Business Process Modeling Language for Performance Evaluation

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***Abstract*—Evaluation of business processes is important for analysis and improvement of an organization. Different methods are used to evaluate the performance like statistics or visualization. However, these methods meet demands mainly on the top organizational level. There is insufficient support to evaluate processes at the process managerial level leading to a limited visibility of deficiencies in business processes at process level. In this paper, we address this challenge and focus on the relation between evaluation of business processes and their representation at the process managerial level. In our research, we follow the design science methodology in order to provide business process models for performance analysis. We also provide constructs and patterns of our proposed modeling language for analysis and improvement of business processes. The analytical business process modeling language is further explained with the help of a case study and demonstrated by extending an existing modeling language.**

***Keywords*-business process modeling, performance representation, business process analysis, analytical modeling language, improvement**

I. Introduction

The business world is competitive and fierce competition exists between companies due to globalization, where even small companies have a reach to wider international markets. Consider the example of purchasing a product by a consumer. She has many options, like purchasing from different retail stores, or over the Internet, from big brand companies to small manufacturers. This has not only increased the competition between companies, but also raised the expectation of customers. Therefore, enterprises seek new ways to provide innovative and quality services to satisfy customer's needs.

In order to respond to the changes in the business world, enterprises continuously try to streamline their organizational structure and operations. This is carried out through effective design and analysis of operations. It requires understanding of operations and their performance evaluation as evaluation is considered as first step for improvement.

The changes are carried out by business experts (process managers) of an enterprise. To carry out such changes, they are interested in performance details of processes in an organization. These details are necessary in order to identify deficiencies and improve processes. Therefore, a class of users (like managers or supervisors) requires descriptive business process models for improvement [7].

We survey existing solutions, modeling languages, and methods. However, these modeling languages do not provide support and represent the performance of processes in business process models [19]. Performance representation in process models is important for improvement. Most of the modeling languages are devised for the development of information systems [1], as indicated in scientific literature and surveys [20], [32]. At the top organizational level, different statistical charts are used for performance representation at a abstract level. However, usage of same abstract representation methods are not adequate to identify deficiencies at process managerial level as those methods will not help to make decisions about process elements. Therefore, new detailed graphical models are required for this purpose.

In this paper, we address the following research questions. 1) How are business processes evaluated for improvement? 2) How can we improve the evaluation of business processes (with a new representation)? 3) How can we visualize the performance of processes (metrics) in process modeling language?

The structure of this paper is as follows: In Section II, we discuss the research methodology followed in this work. In Section III, we discuss the background which includes business process modeling, evaluation, and visualization. This helps the reader to understand the challenges in this domain. In Section IV, we discuss our proposed modeling language with its patterns. In Section V, we explain the proposed modeling language with the help of a case study using business process modeling notations (BPMN). In Section VI, we discuss the related work in this field followed by Section VII, which summarizes our paper and provides an outlook.

II. Research Method

Design science is a problem solving paradigm seeking for ideas, practices, technical capabilities, and artefacts through which problems can be effectively and efficiently solved [23]. The new artefacts attempt to extend boundaries of human and organizational capabilities. In our research, we see the scope of an innovative artefact to solve problems related with business process analysis and improvement. Therefore, our research follows the design science research method. We also consider the guidelines of design science research as mentioned in [10].

We started our investigation by seeking more expressive business process models for analysis and improvement of business process. We identify different methods and modeling languages are used to represent the performance of elements in practice and research. However, they fulfil the requirements only at an abstract level and do not identify deficiencies in processes. Modeling languages are not conceived for this purpose and sometimes create a misunderstanding between stakeholders. To the best of our knowledge, modeling languages are not devised for performance analysis of business processes. This complements the design as a search process and problem relevance part.

Our objective is to provide process models enriched with performance details for better analysis of business processes in the context of improvement. In this regard, we analyze the requirements of post execution analysis of business processes [19]. We also conducted interviews with experts to know their expectations from such models. We found that the community welcomes such modeling representation as it will help users in making decisions related with improvement of processes.

The result of design as a search process and problem relevance part initially helped in designing the artefact. We decided to extend an existing modeling language which is rigorously defined and a standard in business process modeling. In design science, a language specification includes constructs, models, method, and an instantiation part. Therefore, we address these parts to specify of our proposed artefact. In order to explain the artefact, we also provide patterns for use of the modeling language.

The artefact introduced in this paper is an innovative artefact, therefore, we used the descriptive method of evaluation as suggested in [10]. For this purpose, we introduced an example and constructed scenarios using existing methods and our proposed artefact. We compare them with each other and show the benefits of our proposed artefact. In the next section, we discuss the background related with this research.

III. Background

The goals and objectives of an enterprise are achieved by carrying out business operations in a specific way. This specific way is called business process. Business processes can be viewed abstractly as fulfilling customer needs as well as in detail like activities carried out to produce a product. Business processes are the most important elements of enterprises because it is the design of processes which have a significant impact on the overall quality of a product and success of the enterprise.

Different methodologies are devised to address different aspects of business processes (from management to improvement). Here, we take the definition of Harrington from the business process improvement perspective [9], as follows.

"A business process consists of a group of logically related tasks that use the resources of the organization to provide defined results in support of the organization's objectives."

In this definition, the resources of organization and related tasks are key elements to meet the organization's objectives. The effective utilization of resources and structure of tasks are important for time, cost, and quality aspects of a product and an organization itself. In the following section, we address our first research question.

A. *Business Process Models*

The communication of concepts related to business processes is very important between stakeholders. Different techniques are used for this purpose like textual descriptions and graphical representations. Graphical techniques are used to visualize concepts for communication and analysis. Being graphical in nature, they provide an intuitive understanding about concepts.

Different graphical models are built in order to manage business operations in a company. The field which addresses the issues related to management of business operations and graphical models is called business process modeling. Business process modeling is considered as the most important step in business process management [30]. Business process modeling helps in communication of business operations with stakeholders from identification and design of processes to their automation, and afterwards their analysis and improvement. Business process modeling has increased the ability to understand business processes [6].

Different modeling languages are used in different phases of business process management. In the planning phase, Event-driven process chain (EPC) models and Flowcharts are commonly used. In the design and implementation phase, different variants of UML diagrams are used. These modeling languages try to fulfil the communication gap and help to improve the understanding of business processes [20].

B. *Evaluation of Business Processes*

Evaluation the performance of business processes and its involved elements is important as it is used as a tool to control and improve the processes. Different methods are used for this purpose which ranges from economics, statistics fields to computer science. In computer science, focus is to provide support in carrying out business operations (automation), storage (databases), computations (mining methods), and their corresponding representations for communication (graphical models). Here, we focus on evaluation of businesses which involve computation and their corresponding representation.

Different stakeholders are involved in enterprises at different levels. These stakeholders evaluate the performance of processes. Different models are used in order to fulfil the requirements of each stakeholders. In [22], we discuss different stakeholders and their participation in business process elements. Executives are interested in an abstract level evaluation, like overall profit and losses. These abstract evaluations are accompanied with textual descriptions and graphical charts (like reports and statistical charts). Different trends and projections are also estimated for the future. Managers evaluate processes at lower level with more details about activities and involved resources.

The performance is usually evaluated in form of quantitative measurements which help to indicate about quality. Different methods and techniques are also used for this purpose. Business processes and its elements are evaluated in different dimensions like time, cost, and quality. In order to achieve the real benefits of evaluation of all important dimensions, their attributes should be part of the evaluation for product, process, or employee.

In evaluation, it is important for companies to have an end-to-end picture of processes, like from the abstract level to the lower level details. This is important to evaluate the overall impact of changes in processes. Depending on the granularity and stakeholder requirements, different dimensions and their characteristics become important for analysis. This makes the inclusion and filtration of particular data/information from the evaluation (and their perspectives). Based on the perspective requirements, other dimensions can be included or divided into the hierarchies (like time in seconds, minutes, and hours) or into classes based on threshold values (classes like high cost and low cost).

C. Visualization

Visualization methods are used as an effective communication tool and help stakeholders to make decisions. We can define visualization as a process of building graphical representations of concepts. Such representations help the stakeholder for better understanding and communication.

In [24], visualization is defined as

"a cognitive activity, facilitated by external visual representations from which people build an internal mental representation of the world."

Some authors also include the cognitive process and the process of building graphical models in visualization definition [24]. External visual representation can be charts or graphical models built with the help of information technology. Whereas, world means data, information, and concepts. In [4], author differentiates between different visualization types like data, scientific, and information.

Different visualization techniques are also employed to support the evaluation of business processes and its elements. These techniques depend on the user requirement which includes the goal of evaluation, level of detail, and dimension. The goal of the evaluation means what we want to measure. Depending on the goal of the evaluation, the data is prepared for visualization and different views are built. This data can be operational/raw data as in the case of data visualization or abstract as information visualization.

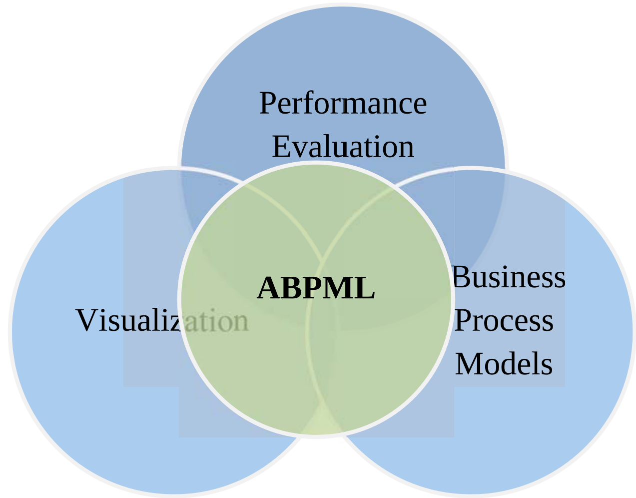

Figure 1: Positioning of ABPML

D. Challenges

Enterprises want to improve their business processes. However, before an improvement, identification of deficiencies in business processes are very important and carried out at the first [21]. Business processes are evaluated at different levels by different stakeholders. At an abstract level, different diagrams are used to visualize trends such as histograms, bar charts, and line charts. These representations are well suited for the abstract level demonstration. However, at the lower level detailed representations are necessary, especially in the context of business processes and their improvement.

At the fine granularity, process managers are responsible for controlling and improvement. The process managerial level is an important level as the changes carried out at lower levels are reflected as results to upper levels. Currently, at a lower level, abstract representations are used for this purpose with different details (just focusing on certain processes and elements). Abstract models are not sufficient for process managers and they need more detailed representation about the performance of employees and processes with process models.

In some approaches (like [16], [17]), attempts are made to use business process models for evaluation of business processes. However, most of the modeling languages are devised for information system development and are not appropriate for such performance evaluations. Usage of the same modeling languages for performance evaluation will create a misunderstanding between the stakeholders.

Performance of processes and involved elements should be represented with the process structure at a detailed level. By doing so, models provide further insights about processes and enable process managers to carry out improvements in the processes. In order to solve this problem, we propose an analytical business process modeling language. This analytical modeling language takes the concepts from business process modeling, evaluation (measure and metrics), and visualization (cognitive aspects). The analytical modeling language addresses our second and third research question. In Figure 1, we position the proposed analytical business process modeling language with respect to earlier discussed domains.

IV. Analytical Business Process modeling Language

We design analytical business process modeling language (ABPML) by performing a thorough analysis of business process performance analysis requirements [18], [19], existing modeling language [20], and different analytical tools (like ProM [11], [31]). We do not only include the best of breed features, but also include some innovative features which provide help in analyzing business processes and identifying deficiencies. Therefore, the problem/solution search space is well investigated and considered in designing the new modeling language.

Here, we take the assumption that the analytical data is already available from an information system and just needs to be represented. The analytical data can be extracted from executional data (process trace data) or database tables. In [13], we discuss the extraction process in context of SAP applications whereas in [22], we provide an overall framework for this purpose.

In design science, a language specification includes constructs, models, method, and instantiation components. Therefore, we address these components for specification of our proposed analytical modeling language. These are correspondingly discussed in the following.

Constructs provide the vocabulary and symbols which are used to represent a problem or a solution [10] or just representing a situation. Constructs are used to represent the tangible or intangible elements of a process. They are used to represent activities, process participants (resources, places), events (communication between elements), gateways (decisions), and other involved objects (materials, orders). Therefore, they are basic building blocks of a graphical model. Semantic defines the meaning of symbols and relationship with each other.

A. BPMN as a Choice

We use the basic constructs of Business Process modeling Notations (BPMN) as described in the BPMN [1] standard [2]. We have select BPMN as it is rigorously defined and has widely accepted as a standard (defined by OMG) for modeling and communicating business processes. It is implemented in different modeling tools and rich in representation. Similarly, various extensions are also proposed in order to suit different business needs. Therefore, adoption of our proposed modeling language will not be a challenge in industry.

[1] http://www.bpmn.org

For our analytical modeling language, we propose some other constructs as an extension and also define the context in which some of the basic constructs have different semantics (meanings and relations) as compared to BPMN standard. Those constructs are used only in a defined context for performance analysis.

BPMN graphical notations are divided into four basic categories [2]. These categories are discussed briefly as follow.

Flow objects consist of activities, involved decision nodes for their order (sequential, parallel, iterations), and events of processes.

Connecting objects, as the name implies are used to connect activities and other elements with each other using different arrows which represent messages and associations between them. This core set of elements defines the control flow perspective of processes.

Different modeling elements are grouped through **Swimlanes** which use pools and lanes [2]. A pool is used to represent process participants while lanes are used to partition these participants and their activities from one to another. A process participant can either be an organizational entity within an organization or different organizations for collaboration in a process. Mostly, organizational perspective is provided by using Swimlanes constructs.

In BPMN, additional information about the process such as involved data object and guidelines for operations are provided by **artifacts**. These elements consist of data objects, annotations and group constructs.

To accommodate different requirements, we combine constructs to build models for analysis in different perspectives, and call them patterns. Different allowed combinations are explained here which also define the method of constructing the models in the analytical process modeling language. Depending on the user's requirements, models are built at different level of granularity to facilitate the understanding of processes. We further explain these constructs and their semantics with the help of our proposed patterns.

B. Modeling Patterns

Patterns are used to share knowledge and solve problems [12]. Therefore, in our context, we define patterns as a combination of constructs to analyze the process and its elements in a particular perspective for improvement.

Each pattern intends to analyze performance with a particular focus involving certain dimensions and their attributes. Here, we provide four patterns for visualization of business process performance (with respect to business process modeling language). We consider these four patterns

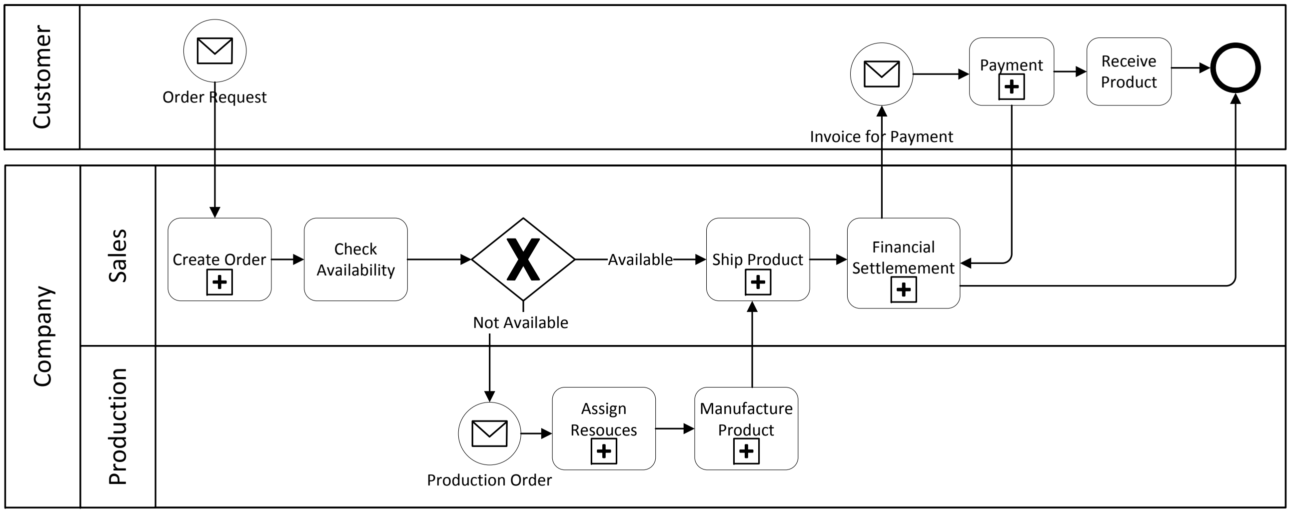

Figure 2: Overall product purchasing scenario in an organization using BPMN

Patterns	Purpose	Constructs
Time	Analyze the performance of resources and activities with respect to time	Swimlanes, activities
Cost	Analyze the performance from the cost perspective like material and resources	Swimlanes, activities, colors
Path	To understand the activities which will be fruitful	Edges, activities, colors
History	To understand which activities are frequently executed in process	Edges, thickness, activities

Table I: Pattern and characteristics

as the most important and frequent in business process analysis.

The analytical data can be used to identify which activities, organizational resources, and involved elements add more value to the enterprise. Based on this information, activities, organizational resources, and involved elements are classified in a particular dimension. The classification of process elements based on performance depends on the metrics used in the enterprise. Overall average values can be used for this classification and threshold values can be set. We recommend that only few classes should be defined for less cognitive loads of models. Enterprises can define their own metrics.

Based on the organizational metrics and values, different colors can be used to indicate the effect of the business objects, like green for optimal cost, yellow for high cost, and red for very high cost. Similarly, these classes can be represented in other dimensions as well like quality and time. Although the relation of cost and time, is not as simple as discussed in [33]. Once such metrics are defined, then they can be represented using our proposed patterns in our modeling language.

1) Time pattern: Time pattern focus on representation of process element's performance from time aspect. A few classes and characteristics in this dimension are classified in Section III and represented in Section V with BPMN. Some examples are idle time and working time. Gantt charts like representations are easier for understanding of stakeholders; however, other representations can also be used.

2) Cost Pattern: Cost is an important factor in business processes. This pattern observes the performance of process elements from cost and other related aspects involving material and other resources. Different colors can be used to distinguish between high cost and low cost elements of process. Similarly, process elements can also be grouped based on the cost incurred by them.

3) Path Pattern (Time-Cost Pattern): The time-cost pattern is helpful to decide at which path the execution will be effective (or beneficial for the organization). In case of different available paths, a path with company best practice can be colored to distinguish it from other options. Similarly, problematic paths (incurring cost and problems) can also be distinguished using colors from the others.

4) History Pattern: History path pattern represents which path is taken in most of the process executions. A thick edge represents that this particular path is taken by most of the cases during execution compared to a thin edge path which represent the opposite.

The proposed patterns, their elements, and meanings are summarized in Table I. In the following patterns, different other attributes of the dimensions can be added and correspondingly represented using our proposed modeling language and its cognitive aspects (like color, shape, and size). The above mentioned patterns are further explained with the help of an case study in Section V.

Our current pattern catalog is not meant to be complete, as different patterns can be created based on requirements and creativity of a user/analysis. A pattern catalog can be made by an enterprise for performance evaluation and analysis. Due to space limitation, we do not include a complete list

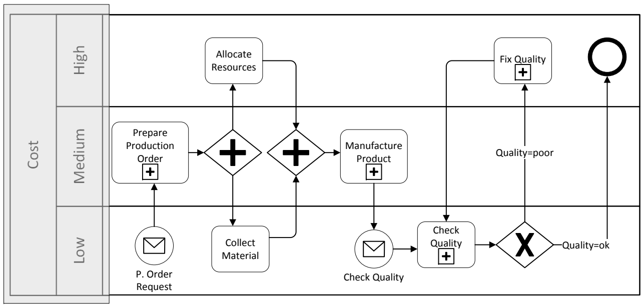

Figure 4: Cost of activities in ABPML

Figure 5: Order completion time

of our proposed patterns here.

V. Case Study

Instantiation demonstrates the feasibility of a proposed modeling language to solve the problem and its benefit. For this purpose, we take a small example of a real life scenario. This typical purchasing scenario may have different implementations (order of activities and roles) in organizations depending on their requirements. Here, it is taken from a small company.

Consider a typical purchasing scenario where a customer orders a product. Once the order is received, the product is checked in the stock. If the product is available, then it is shipped to the customer. An invoice is also generated and the payment process also starts. If the product is not in stock, then a production order is created for manufacturing the product. In this way, the customer order scenario is completed. Several processes are involved in successfully completing this order-scenario like fulfilling an order request, transfer of payment, manufacturing the product, quality evaluation, and shipping process. The whole process is abstractly represented in Figure 2 using BPMN.

In production, first, the production order is created by a foreman for the required products. Once the production order is created the assignments of resources are made like scheduling of machines and persons for manufacturing. In parallel to this, the raw material is also collected from the store or suppliers. Afterwards, the product is manufactured by workers. On completion of product manufacturing, quality inspector examines the quality of the manufactured product. If the quality of the product is at the desired level, then the shipping process and financial processes are started. Otherwise, the quality of product is brought to the desired level by sub-process “fix quality”. Therefore, the overall order is completed and marked as completed. This production process is shown in Figure 3 using BPMN.

When all these steps are recorded in information systems, we can use this data to analyze the performance of organizational elements and ordering of activities.

The whole process can be analyzed with abstract details like how much time it takes to complete the order, Figure 5. This representation is suitable at an abstract level. However, at the managerial level the process can be analyzed with more graphical details that help to identify deficiencies and improve the process. For this detailed representation, we discuss our proposed patterns in the context of this example.

In BPMN, Swimlanes (pool and lane) are used to represent process participants and their interaction during execution. We propose to use Swimlanes not only to see participant interaction, but also the performance of organizational resources and activities. Based on collected data, process participant performance should be computed and their lanes should be colored (like green, yellow, and red). Similarly, activities can also be aligned using Swimlanes based on their computation in a particular dimension and their attributes. Consider Figure 4, where three classes are defined in cost dimension to arrange the process activities and their involved elements.

Similarly, different dimension can also be defined as pools where lanes represent further attributes of these dimensions like in time dimension, Idle time can be defined as an attribute and other classes (like high, medium, and low) align activities for representation. Moreover, different dimensions and their attributes can be combined with one another for further business process analysis.

When we represent performance details using Swimlanes in the BPMN model, we can find out which activities are consuming time and taking high costs. Afterwards, these activities can be further investigated to identify their deficiencies for improvement.

Similarly, successful paths (or best practices) can be determined by evaluating the performance of processes and its involved elements. The successful paths can be represented by coloring the edges. The frequency of execution on a particular path can be represented by changing the thickness of edges (connecting objects). This corresponds to the history pattern of proposed modeling language.

Based on these extended notations, we represent an extended business process model of our production process in

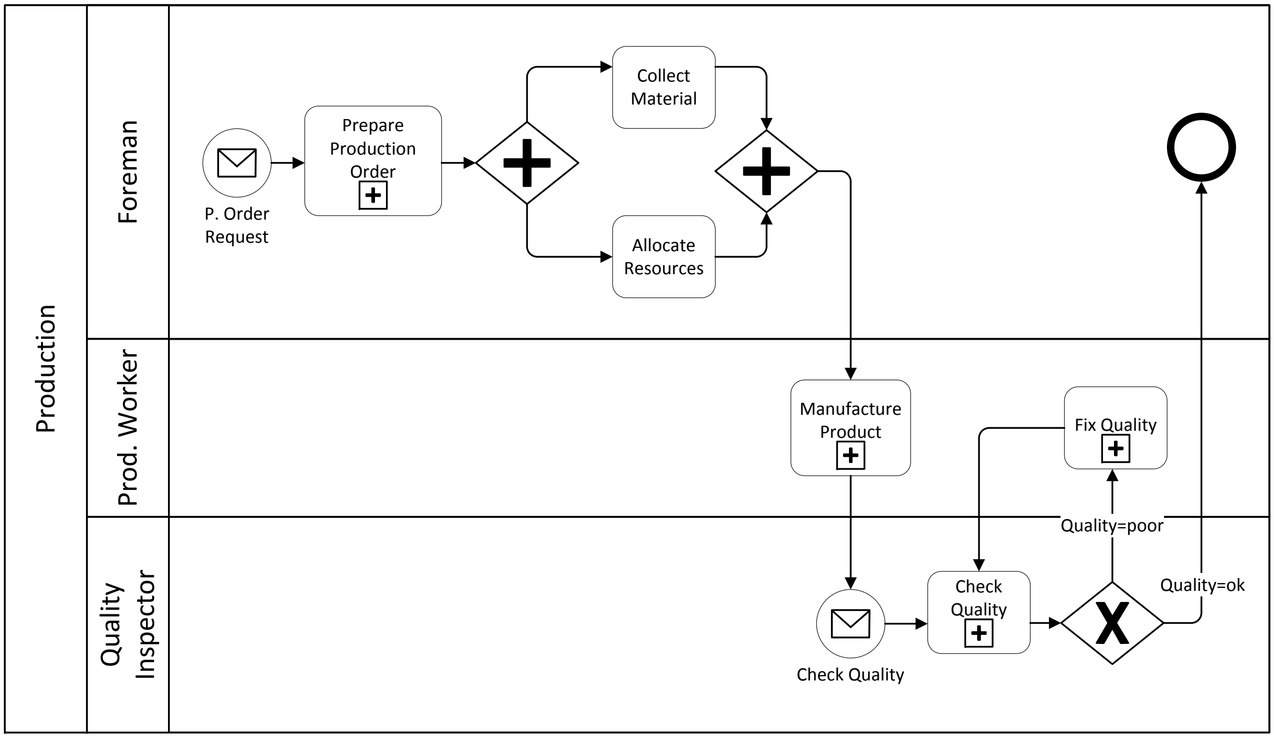

Figure 3: Representation of production process using BPMN

Figure 6. The colors red, yellow, and green represent activities with high, medium, and low cost respectively. In order to avoid confusion, in this figure, we only colored the activities to represent the performance aspects whereas Swimlanes are kept with their classical BPMN semantics [2], such as process participants. Figure 6, also represents that the quality of production is poor and frequently activity "fix quality" is executed to improve the quality of product. Similarly, it can be further investigated why activity "manufacture product" is consuming extra resources, which may result a representation that product manufactured by certain employee often need quality fixes or often certain paths with loops are executed.

VI. Related Work

Our work is compared and contrasted with existing modeling languages and methods. However, most of the research in business process modeling domain is related to the information systems, like its development [1], workflow management [27], simulation of business processes [14], or alignment of IT services with business processes [28], or configuration of information systems [8]. There is limited research with the focus on performance analysis of business processes using modeling language. There are some approaches to analyze business processes after execution, however, in those approaches same models are used which are conceptualized for information system development like some process mining [29] tools use Petri nets [27]. Therefore, the solution provided by those tools serves only on ad-hoc basis which is not appropriate.

A survey on business process analysis for optimization and improvement is provided in [32]. In that survey, the authors categorize different approaches to notational, formal and semi-formal categorizing. Their survey shows the lack of business process modeling languages for post executional phases. However, they do not provide any extensions or examples of modeling languages which we have provided in this paper. The concept of excluding activities at the abstract level and including them at the detailed level is also discussed in [2], [8] whereas in [3], it is discussed at the attribute level. Different views of models are generated based on the environment of execution as discussed in [5]; however, they are discussed from the software process perspective, irrespective to business processes.

An interesting work in BPMN domain is presented in [25] where an approach to transform business process dimensions (time, business rules, and information) into BPMN constructs is discussed. However, the author focus is not on the performance analysis of business processes. Here, we provide different patterns for better understanding and representation of a business process for performance evaluation. Similarly, there are also some other attempts to extend BPMN models in different dimensions like knowledge in [26] or for modeling process goals and its measures in [15].

Different business process management suites also provide cockpits to represent performance metrics in graphical forms like histograms, radial graphs, and several other techniques. However, these representations are abstract representations without providing information about the structure. Similarly, process mining tools (like ProM [31], EVS [11] also exhibit performance metrics through different graphical models. These approaches lack the support of business process modeling language to provide process perspective for improvement. In our work, we demonstrate the performance of processes with business process modeling language.

VII. Summary and Outlook

In this paper, we presented a design science artefact (modeling language) to solve the problem of performance analysis of business processes. We followed the design science guidelines for the specification of modeling language. We presented the patterns of our proposed modeling language for performance analysis of business processes. These patterns are explained with the help of an example using a rigorously defined modeling language (BPMN). Therefore, we extended BPMN for performance analysis.

In the future, we plan to add some further patterns in our pattern catalog for analysis and improvement especially from the cognitive perspective. We also plan to conduct the analytical evaluation of our proposed modeling language. Afterwards, we want to do observational evaluation using different case studies with participants which will help in empirical evaluation. This will help to further improve the proposed modeling language. We want to provide by a developed tool for generating and presenting the proposed modeling language for analysis and improvement purpose.

References

[1] G. Booch, J. Rumbaugh, and I. Jacobson, *Unified Modeling Language User Guide*, 2nd ed. Addison-Wesley, May 2005.

[2] BPMI.org and OMG, "Business Process Modeling Notation Specification, Final Adopted Specification," Object Management Group, OMG Headquarters, 140 Kendrick Street, Building A, Suite 300, Needham, MA 02494, USA, February 2006. [Online]. Available: http://bpmn.org/Documents/OMG_Final_Adopted_BPMN_1-0_Spec_06-02-01.pdf

[3] T. R. Browning, "The many views of a process: Toward a process architecture framework for product development processes," *Syst. Eng.*, vol. 12, no. 1, pp. 69–90, 2009. [Online]. Available: http://portal.acm.org/citation.cfm?id=1507340

[4] E. H. Chi, "A Taxonomy of Visualization Techniques Using the Data State Reference Model," in *INFOVIS '00: Proceedings of the IEEE Symposium on Information Vizualization 2000*. Washington, DC, USA: IEEE Computer Society, 2000, pp. 69+. [Online]. Available: http://portal.acm.org/citation.cfm?id=857691

[5] D. Correal and R. Casallas, "Using domain specific languages for software process modeling," in *ACM OOPSLA, Workshop on Domain-Specific Modeling*, 2007. [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.102.64

[6] M. Cumberlidge, *Business Process Management with JBoss jBPM: A practical guide for business analysts*. Packt Publishing, 2007.

[7] D. Delen, N. P. Dalal, and P. C. Benjamin, "Integrated modeling: the key to holistic understanding of the enterprise," *Commun. ACM*, vol. 48, no. 4, pp. 107–112, 2005. [Online]. Available: http://portal.acm.org/ft_gateway.cfm?id=1053296&type=html&coll=GUIDE&dl=GUIDE&CFID=54687751&CFTOKEN=24268209

[8] A. Dreiling, M. Rosemann, W. van der Aalst, and W. Sadiq, "From conceptual process models to running systems: A holistic approach for the configuration of enterprise system processes," *Decision Support Systems*, vol. 45, no. 2, pp. 189–207, 2008. [Online]. Available: http://www.sciencedirect.com/science/article/B6V8S-4N43RHR-1/2/fbc3c60644d31ffffb4665412e09fe5e

[9] J. H. Harrington, *Business Process Improvement: The Breakthrough Strategy for Total Quality, Productivity, and Competitiveness*. McGraw-Hill, April 1991. [Online]. Available: http://www.amazon.ca/exec/obidos/redirect?tag=citeulike09-20\&path=ASIN/0070267685

[10] A. R. Hevner, S. T. March, J. Park, and S. Ram, "Design science in information systems research," *MIS Q.*, vol. 28, no. 1, pp. 75–105, Mar. 2004. [Online]. Available: http://dl.acm.org/citation.cfm?id=2017212.2017217

[11] J. E. Ingvaldsen, J. A. Gulla, O. A. Hegle, and A. Prange, "Empirical business models," in *CAiSE Short Paper Proceedings*, ser. CEUR Workshop Proceedings, vol. 161. CEUR-WS, 2005.

[12] A. Khan, C. Kästner, V. Köppen, and G. Saake, "Service variability patterns," in *Proceedings of the 30th international conference on Advances in conceptual modeling: recent developments and new directions*, ser. ER'11. Berlin, Heidelberg: Springer-Verlag, 2011, pp. 130–140. [Online]. Available: http://dl.acm.org/citation.cfm?id=2075202.2075225

[13] A. Khan, A. Lodhi, V. Köppen, G. Kassem, and G. Saake, "Applying process mining in SOA environments," in *Service-Oriented Computing ICSOC Service Wave 2009 Workshops*, ser. Lecture Notes in Computer Science, A. Dan, F. Gittler, and F. Toumani, Eds. Springer, 2010, vol. 6275, pp. 293–302. [Online]. Available: http://dx.doi.org/10.1007/978-3-642-16132-2_28

[14] S. Klink, Y. Li, and A. Oberweis, "INCOME2010 - A toolset for developing process-oriented information systems based on Petri nets," in *Simutools '08: Proceedings of the 1st international conference on Simulation tools and techniques for communications, networks and systems & workshops*. Belgium: ICST, 2008, pp. 1–8.

[15] B. Korherr and B. List, "Extending the EPC and the BPMN with business process goals and performance measures," in *Proceedings of the 9th International Conference on Enterprise Information Systems (ICEIS)(3)*, J. Cardoso, J. Cordeiro, and J. Filipe, Eds., 2007, pp. 287–294.

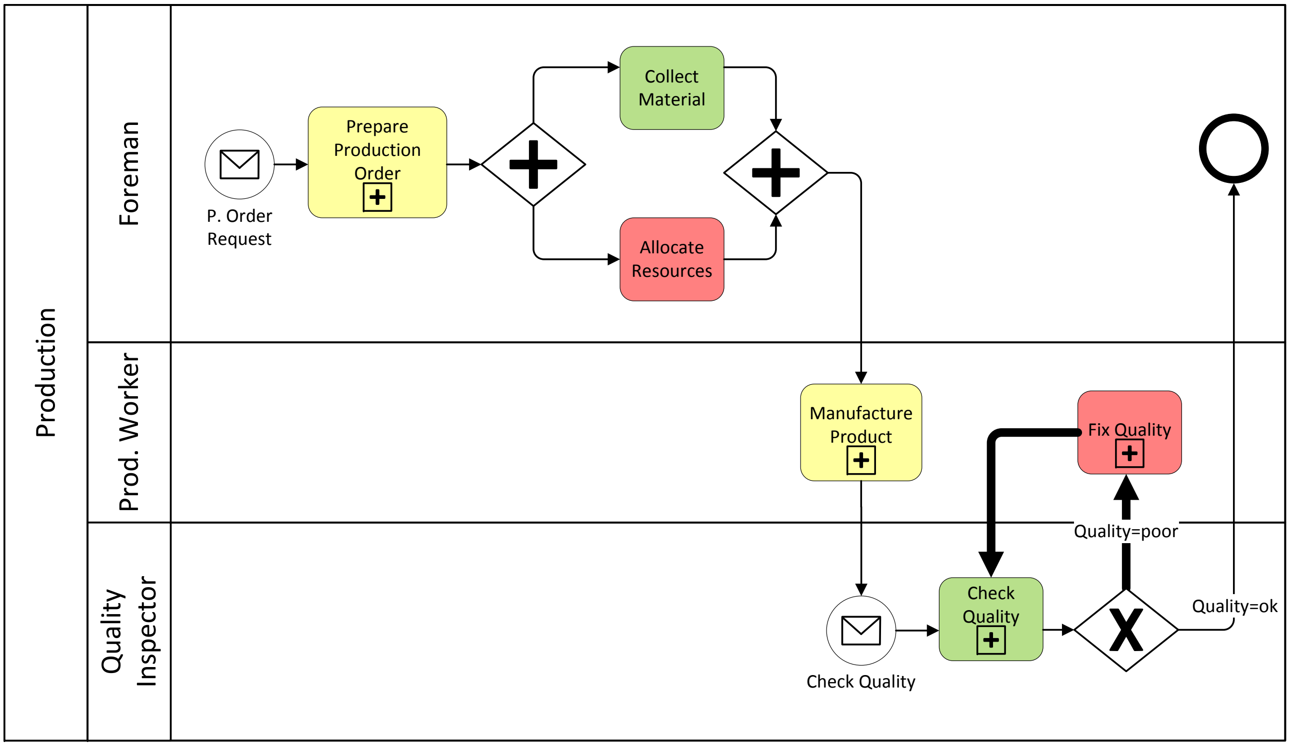

Figure 6: Production process in ABPML

[16] A. Lodhi, G. Kassem, and C. Rautenstrauch, "Application of process mining in knowledge management," in *Proceedings of The 3rd International Conference on Interactive Mobile and Computer Aided Learning (IMCL 2008)*. Amman, Jordan: CD-ROM, ISBN 978-3-89958-351-9, April 2008.

[17] ——, "Modeling and analysis of business processes using business objects," in *Proceedings of The 2nd IEEE International Conference on Computer, Control and Communication*. Karachi, Pakistan: IEEE Computer Society, February 2009, pp. 1–6. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4909176&isnumber=4909154

[18] A. Lodhi and V. Köppen, "Business process modeling for post execution analysis and improvement," in *Proceedings of the 5th IEEE International Conference on Software, Knowledge Information, Industrial Management, and Applications (SKIMA)*. Benevento, Italy: IEEE Computer Society, September 2011. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6089982

[19] A. Lodhi, V. Köppen, and G. Saake, "Post execution analysis of business processes: Taxonomy and challenges," University of Magdeburg, Tech. Rep. 9, 2010. [Online]. Available: http://wwwiti.cs.uni-magdeburg.de/iti_db/publikationen/ps/auto/AzVkGsTR1001.pdf

[20] ——, "Business process modeling: Active research areas and challenges," University of Magdeburg, Tech. Rep. 1, 2011. [Online]. Available: http://wwwiti.cs.uni-magdeburg.de/iti_db/publikationen/ps/auto/AzVkGsTR1002.pdf

[21] ——, "An extension of bpmn meta-model for evaluation of business processes," *J. Riga Technical University*, vol. 43, pp. 27–34, 2011. [Online]. Available: https://ortus.rtu.lv/science/en/publications/10971/fulltext

[22] A. Lodhi, V. Köppen, and G. Saake, "Business process improvement framework and representational support," in *Proceedings of the Third International Conference on Intelligent Human Computer Interaction (IHCI 2011), Prague, Czech Republic, August, 2011*, ser. Advances in Intelligent Systems and Computing, M. Kudelka, J. Pokorny, V. Snasel, and A. Abraham, Eds. Springer, 2013, vol. 179, pp. 155–167. [Online]. Available: http://dx.doi.org/10.1007/978-3-642-31603-6_14

[23] S. T. March and G. F. Smith, "Design and natural science research on information technology," *Decis. Support Syst.*, vol. 15, no. 4, pp. 251–266, Dec. 1995. [Online]. Available: http://dx.doi.org/10.1016/0167-9236(94)00041-2

[24] R. Mazza, *Introduction to Information Visualization*, 1st ed. Springer, 2009.

[25] L. Penicina, "The approach of transformation between business process dimensions in BPMN modeling tool," in *Proceedings of the 15th International Conference on Information and Software Technologies*, Lithuania, Kaunas, April 2009, pp. 72–81.

[26] I. Supulniece, L. Businska, and M. Kirikova, "Towards extending BPMN with the knowledge dimension," in *Enterprise, Business-Process and Information Systems Modeling*, ser. Lecture Notes in Business Information

Processing, W. van der Aalst et.al., Ed. Springer, 2010, vol. 50, pp. 69–81. [Online]. Available: http://dx.doi.org/10.1007/978-3-642-13051-9_7

[27] W. van der Aalst, "The application of Petri nets to workflow management." *The Journal of Circuits, Systems and Computers*, vol. 8, pp. 21–66, 1998.

[28] ——, "Business alignment: Using process mining as a tool for delta analysis and conformance testing," *Requirement Engineering*, vol. 10, no. 3, pp. 198–211, 2005. [Online]. Available: http://portal.acm.org/citation.cfm?id=1342177

[29] W. van der Aalst, H. A. Reijers, A. Weijters, B. van Dongen, A. Medeiros, M. Song, and H. Verbeek, "Business process mining: An industrial application," *Information Systems*, vol. 32, no. 5, pp. 713–732, 2007.

[30] W. van der Aalst, A. ter Hofstede, and M. Weske, "Business process management: A survey," in *Business Process Management*, ser. Lecture Notes in Computer Science, W. van der Aalst, A. ter Hofstede, and M. Weske, Eds., vol. 2678. Springer, 2003, pp. 1–12. [Online]. Available: http://link.springer.de/link/service/series/0558/bibs/2678/26780001.htm

[31] W. van der Aalst, B. van Dongen, C. Günther, A. Rozinat, H. Verbeek, and A. Weijters, "ProM: The process mining toolkit," in *Proceedings of the BPM 2009 Demonstration Track*, ser. CEUR Workshop Proceedings, A. K. A. de Medeiros and B. Weber, Eds., vol. 489. CEUR-WS.org, September 2009, pp. 1–4. [Online]. Available: http://ceur-ws.org/Vol-489/paper3.pdf

[32] K. Vergidis, A. Tiwari, and B. Majeed, "Business process analysis and optimization: Beyond reengineering," *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 38, no. 1, pp. 69–82, 2008.

[33] M. J. Vullers, P. Kleingeld, M. Loosschilder, and H. A. Reijers, "Performance measures to evaluate the impact of best practices." in *Proceedings of Workshops and Doctoral Consortium of the 19th International Conference on Advanced Information Systems Engineering (BPMDS)*. Tapir Academic Press Trondheim, 2007, pp. 359–368.