrics, provide a ranking of business process model metrics, introduce an integrated approach in the existing framework and finally propose a solution approach of how the concept can be operationalized.

I. Introduction

Business process monitoring is a central component in business process management to improve the performance of organizations. Traditional process monitoring methods combined with the availability of process execution data provide managers and analysts with an overview of the current performance and thus establish a way to intervene accordingly. Next to traditional process monitoring techniques - which only provide a snapshot of the current performance - a growing interest in the prediction of process outcomes has led to the emergence of predictive process monitoring (PPM) [8], [14], [17]. In recent years, organizations and researchers exploit prediction models in order to improve process performance and mitigate risks [11]. There are many scenarios where it is useful to have reliable process predictions, such as predicting compliance violations [3], the remaining sequence of activities [5], [12], or the remaining execution time of a case [4], [10]. Due to the high complexity in this research area, a wide range of different experimental setups and methods exists. Meaning that researchers have used different prediction models, data sets, domains or prediction goals.

The objective of this paper is to improve the comparability and comprehensibility of experimental setups by proposing a concept to establish a ranking for business process models characteristics in the context of PPM and further make the ranking accessible in an intuitive and easy way. The motivation hereby is to establish a benchmark using business process models metrics in future work.

The remainder of the paper is organized as follows: The second section describes the framework of PPM and what role business process models play. Section three points out the research problem, followed by the research methodology in section four. In section five the concept gets introduced in detail which identified four academic contributions in order to develop and operationalize a ranking of business process model metrics in the context of PPM. Finally, the last section summarizes the academic contribution of this paper and discusses future work.

II. Research Area

The PPM methodology aims to predict the future of quantifiable values during a running process execution [6], [11]. The core of every experimental PPM setup is to build an accurate prediction technique. In the research field of PPM, the frameworks proposed by [7], [8] are commonly used when performing experiments. In general, the methodology can be divided into two steps: training and runtime as visualized in figure 1.

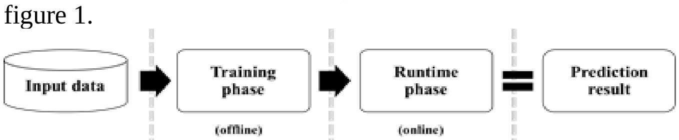

Fig. 1 Experimental setup for predictive process monitoring

In the training phase, the prediction model is built from finished (offline) input data. The technical format of input data consists either of event streams or event logs. Regardless of the technical format, the main input data for PPM methods are finished traces, which further can be classified according to [5] in four different perspectives: the control-flow perspective (concerns the order and relation of activities), the data-flow perspective (concerns the data attributes attached to events), the time perspective (concerns various types of duration such as service times, flow times, waiting times) and the resource/organization perspective (concerns the resource executing the event or corresponding activity). Depending on the used prediction model it is not necessary to provide all input data perspectives for training. For example, [7] differentiates between process-aware and non-process aware prediction models. Approaches that are process-aware consider the control-flow perspective as input data explicitly whereas methods that are non-process aware consider the control-flow perspective implicitly. In this paper, only approaches that are process-aware will benefit from the ranking of business process model characteristics. However, after identifying the input data it is necessary to describe an encoding to prepare the relevant information to finally use the manipulated data to train the prediction model. Further, the type of prediction model specifies the type of prediction outcome assessment: in case of classification methods, classification measures such as precision are used. In case of regression methods, regression measures such as root-mean squared error are commonly used. In the second phase, the trained prediction model exploits data corresponding to running and unfinished (online) traces to predict the outcome during runtime [6]. Based on the prediction result, the idea is to enable the business to proactively improve process performance and mitigate risks [10].

III. RESEARCH PROBLEM

As shown in section two, business process models can play a crucial role in the area of PPM. To consolidate the need of business process models in the context of PPM a broad literature review of experimental setups was conducted in [13]. As a result, the field of use and the associated research gaps are identified. One key gap is the lack of understanding how and to what extent the technical structure of business process models affects the prediction outcome. There is currently no consensus on how to use business process model metrics as a benchmark to ensure comparability and understandability although different authors have already used different metrics for business process models in different constellations. These observations strengthen the need of a concept to develop and operationalize a ranking of business process model metrics and establish a generic benchmark. To do so, the concept addresses the following research questions in this paper:

1. ***Research question (RQ1):*** How to identify and categorize relevant business process model metrics?
2. ***Research question (RQ2):*** How to rank business process model metrics in the context of prediction outcome?
3. ***Research question (RQ3):*** How to embed the ranking of business process models in the framework of predictive process monitoring?
4. ***Research question (RQ4):*** How to operationalize metrics as an incremental software approach?

Consequently, the concept aims to quantify what, how and to what extent business process models can affect prediction outcomes and how the concept can be publicly available. In other words, the goal of the project is to move the state of the art in the use of business process model metrics as a benchmark from ad-hoc approaches to a universal solution to support researchers and practitioners in the context of PPM.

Beside the presented research questions, the analysis of the area of research reveals an early stage of development and is accordingly connected to many challenges. In order to meet these challenges, limitations are formulated. The first limitation stems from the fact that due to a high complexity a wide range of different experimental setups and methods exists. This results in a huge possible combination of different prediction models, amount of available data, quality of data, manipulation of data and types of prediction outcome. By following the goal to generate a ranking based on business process model metrics, the information is provided but excluded in drawing scientific conclusions despite having the awareness those factors play an important role. Moreover, explaining the reason for the degree of impact of each metric is strictly limited to the observation during the experiment and the formulation of possible hypotheses. Finally, despite the limitations considering resources such as time, a degree of generalizability is given which then can be used as a springboard to suggest future research.

IV. RESEARCH METHODOLOGY

In line with the research problem, the solution approach will be verified by using, on the one hand, a qualitative strategy and, on the other hand, the design science method by creating a software artefact. The qualitative strategy can be divided into two steps. First, a set of business process model metrics gets identified by conducting a literature review. Secondly, an experimental setup is introduced to rank the metrics based on their impact in the context of prediction outcome. Finally, the results will be devised and operationalized in a software prototype that follows the design science research method, since the listed contributions cover design aspects [7].

V. SOLUTION APPROACH

To address the research questions, the paper proposes a solution approach for each research question. In the first step of the concept, business process model metrics are identified and categorized in a standardized way. Further, an experimental concept to rank business process metrics based on their impact on prediction outcome is proposed. Afterwards a solution approach to embed the ranking into the existing PPM framework gets proposed. Lastly, to make the ranked metrics publicly available, the idea of the concept is to consolidate the academic contributions into a web-based business process model metric suite. In summary, the ranking of business process model metrics will be quantified and then operationalized in a web-based metric suite that allows researchers and practitioners to receive assistance in a generic manner. In the following, a detailed description is proposed on how to answer the identified research questions.

A. RQ1 - How to identify and categorize relevant business process model metrics

The need for comparability and comparison in regard of business process models in the context of PPM has been pointed out in [13]. The results further underline the scientific need to develop a ranking of business process model metrics. To propose a ranking, the first step is to identify and categorize business process model metrics. Business process model metrics have to fulfill the following criteria in order to be perceived as relevant:

- *Calculability* - The execution of the metric should lead in finite time to a result
- *Implementation* - The metric should be implementable with reasonable effort
- *Repeatability* - Metric measurement results must be repeatable regardless of the person performing or the executed software tool
- *Automation* - The metric must be executable in an automated way
- *Comprehensibility* - The metric is easy to understand

After conducting a literature review, including 48 papers, and applying the mentioned criteria, 16 metrics are identified and assigned to five categories. The result of answering RQ1 is shown in the following table.

TABLE I

BUSINESS PROCESS MODEL CATEGORIZATION & METRICS

CATEGORY	METRICS
Size	Number of activities (NOA), Number of activities and control-flow elements (NOAC), Coefficient of Network Complexity (CNC), Density
Structure	Separability, Sequentiality. Diameter
Operators	Maximum nesting depth, Average degree of connectors, Maximum degree of connectors, Binary decisions, Control flow complexity (CFC), Concurrency
Cycle	Cyclicity, Cyclomatic Number
Cognitive weight	Cognitive weight

The first category *Size* includes all metrics that concern the physical size of how big a business process model is. A classic example is the simple counting of graphical elements in different combinations such as NOA or NOAC. By taking the prediction outcome into account, the hypothesis is that bigger business process models have a greater impact in influencing the prediction outcome. Thus, several papers point out that *Size* is an important factor for the comprehensibility and comparability of software and business process models [1], [2], [6], [15]. Because *Size* alone doesn't matter, the category *Structure* gets introduced as a generic term that refers to any metric that focuses on the arrangement of graphical elements to each other. Consequently, *Structure* measures the depth or sequentiality of a business process model based on single graphical elements. It is hypothesized that business process models with greater depth or a low sequentiality are more difficult to predict because the number of available tracks is assumed to influence the prediction outcome. The third category *Operator* refers as a generic term to all metrics that relate to the relationship between logical operators and their relationship among them. In the context of prediction, the hypothesis is that business process models with a great amount or variety in regard of operators can indicate a negative effect on the prediction outcome. The category *Cycle* presents all metrics of the business process model which focus on repetition of graphical elements. Cycles are presumably more difficult to understand than sequential parts. Consequently, it is assumed that a high occurrence of cycles affects the prediction outcome in a negative way. Finally, the last category *Cognitive weight* examines the process model by graphical elements on how information is understood. It is assumed that a high *Cognitive weight* has a negative impact on the prediction outcome because of an increase in complexity which may is directly connected to the other categories.

B. *RQ2 - How to rank business process model metrics in the context of prediction outcome*

A promising approach to rank metrics is to evaluate already conducted experimental setups and to compare their available information among each other by using business process model metrics. Figure 1 visualizes the experimental setup of how to rank the identified and categorized business process model metrics in the context of PPM in five steps.

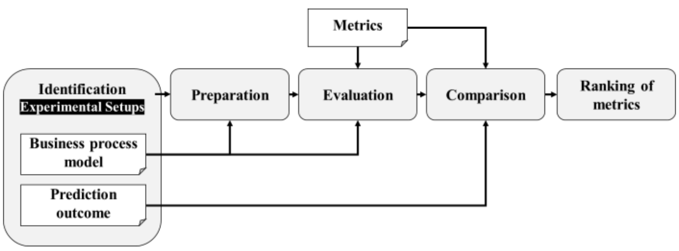

Fig. 2 Experimental approach to rank business process model metrics

In the first step process-aware experimental setups get *identified*. The data then gets searched for two types of information: the applied business process model and the prediction outcome. On the one hand, the business process model as a evaluation basis for metrics and on the other hand, the prediction result as a central success factor in order to be able to compare the experimental setups among each other. It is assumed that one business process model can always be linked to exactly one prediction model and therefore results in exact one prediction outcome. To ensure comparability and an equivalent data basis among all experimental setups it is necessary to provide the same format and graphical elements for each business process model. Because the standard is BPMN 2.0. a *preparation* can be necessary for example by converting process flows into BPMN 2.0 models. After the preparation of business process models is complete, the *evaluation* by metrics can be performed and documented. For the evaluation of business process models the business process model metrics listed in table 1 are used. The evaluation is performed manually and automated to minimize the error probability in the evaluation step. In the second last step the created data of the evaluation gets *compared* among all experimental setups. The hypothesis claims that different types of prediction outcome can be linked to specific values of business process model metrics. The evaluation of the experimental approach takes place with the help of different statistical methods. Here, the metrics are put into context with the prediction results. Based on this observation, it is possible to propose a *ranking* of metrics and quantify their importance in the context of prediction results.

C. *RQ3 - How to embed the ranking of business process models in the framework of predictive process monitoring*

The paper has identified two promising approaches to make use of business process models in the framework of PPM. First, the metrics can be used to prevent an undesired outcome before the prediction has been progressed based on the research result of the ranking. Secondly, the metrics can be used after the prediction to provide comparability and comprehensibility for other researchers. Both approaches can be linked to specific steps in the framework of PPM as visualized in figure 3.

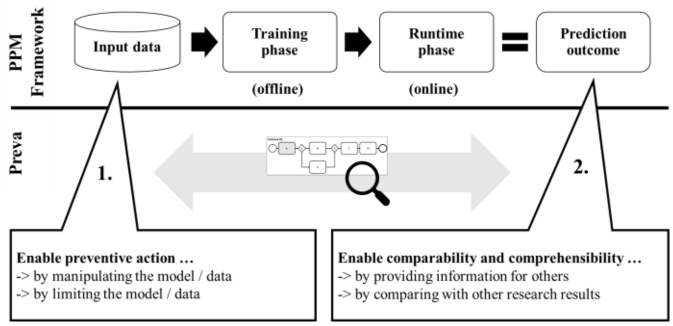

Fig. 3 Embedding business process model metrics in the framework of PPM

In the first approach the main goal is to prevent undesired outcomes based on the ranking of business process model metrics before the prediction outcome. The idea is to enable practitioners and researchers to intervene accordingly based on the result of the ranking before the training phase. Possible countermeasures can be on the one hand, the manipulation of the business process model by removing/adding new graphical elements. On the other hand, to limit the business process model for example by downsizing the relevant process path.

The second approach follows the idea to enable comparability and comprehensibility after the prediction outcome. Preva enables practitioners and researchers to provide business process model metrics as a benchmark in an intuitive and standardized way. The result can for example be exported and attached to research work. This feature ensures a long-term support and quantity way to compare different research results.

D. RQ4 - How to provide metrics as an incremental software approach?

The web-based software approach called "Preva" (an acronym for "process evaluation") consolidates and operationalizes the scientific contributions of RQ1, RQ2 and RQ3. Meaning, to automatically generate a categorized and ranked view of different business process model metrics. Therefore, the software can be identified as a metrics suite. From an architectural point of view the software consists out of four components which can be progressed in a chronological order: Upload, Evaluation, Dashboard and Export (see figure 2).

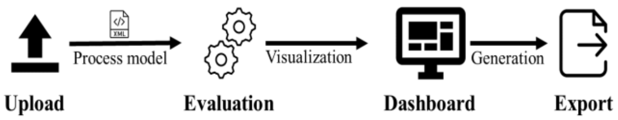

Fig. 4 Software concept to rank business process model metrics

The first step is to *upload* a business process model as a BPMN 2.0 format file. This limitation arises from technical restrictions related to the evaluation of business process models. The uploaded business process model then will be *evaluated* based on business process model metrics. The result gets *visualized* in a dashboard. The user then can filter the values based on the categorization or ranking. The goal is to provide researchers and practitioners an indication of how the business process model may influence the prediction outcome in a positive or negative way. The indication is referenced on the ranking of metrics. Finally, to allow comparability and comprehensibility an *export* is available which can be attached to recent work. In summary, the software concept allows researchers to quantify and document characteristics of business process model as a benchmark in a standardized way.

II. CONCLUSION AND FUTURE WORK

In this section the present academic contribution in line with the formulated research questions is concluded. First to address *RQ1*, business process model metrics got identified and categorized. Specifically, 16 metrics are mapped to five categories. The identification of business process model metrics was conducted by a literature review including 48 papers. The categorization was performed manually, similar approaches exists in [9], [16]. The outcome of RQ1 is visualized in table I. Next, *RQ2* has been tackled by proposing an experimental concept to evaluate business process models based on their impact in the area of PPM. The evaluation to create a ranking of business process model metrics consists out of five steps. The outcome of the concept can be formalized in a next paper. To address *RQ3*, two promising approaches got developed. The first approach enables practitioners and researchers to intervene accordingly based on the result of the ranking before the training phase. The second approach follows the idea to enable comparability and comprehensibility after the prediction outcome by using business process model metrics as a benchmark. Finally, to address *RQ4* a first prototype of preva has already been developed to proof its technical feasibility. The prototype is currently in the alpha phase and can be viewed publicly at www.processevaluation.de

In conclusion, the paper explained a detailed outline of the concept and associated research questions. Based on the identified research questions solution approaches are proposed to move the state of the art of using business process model metrics as a benchmark from ad-hoc approaches to a universal solution. Future work is to publish the ranking results and further to develop preva until a level of maturity useful to the public.

REFERENCES

[1] Canfora, G., García, F., Piattini, M., Ruiz, F., and Visaggio, C. A.: A family of experiments to validate metrics for software process models., J. Syst. Softw., vol. 77, no. 2, pp. 113–129, (2005).

[2] Cardoso, J., Mendling, J., Neumann, G., and Reijers, H. A.: A Discourse on Complexity of Process Models., in BPM 2006: Business Process Management Workshops, Springer, Berlin, Heidelberg, pp. 117–128, (2006).

[3] Castellanos, M., Casati, F., Dayal, U., and Shan, M.-C.: A Comprehensive and Automated Approach to Intelligent Business Processes Execution Analysis., Distrib. Parallel Databases, vol. 16, no. 3, pp. 239–273, (2004).

[4] van Dongen, B. F., Crooy, R. A., and van der Aalst, W. M. P.: Cycle Time Prediction: When Will This Case Finally Be Finished?., in OTM 2008: On the Move to Meaningful Internet Systems: OTM 2008, pp. 319–336, (2008).

[5] Evermann, J., Rehse, J.-R., and Fettke, P.: A Deep Learning Approach for Predicting Process Behaviour at Runtime., in International Conference on Business Process Management 2016, pp. 327–338, (2017).

[6] Fenton, N. E. et al.: Software Metrics (2nd Ed.): A Rigorous and Practical Approach. 2nd Editio.USA: PWS Publishing Co., (1997).

[7] Hevner, A. R., March, S. T., Jinsoo Park, and Sudha Ram: Design Science in Information Systems Research., MIS Q., vol. 28, no. 1, p. 75, (2004).

[8] Maggi, F. M., Di Francescomarino, C., Dumas, M., and Ghidini, C.: Predictive Monitoring of Business Processes., in Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 8484 LNCS, pp. 457–472, (2014).

[9] Mendling, J.: Metrics for Business Process Models., pp. 103–133, (2008).

[10] Rogge-Solti, A. and Weske, M.: Prediction of Remaining Service Execution Time Using Stochastic Petri Nets with Arbitrary Firing Delays., in ICSOC 2013: Service-Oriented Computing, pp. 389–403, (2013).

[11] Salfner, F., Lenk, M., and Malek, M.: A survey of online failure prediction methods., ACM Comput. Surv., vol. 42, no. 3, pp. 1–42, (2010).

[12] van der Spoel, S., van Keulen, M., and Amrit, C.: Process Prediction in Noisy Data Sets: A Case Study in a Dutch Hospital., Int. Symp. Data-Driven Process Discov. Anal., pp. 60–83, (2013).

[13] Spree, F.: Business Process Models in the Context of Predictive Process Monitoring., Rev. Informática Teórica e Apl., vol. 28, no. 1, pp. 39–46, (2021).

[14] Spree, F.: Predictive Process Monitoring: A Use-Case-Driven Literature Review., EMISA Forum, vol. 40, (2020).

[15] Stephen H. Kan: Metrics and Models in Software Quality Engineering. (2002).

[16] Vanderfeesten, R., Cardoso, J., Mendling, J., Reijers, H. A., and van der Aalst, W. M. P.: Quality Metrics for Business Process Models., Work. Handb., pp. 179–190, (2007).

[17] Verenich, I.: A general framework for predictive business process monitoring. vol. 1603 (2016).