Interdisciplinary Assessment of Process Modeling Languages Applicable for Small to Medium-sized Enterprises

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ABSTRACT
In the context of global competition, effective and sustainable business process management is about capturing, analyzing, and redesigning business processes, as well as in SME. Process models support this procedure by creating a common understanding of the process organization and providing an indication of how to develop optimizing strategies. The implementation of a business process modeling language is a fundamental requirement for all process management efforts, but the selection is hindered by an unmanageable number of Business Process Modeling Languages from various disciplines. Since resources availability is a primary concern in SME, there is a need for a resource-saving establishment and maintenance of business process management, based on an expressive business process modeling language and taking SME-specific requirements into account. To this purpose, common business process modeling languages are analyzed respective their applicability in SME. An interdisciplinary evaluation framework evolved from this approach, primarily focusing on the expressiveness and comprehensiveness of the graphical notation. This approach successfully combines engineering knowledge about process modeling in general, enriched with a psychological view on the effects of visual-graphical characteristics of graphical notations. The interdisciplinary evaluation framework aims at providing decision guidance for SME in the phase of choosing a business process modeling language.

Keywords: business process management, process modeling, cooperative work, organizational learning, small to medium-sized enterprises

1. INTRODUCTION
Competition in the global market has increased managerial challenges and the need for coordination and integrated decision support for almost every enterprise [1]. One opportunity to remain competitive in the market is an efficient and sustainable Business Process Management (BPM) [2]. Curtis et al. [3] point out that BPM has even become a necessity for companies in a highly competitive business environment as it is a powerful tool to improve process and service performance to meet and exceed customer expectations [4].

BPM primarily relies on process models which can provide both tangible benefits, in terms of cost, delivery and quality [5], and intangible benefits in terms of communication [6], employee empowerment [5], motivation [7], accountable collaboration [8], and “situation visibility” [9]. They thereby contribute to cultural change by improving the communication between different groups or departments within an enterprise. In particular, process models provide a common language by which all process stakeholders can locate themselves within the enterprise as a whole. Furthermore, process models support knowledge management (KM) implementation and maintenance [10].

2. REQUIREMENTS OF SME
The approach presented in this paper accounts for the challenges related to the establishment and maintenance of BPM in general, in particular for the specific requirements of SME with regard to selecting and applying a BPML. We identified the following distinctive aspects that require considerable attention in the SME sector:

(1) Resources needed for model development: Designing a new process model of an organizational work process is a timely and valuable, but also complex and error-prone task [11; 12]. Experienced process modelers and managers with an academic or even engineering background are, therefore, entrusted with this procedure [13; 12]. A critical success factor for process modeling is efficient information gathering and sharing. Relevant information can be obtained from various sources, e.g., process owners or managers, documents, and IT-systems. A process modeler typically uses a mixture of information sources, by collecting most of the data in verbal interaction with specific interview techniques. The staff interviewed on the shop floor is usually not familiar with formal modeling languages [6] and often lacks a methodological background or an academic education [14]. Process modelers, therefore, need to communicate efficiently in order to obtain all relevant information for a graphical representation of the organizational process. With regard to this workload for process modelers, capturing, analyzing, as well as redesigning business processes should be based upon a process owner’s everyday experience with the process. This aspect is a primary concern in SME. Whereas large companies may have the resources to establish an organizational unit dedicated to capturing, analyzing, and redesigning processes, financial and personnel resources are a primary and often limiting consideration for SME. They usually need to take a smaller scale approach to BPM for reasons of limited resources. BPM activities, like process modeling, are an add-on task to everyday business and are often neglected in SME. Thus, a critical success factor of efficient and sustainable BPM is to reinforce a corporate culture that supports participative process modeling, i.e., involves process modeler, process manager and process owner on equal
terms, and provides time and resources for BPM related activities like process modeling.

(2) Application range: BPMLs originate from a variety of scientific disciplines like software engineering, project management, systems engineering, and information systems. Since there is a wide range of BPMLs available—each with a different graphic notation, offering a single or multiple perspectives and views [1]—selecting a BPML for a specific application poses a challenge for enterprises of any size. With regard to the application of a BPML, practitioners often experience circumstances that are easy to express using one notation, but are more difficult to express in the other [15; 6]. Some working processes even cannot be represented by one notation. The usage of several BPMLs within an enterprise is often common practice [7], resulting in interface problems and waste of resources as a major concern, also having a negative influence on the efficiency of BPM. The application range of a BPML is of particular interest with regard to the specific features of SME [16; 17]. Considering low personnel and financial resources, a BPML should be capable of representing manufacturing and development processes. Both have certain characteristics that require a set of concepts and graphical elements within a process model.

(3) Usability: Learnability and ease-of-use are usability issues [18]. They are particularly important in everyday business where time-consuming training and education sessions for process modeling usually cannot be provided. For reasons of resource consumption, these sessions must, therefore, be restricted to the essentials of process modeling, while also teaching the necessary basics of graphical syntax and semantics to the participants. Further skills and knowledge often have to be acquired in a self study [18] or in mutual exchange, e.g. according to the mentor—mentee principle [19]. The graphical elements of a notation are often misinterpreted by process stakeholders and cannot serve as a communication vehicle between different process stakeholders [20]. Process models often have to be enriched with additional textual information to compensate graphical complexity of a notation element and enhance comprehensiveness for the observer [21]. Comprehensiveness for process stakeholders can be provided by considering cognitive aspects of visual representations in BPMLs [22]. The heterogeneity of process stakeholders and users is represented by their age, gender, vocational education, and related experiences. Considering the diversity of users, the BPML of choice should keep time for distributing BPM knowledge short; learning to apply a BPML should be possible with little expenditure of time. This can be achieved by a lean but sufficient set of intuitive symbols; allowing capturing processes in manufacturing and development, and service. In addition, reusability of process components should be provided in order to increase modeling velocity as well as efficiency of modeling. A common communication “language” can, thus be provided by enhancing organizational learning and information exchange at the same time. Since especially inexperienced modelers face higher problems in developing process models and understanding the meaning of notation elements [23], it is also necessary to consider the effects of visual design characteristics of BPML notation elements in selecting an adequate BPML for SME. Up till now, research activities regarding BPMLs were almost exclusively directed on semantic issues of process modeling languages [20]. Facing the highly visual nature of process modeling methods and their graphic representations, it remains open, why the effects of visual-graphical characteristics of notation system design have been neglected in BPML research so far. Previous studies of our research group show [23] that the comprehensibility of notation elements is often restricted and that graphically similar notation elements often get mixed up, especially by inexperienced users of BPMLs.

In order to sufficiently address the aforementioned requirements of SME, the presented approach comprises an engineering perspective and a psychological perspective on BPMLs. In the following, our methodology is introduced.

3. METHODOLOGY

This paper is based on literary analysis and expert interviews conducted within a research project. In order to address the challenges related to process modeling and the requirements of SME, the approach comprises the following stages. First, in the form of an extensive literature analysis, well-established BPMLs were identified for further examination. The resulting set of eleven BPMLs originates from disciplines like software engineering, project management, systems engineering, and information systems.

Second, and for further examination, an interdisciplinary evaluation framework for BPMLs was developed. This framework focuses primarily on the expressiveness of graphical notations on the first stage, complemented by a psychological perspective on the second stage. The framework, therefore, combines criteria from two scientific disciplines: industrial engineering and psychology.

For the first stage—a pre-selection of BPMLs—the following eleven BPMLs were systematically analyzed with SME-specific criteria from an industrial engineering perspective: 1) Structured Analysis and Design Technique (SADT) and Integration DEFinition (IDEF), 2) Petri Nets, 3) Gantt-Charts, 4) Flow Charts (according to DIN 66001), 5) Project Network Techniques (CPM, PMP, and GERT), 6) Extended Event-Driven Process Chain (eEPC), 7) Structured Analysis (SA) and Data-Flow Diagram (DFD), 8) UML 2.0 Activity Diagrams (AD), 9) Business Process Modeling Notation (BPfMN), 10) C3-Method, and 11) OMEGA. The applied criteria primarily focused on the expressiveness and comprehensiveness of the graphical notation, as well as the efficiency of application in SME. Furthermore, the applicability of these BPMLs for manufacturing processes and development processes is taken into account. As a result, the original set of BPMLs was reduced to three relevant BPMLs for further evaluation [24].

For the second stage, the Extended Event-Driven Process Chain (eEPC), the Business Process Modeling Notation (BPfMN), and the C3-Method were analyzed with psychological criteria (see Figure 1), focusing on visual-graphical characteristics of graphical notations of BPMLs.

Our framework includes two stages, since only a limited set of BPMLs can be investigated within the detailed analysis.

Figure 1: Interdisciplinary two-stage framework
4. PRE-SELECTION

Eleven BPMLs were analyzed in the pre-selection. The following three main criteria—each containing various sub-criteria—were developed from an industrial engineering point of view and primarily focus on the requirements of SME.

1) Expressiveness of the graphical notation: The specification of a BPML provides information about the number of graphical elements, their shape and size, as well as semantics to be used in a diagram. This criterion is therefore directly related to (1) and (2) (see section 2) since the graphical notation determines the modeling aspects that can be expressed. These aspects are either covered by a single graphical element or a construct, i.e., a combination of elements. Ideally, there should be a corresponding graphical element or construct for every concept investigated. The non-existence of a graphical element therefore limits the application range of the BPML in terms of representing either manufacturing and development processes, or both.

2) Comprehensiveness of graphical elements: This criterion addresses usability issues mentioned in (3). It comprises both the comprehensiveness of graphical elements and the process model. From the viewpoint of an observer, the following details should be clearly recognizable:
   - The sequence of process steps,
   - start event and end event,
   - allocation of activities to organizational units, and
   - differences between graphical elements in terms of shape and size.

Despite, the degree of formalization should not have a negative impact on the comprehensiveness of the process model, i.e., the level of abstraction should provide intuition, meaning that the process model should produce a clear mental picture of the model with few or without any methodological background of the employee.

3) Efficiency of application: This criterion comprises sub-criteria that determine the effort for the introduction and application of a BPML. With regard to capturing processes, the time needed to draw a paper-based process model on the shop floor is also an issue. Within this context, the graphical complexity of the notation elements is a concern. This criterion complements our first criterion since both aspects are defined in the specification of a BPML.

Our set of criteria was applied to the eleven BPMLs. The results are briefly described in the following:

**Structured Analysis and Design Technique (SADT) and Integration DEFinition (IDEF):** The graphic modeling language SADT was developed by Ross [25] as a tool for system design. It comprises a data model and an activity model, whereas the activity model can be used for the graphical representation of organizational processes. Organizational processes modeled with SADT’s derivative functional modeling method IDEF show only few notation elements: functions, a single type of connector, and—dependent on the development stage (IDEF0 and IDEF14)—gateways and constructs representing decision-making. Comprehensiveness is therefore provided but, on the other hand, expressiveness of the graphical notation is violated to a large extent. SADT and IDEF diagrams provide a too lean set of elements to satisfy the needs of SME.

**Petri Nets:** Petri nets [26] are a tool for modeling, analysis, and simulation of dynamic systems with concurrent and non-deterministic procedures. Applying Petri nets to extensive modeling of complex organizational processes, however, does not lead to a clear mental model on the side of the observer. Comprehensiveness is therefore not provided since Petri nets use a very abstract notation. Due to their mathematical foundation Petri nets cannot be assimilated by employees without an adequate methodological background. Petri nets primarily consist of nodes, places, and transitions, so that they should be easy to learn. Expressiveness is particularly violated because of the too lean set of graphical symbols.

**Gantt-Charts:** This presentation format is preferred by many executives since it clearly illustrates milestones, and demonstrates individual resources scheduled to time. To this purpose, they use an arrangement of parallel bars of different colors. Even extended Gantt-Charts [27] offer only a very limited graphical notation. They do not offer a sufficient amount of concepts and graphical elements and, therefore, cannot adequately illustrate a sequence of organizational process steps with information flows and decisions to be made.

**Flow Charts (according to DIN 66001:1980[28]):** Flow charts are easy-to-understand diagrams illustrating the flow between actions and decisions with the help of connectors. They were developed for program scheduling in system design. Their notation is easy-to-use due to a manageable amount of elements. Therefore, the mapping of organizational operations in a flow chart can be enacted without a specific methodological background—comprehensiveness is provided. There are several drawbacks compared to other examined BPMLs, mainly concerning the expressiveness of the graphical notation.

**Project Network Techniques (according to DIN 69900:2009[29]):** Network techniques have proven themselves as important tools of project scheduling in science and practice. Both the deterministic (CPM and PMP) and the stochastic techniques (PERT and GERT), however, do not provide an expressive and comprehensive graphical notation. Thus, the enactability of organizational processes is limited. Increased efficiency can be obtained by application of software tools but employees would have to face time-consuming and cost-intensive trainings to achieve an adequate level of expertise.

**Extended Event-Driven Process Chain (eEPC):** The industry standard eEPC [30] has been developed for designing, implementing, and controlling organizational processes. The different views of eEPC are easy-to-understand and use, but the integration of different views is necessary in order to sufficiently capture an entire process—including roles, activities, and resources. Besides, expressiveness is satisfactory as eEPC includes a graphical element for event, function, organizational unit, information, as well as control and information flow. The eEPC are therefore taken into consideration for further examination.

**Structured Analysis (SA) and Data-Flow Diagram (DFD):** The SA [31] is an important tool within the field of software engineering, originally designed for systems design and analysis. Its graphical representation—showing the data flow through an information system—is a data-flow diagram (DFD). These diagrams are easy-to-understand as the graphical notation only uses elements for function, file/database, input/output, and flow. Although the graphical notation allows the representation of organizational processes to a certain degree, it is too lean to satisfy the needs of SME in terms of expressiveness and comprehensiveness. With regard to DeMarco’s [31] recommendation not to exceed more than seven activities in a
DFD, the SA is not a reasonable choice for capturing, analyzing, and designing organizational processes.

**UML 2.0:** UML [32] Activity diagrams (AD) were originally designed to represent processes and flows in software systems. Besides common graphical notation elements, UML 2.0 AD incorporates roles (swimlanes) and, therefore, enables the allocation of activities to organizational units. The graphical representation however, does not provide graphical elements for cooperative work, iterations, and aggregation of activities. The latter is an important issue in the pre-selection, to enable modeling of manufacturing and development processes on equal terms. Considering the mentioned deficiencies UML is excluded from further examination.

**Business Process Modeling Notation (BPMN) 1.2:** The development of BPMN [33] aimed at providing a business-oriented standard graphical notation to facilitate collaboration within and between companies, and providing a knowledge basis for business process improvement. The BPMN specification (Version 1.2) reveals a very rich set of graphical elements and icons, which broadens the application range of the BPMN, but is supposed to be time-consuming to learn. Some elements are very subtle and, therefore, difficult to draw. There is a high level of graphical complexity for some elements, which is made more complex by the fact that some elements hardly differ from each other. Expressiveness and Comprehensiveness is nevertheless provided. With regard to the fulfillment of these application-oriented criteria, and a detailed specification, BPMN will be subject to further examination.

**C3 (Coordination, Cooperation, and Communication):** The characteristics of development processes were catalyst for the development of C3. Its graphical notation, therefore, offers elements for cooperative work, communication among process stakeholders, and shortcomings [34]. Most of the elements originate from UML, complemented by selected elements from Higraphs [35] and Task Object Charts [36]. Experience from various applications shows that the C3 graphical notation is comprehensive and expressive on equal terms, no matter if the observer or model designer is an expert or not [37].

**OMEGA:** This method [38] for capturing, modeling, and analyzing business processes has been further developed since 1998. Its graphical notation incorporates elements for organizational units and communication between them, input and output objects, splitting, and synchronization, expressiveness is provided to a large extent. There are two major shortcomings: 1) The high graphical complexity of its elements, and 2) the difficult perception of responsibilities of an organizational unit due to non-stationary representation of organizational units. Moreover, the characteristics of development processes are not considered, and therefore do not make OMEGA a reasonable choice for the modeling of organizational processes in SME.

For the detailed analysis, BPMN, eEPC, and the C3-method will be examined from a psychological point of view.

### 5. DETAILED ANALYSIS

The development of psychological evaluation criteria was based 1) on theories of cognitive psychology and human information processing [39; 40; 41] and 2), on existing evaluation frameworks [22] which were fine-adjusted with regard to our specific evaluation purposes.

In this section, the psychological evaluation criteria are described (Table 1). They refer to “external” visual-graphical characteristics and design features, as well as to “internal” semantic aspects such as the conceptual meaning of notation elements.

| Table 1: Description of psychological evaluation criteria |
|-----------------|-----------------|-----------------|
| **Criterion**   | **Description**  |
| Method-specificity | The BPMN has a method-specific notation system. |
| Standardization  | The visual-graphical design of notation elements is standardized. |
| Number of notation elements | The number of notation elements of the specific BPML. |
| Level of abstraction | The notation system consists of abstract notation elements. |
| Visual expressiveness | The notation elements have a high visual expressiveness (due to the visual features used for notation element design). |
| Visual redundancy | The compared notation systems use identical notation elements. |
| Conceptual completeness | The notation system has a wide conceptual expressiveness. |

### Application of psychological evaluation criteria

Three trained experts carried out the application of evaluation criteria to the notation systems. In total, the expert ratings showed high levels of consistency ($r = .7$, $p < 0.05$). Deviant ratings were discussed among experts until a common rating was found.

The findings, i.e. the expression of each criterion for the respective notation systems are visualized in Table 2. Moreover, the findings regarding the application of visual-graphical evaluation criteria to the specific graphical notation are summarized and evaluated with regard to their learnability and usability when used by SME.

| Table 2: Application of psychological evaluation criteria |
|-----------------|-----------------|-----------------|-----------------|
| **Criterion**   | **BPMN** | **eEPC** | **C3** |
| Method-specificity | ● | ● | ● |
| Standardization  | ○ ● | ○ ● | ○ ● |
| Number of notation elements | ● | ○ | ● |
| Level of abstraction | ● | ● | ● |
| Visual expressiveness | ○ | ○ | ○ |
| Visual redundancy | * | * | * |
| Conceptual completeness | ○ | ○ | ● |

Legend: ● = high expression of the criterion, ○ medium expression of the criterion, O = low expression of the criterion. * The criterion of visual redundancy is not described in the table, since the redundancy relationships between the graphical notation (C3-eEPC, C3-BPMN, and eEPC-BPMN) cannot be integrated into the chosen type of visualization.

Applying the evaluation criteria to the C3-method, it can be stated that the C3-method has an own, method-specific notation system, which should be easy to learn and use due to its manageable number of notation elements (23 elements). The limited degree of standardization of the C3-method allows for individual adaptation. However, the semi-formality of notation
element design might complicate further (computer-based) processing steps (e.g. for simulations). The high level of abstraction and the low visual expressiveness of C3-notation elements might lead to confusion among users and to a limited comprehensiveness of notation elements. Further, for C3- and BPMN notation elements a high degree of visual redundancy was found. Finally, the C3 notation system has a comparably high conceptual expressiveness, i.e. the notation system comprises of a broad range of concepts necessary for process modeling.

The eEPC-notation system represents the oldest notation system of the modeling method sample and it is used by several BPMLs [42]. The notation system is not method-specific and – in its original form – it contains the lowest number of notation elements (11 elements). The eEPC-elements are characterized by a high level of abstraction, a low level of visual expressiveness and a comparably low degree of standardization. Moreover, the conceptual span of the eEPC system is rather incomplete. The restricted number of notation elements, the conceptual incompleteness and the low degree of standardization might be the reason for the multitude of variations of eEPC, which can be found in praxis.

The BPMN notation (Version 1.2) system is the “youngest” notation system in the sample. The notation system is not method-specific, as is used by executable languages like BPEL. Although the BPMN-system has a rather high number of notation elements (37 elements), it only has a medium degree of conceptual completeness. The high number of notation elements might complicate the acquisition and application of the BPMN-notation system by SME. By using colors in notation elements, however, the BPMN-system achieves higher a degree of visual expressiveness.

Summarizing so far, the application of psychological criteria showed, that the analyzed notation systems distinctly differ according to their degree of standardization, level of abstractness, visual expressiveness, visual redundancy, and conceptual completeness, which has significant implications for usability of BPMLs.

6. CONCLUSIONS

Effective, efficient, and sustainable use of a BPML poses a challenge for any enterprise, particularly for SME due to scarce financial and personnel resources. Since SME need decision support to select an adequate BPML, an interdisciplinary evaluation framework was developed and applied to a relevant set of practice-oriented BPMLS. This framework primarily focused on the graphical notation of BPMLs and incorporated criteria from an engineering perspective, as well as from a psychological perspective regarding visual-graphical characteristics of graphical notations. In the following, the findings of the evaluation with regard to the selection of the most suitable BPMLs for SME and the methodological approach of an interdisciplinary evaluation framework are discussed.

Summarizing the findings of the interdisciplinary evaluation framework so far, it can be concluded that the C3-method is the most suitable BPML for SME. The application of the evaluation framework demonstrated that only C3, BPMN, and eEPC are capable of modeling manufacturing and development processes on equal terms. Moreover, most BPMLs, e.g., SADT (IDEF), Petri Nets, Gantt-Charts, Flow Charts, Project Network Techniques (CPM, MPM, PERT and GERT), SA (DFD), UML, and OMEGA, only offer a limited set of notation elements, do not support the modeling of development processes, and are not capable of representing inter-departmental relations and decision processes. The C3-method is an exception. Its graphical elements primarily descended from the UML notation in 1999, complemented with graphical elements for cooperative task modeling. The C3-method has already proven its practical suitability in various research projects and has been included in a training concept for process capturing and modeling. Within the scope of the project, the training concept was successfully tested with inexperienced employees from a cooperating SME.

Summarizing the engineering perspective with psychological criteria, it was confirmed, that the C3-notation system—in comparison to the other two notation systems (eEPC and BPMN)—offers the highest degree of conceptual completeness, i.e. it contains a broad range of concepts necessary for process modeling. On the other hand, the manageable number of notation elements of the C3-system might benefit the acquisition and application of the method, even by users with restricted experience in process modeling. Thus, the evaluation framework and the identified BPML – the C3-method - enable SME to use and to take advantage of BPMLs to meet their economical requirements in a competitive global market. Moreover, the application of psychological evaluation criteria leads to two recommendations:

1. Due to the limited visual expressiveness of the C3-elements we strongly recommend a design evaluation of C3-notation elements, which might lead to a design revision in order to improve the comprehensiveness and usability of notation elements.

2. As the high level of abstractness of notation elements (and the whole process of process modeling itself) might hamper an effective and efficient usage of BPMLs in SME. C3 trainings should be developed in order to support first-time-users of BPMLs in SME.

The methodological approach of combining evaluation criteria from different scientific perspectives in one evaluation framework regarding BPML was found to be a promising approach, which should be expanded in future research activities. The joint application of criteria from engineering science and psychology on BPMLS leads to a broader evaluation range (including visual-graphical characteristics of BPML) and allows for cross-validation purposes (e.g. regarding the conceptual power of BPML). It enables the deduction of concrete action steps (design revision, training) when using BPMLs in SME.

Within the scope of the project, further empirical studies including user error analysis, problem-solving tasks, recall tasks, and comprehension tasks, application-oriented aspects of process modeling will be investigated. The results might provide new insights concerning the usability of BPMLs, broaden their application range, and lead to a more extensive use of BPM in SME.

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8. REFERENCES
