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Business Process Analysis and Optimization: Beyond Reengineering

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***Abstract*—There is an abundance of business process modeling techniques that capture and address different aspects of a business process. A limited number of these process models allow further quantitative analysis, and only a few enable structured process improvement. This paper reviews and classifies the main techniques for business process modeling with regard to their analysis and optimization capabilities. Three primary groups are identified, and a selection of representative business process modeling techniques is classified based on these. Similar classification is also presented for the analysis and optimization approaches for business processes that were identified in relevant literature. The main contribution of the paper is that it identifies which types of business process models are suitable for analysis and optimization, and also highlights the lack of such approaches. This paper offers a state-of-the-art review in the areas of business process modeling, analysis, and optimization—underlining that the latter two have not received enough coverage and support in the literature.**

***Index Terms*—Business process (BP), BP analysis, BP modelling, BP optimization, business processes, reengineering.**

I. Introduction

BUSINESS processes have received ample attention for more than a decade. Many approaches have been proposed, many promises were made, but the spectacular results that the reengineering revolution vowed were never fully realized, making more and more people hesitant about the whole concept. One of the many reasons is that apart from enthusiastic descriptive proposals, a structured and repeatable methodology that could be generally applied to business process modeling and improvement was never established. Compared with the large number of proposed business process modeling techniques and qualitative analysis approaches found in literature, business process optimization has received little coverage. While the term "*improvement*" implies a qualitative approach of developing an existing business process to a better version, "*optimization*," as discussed in a later section, is more automated improvement of business processes using prespecified quantitative measures of performance (objectives).

This paper discusses business processes by introducing a novel classification scheme for business process models and presenting the current trends in analysis and optimization approaches. The paper is organized as follows. Section II introduces the most representative business process modeling approaches and classifies them in three groups based on their characteristics. Section III identifies the different types of business process analysis techniques and classifies them in a similar way. Section IV justifies the necessity to move from business process improvement to structured optimization and identifies the scarce optimization approaches in the literature. The last section presents an overview of all the classifications presented and highlights the current situation, the research gap, and the directions for future development regarding modeling, analysis, and optimization techniques for business processes.

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II. Business Process Models: A Novel Classification

Havey [28] provides a simple definition of business processes as "step-by-step rules specific to the resolution of a business problem." Since the 1990s when the first definitions of business processes appeared in the literature, many authors attempted to focus business processes on specific directions. However, in almost every reference in this area, two particular business process definitions are reverently cited. The first comes from Hammer and Champy [25], who state that "a *business process* is a collection of activities that takes one or more kinds of inputs and creates an output that is of value to the customer," and second is from Davenport [14], who claims that "a *business process* is defined as the chain of activities whose final aim is the production of a specific output for a particular customer or market." There are references such as [46], [47], and [67] that provide compilations of the various business process definitions.

Business process modeling plays a major role in the perception and understanding of business processes. In most of the cases, a business process is as expressive and as communicative as is the technique that has been used to model it. Therefore, the elements and the capabilities of a business process model play a significant role in describing and understanding a business process. There is an abundance of business process modeling techniques with approaches that capture different aspects of a business process, each having distinctive advantages and disadvantages. Authors such as Kettinger *et al.* [34], Melao and Pidd [47], and Aguilar-Saven [2] have provided frameworks for presenting and classifying different business process modeling techniques. Kettinger *et al.* [34] conducted a thorough study of business process reengineering methodologies (25), techniques (72), and tools (102) that are adopted by 25 international consultancy firms. The study reveals that, in every stage of the reengineering process, there are a variety of approaches followed. Kettinger *et al.* [34] report a widespread use of process capture and modeling techniques. They also present a comprehensive list of the appropriate software tools and the techniques (e.g., process flowcharting, data flow diagramming) that each of the tools supports. However, there is not much emphasis on process modeling itself as it is viewed merely as a technique among others that constitute the wider picture of business process reengineering.

Melao and Pidd [47], on the other hand, focus exclusively in business processes and their modeling. They adopt four different perspectives for understanding the nature of business processes first, and then, identify the most common modeling approaches for each perspective. The first perspective views business processes as *deterministic machines*, that is, as a fixed sequence of well-defined activities that convert inputs to outputs in order to accomplish clear objectives. For this perspective, static process modeling is sufficient, with techniques such as integrated definition methods (IDEF0, IDEF3) and role activity diagrams (RADs). The second perspective views business processes as *complex dynamic systems*, assemblies of interchangeable components. This second viewpoint focuses on the complex, dynamic, and interactive features of business processes. The authors suggest discrete event simulation (discussed later in this paper) as a suitable way to model the dynamic behavior of this approach. The third perspective of business processes is *interacting feedback loops* that highlight the information feedback structure of business processes. System dynamics modelers are recommended for this perspective. The last perspective of business process is *social constructs*, and emphasizes more on the people side. It is the people who made and enact business processes, people with different values, expectations, and roles. This soft side of business processes can be modeled with soft unstructured illustrative models. However, a real-life business process involves elements for all the four perspectives, and therefore, it is evident that there is no such modeling technique that can embrace all this variety of characteristics that constitute a business process.

Another notable review regarding business process modeling classification comes from Aguilar-Saven [2]. The author presents the main process modeling techniques and classifies them based on two dimensions: the first dimension is concerned with four different purposes of use, and classifies the business process models based on whether they are: 1) descriptive for learning; 2) enable decision support for process development/design; 3) enable decision support for process execution, or 4) allow information technology (IT) enactment support. The second dimension distinguishes between *active* and *passive* models. As *active* are considered those models that allow the user to interact with them (dynamic model), while *passive* are those that do not provide this capability. It is important to note that Aguilar-Saven [2] provides an extensive and updated list of software tools that are associated with all the process modeling techniques presented in the paper.

As seen from the references described before, each of the authors provides a different modeling framework according to his or her focus on specific directions. In the current paper, the authors propose a new classification scheme for business process models. The purpose of this scheme is to classify the most a range of business process models according to their structural characteristics and their capabilities for analysis and optimization. The authors propose *three sets* to classify business process

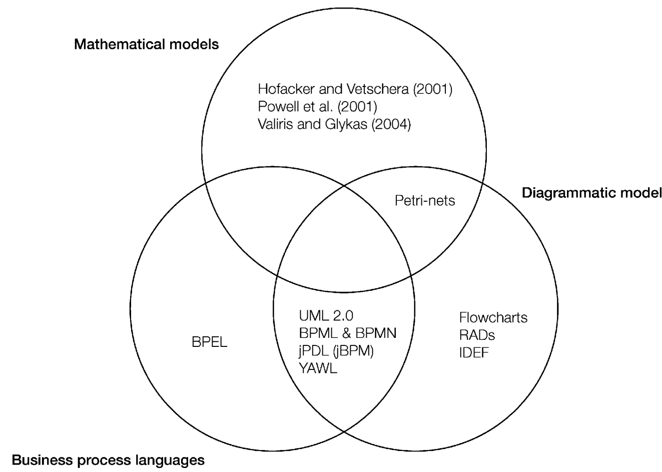

Fig. 1. Classification of business process modeling techniques.

modeling techniques, as demonstrated in Fig. 1. The first set (i.e., diagrammatic models) involves business process models that sketch a business process using a visual diagram. The second set (i.e., mathematical models) corresponds to models in which all the elements have a mathematical or a formal underpinning. Finally, the third set (i.e., business process languages) contains software-based languages that support business process modeling and most of the times process execution. The classification of the most representative modeling techniques is demonstrated using a Venn diagram in Fig. 1. Each of the techniques is further discussed later in this section. Table I presents the classification of Fig. 1 and also cites a selection of references for each of the key techniques. The remaining of this section discusses the main features of these process modeling techniques based on the set (or sets) that they belong to.

A. Diagrammatic Models—Simple and Communicative

The first techniques that were used for business process modeling were plain graphical representations (i.e., flowcharts) that were initially developed for software specification [13], [35]. These simplistic diagrams depicted a business process, but most of the times without using a standard notation [28]. These techniques are useful for fast and informal process representation, but they lack the necessary semantics to support more complex and standardized constructs. This led to the development of standard methodologies such as IDEF and Unified Modeling Language (UML) for process modeling and/or software development. Business process modeling benefited from these standardized diagrammatic approaches, as well since they are simple and easy to use. However, they have also received a series of criticisms from various authors. The central point of argument is that these modeling approaches are based on graphical notations only [85], thus lacking formal semantics [70]. They also lack quantitative information that obstructs any further analysis and development of analysis methods and tools [80]; there is no formal underpinning to ensure consistency across models [70]. Phalp and Shepperd [52] note that any analysis which attempts using these types of models often consists solely of inspection

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TABLE I
MAIN MODELING TECHNIQUES, CORRESPONDING SETS, AND SELECTED REFERENCES

Business process modelling techniques	modelling set(s)	Selected references
–Flowcharts	–Diagrammatic models	–(Knuth, 1963) –(Chapin N., 1971) –(Chapin, 1974) –(Feldman, 1998) – (Lakin *et al.*, 1996)
–IDEF	–Diagrammatic models	–(Mayer *et al.*, 1994) –(Menzel and Mayer, 1998) – (Peters and Peters, 1997) – (Zakarian and Kusiak, 2001) – (Zakarian and Kusiak, 2000) – (Zakarian, 2001) – (Badica *et al.*, 2003a) – (Shimizu and Sahara, 2000) – (Zhou and Chen, 2002)
–RADs	–Diagrammatic models	–(Ould, 1995) –(Holt, 2000) – (Phalp and Shepperd, 2000) – (Badica *et al.*, 2003b)
–UML	–Diagrammatic models –Business process language s	– (Quatrani, 2001) –(Kim *et al.*, 2003) – (Wohed *et al.*, 2004)
–Petri–nets	–Diagrammatic models –Formal/mathematical models	– (van der Aalst, 1998) – (Li *et al.*, 2004b) – (Donatelli *et al.*, 1995) – (Raposo *et al.*, 2000) – (Peters and Peters, 1997)
–Business process models based on mathematical or algorithmic models	–Formal/mathematical models	– (Hofacker and Vetschera, 2001) – (Powell *et al.*, 2001), – (Valiris and Glykas, 1999)
–BPEL –BPML	–Business process language	– (Reimer *et al.*, 2000) – (Havey, 2005) – (Grigori *et al.*, 2004) – (Smith, 2003)
–jPDL (jBPM)	–Diagrammatic models –Business process languages	– (Koenig, 2004)

of diagrams and the conclusions are heavily dependent upon the skills of the analyst.

Although visual inspection of diagrams tends to be highly subjective, these diagrams are still widely used in business process environments. The unbeatable advantage to visually depict the flow of a business process in a way that no technical expertise is required is very appealing to the business analysts. Even advanced and more sophisticated modeling techniques are influenced by this perspective, and they support apart from formal semantics and a visual representation of the modeled processes. A typical example is the Petri nets, discussed later.

B. *Formal/Mathematical Models—Consistent But Complex*

The necessity for formal semantics to business process modeling led to a second generation of *formal* models. Formal models are the ones in which process concepts are defined rigorously and precisely, so that mathematics can be used to analyze them, extract knowledge from them, and reason about them. An advantage of formal models is that they can be verified mathematically, and can be checked for consistency and other properties [38]. These models are in line with van der Aalst *et al.*'s [79] suggestion that business process models "should have a formal foundation" because formal models do not leave any scope for ambiguity and increase the potential for analysis. However, there is a lack of formal methods to support the design of processes [30] because business process elements and constraints are mostly of qualitative nature, and it is hard to characterize them in a formal way amenable to analytical methods [68]. This explains the difficulty of developing "parametric" models of business processes and the fact that only a few practical examples are found in relevant literature [30].

A Petri net is an example of a business process modeling technique that combines visual representation using standard notation with an underlying mathematical representation. A Petri net is a graphical language that is appropriate for modeling systems with concurrency [73]. The graph of a Petri net is a directed, bipartite graph consisting of two kinds of nodes, called places and transitions. Petri nets have been modified and extended by various researchers to allow for more powerful modeling capabilities. Some of their variations include timed Petri nets, stochastic Petri nets, colored Petri nets, and hierarchical Petri nets [36].

Coming to the approaches that use mathematical models only, there is not a widely accepted model. This results into different authors presenting their individual approaches toward mathematical business process modeling. An approach that has a mathematical basis is proposed by Hofacker and Vetschera [30]. They describe a business process using a series of mathematical constraints (that define the feasibility boundaries of the business process) and a set of objective functions (that consist of the various objectives for business process design). Although this approach cannot model complex modeling constructs and there is no emphasis on the diagrammatic representation, it is appropriate for further quantitative analysis and improvement as it is based on a mathematical model. A similar approach is presented by Powell *et al.* [54]. They describe a mathematical model that has the main ingredients of a generic business process. Valiris and Glykas [70] also propose the use of formal mathematical notations as a way of introducing business rules and verifying the logical consistency of diagrammatic models.

Despite their advantages over simple diagrammatic approaches, criticisms for formal/mathematical business process models have also been reported. Building a formal business process model can prove much more complex and demanding compared to traditional techniques where a process diagram is sufficient [30]. These authors also show that the representation of real-life processes using mathematical models may be complex and sometimes not possible as these include complex features such as decision points, feedback loops, and parallel or hierarchical flow. Koubarakis and Plexousakis [38] note that the use of complex mathematical notations might discourage the business analyst since "it is a lot of work to create, maintain a formal business process and retain its consistency." However, as a diagram can lead to ambiguity about the process, the formal model ensures that the process is described accurately, and analysis tools can be used to extract quantitative information about the process. This is the main advantage of formal business process modeling techniques.

C. Business Process Languages—New and Executable

The third—and most recent—generation of business process modeling techniques came as an attempt to tackle the complexity of the formal models but retain their consistency and potential for further analysis. As the first generation of business process modeling techniques was strongly influenced by the ones used in software development; so is this generation. Perhaps it is the dynamic, complex, and rapidly evolving nature of business process models that makes them similar to software development techniques. The third set presented here takes business process modeling a step further as it uses *process languages*—usually XML-based—to model and execute a business process. This is how business process languages were evolved. These context-specific executable languages are the latest trend in business process modeling, a trend that has already produced a number of different semantic packages, with Business Process Execution Language for Web Services (BPEL4 WS—also known as BPEL) and Business Process Modeling Language (BPML) being the most distinctive. van der Aalst *et al.* [79] remark that process languages with clear semantics are useful as they can express business process models and contribute to the analysis of their structural properties.

Havey [28] claims that BPEL is the most popular as it is supported by IBM, Microsoft, and BEA. BPEL is not a notational language but it is also XML-based, and as such, it inherits XML attributes such as programmability, executability, and exportablility. BPML is a product of the Business Process Modeling Initiative (www.bpmi.org). It is also an XML-based language that encodes the flow of a business process in an executable form. BPML is accompanied by Business Process Modeling Notation (BPMN), a graphical flowchart language that is able to represent a business process in an intuitive visual form [28]. Each BPML process has a name, a set of activities, and a handler; it also supports subprocesses. Yet Another Workflow Language (YAWL) is another—as the name itself says—graphical process language created by van der Aalst and ter Hofstede [78]. YAWL is a Petri-net-based language that was built with the primary target to support a wide range of business process patters. It has received criticism for being inadequate in terms of expressiveness and system integration capabilities [28]. JBoss Business Process Management (jBPM) execution language named jPDL [37] is also a novel approach to business process modeling and execution. This new approach facilitates the natural transition from declarative input by the business analyst to the programming logic needed to implement a business process, thus simplifying business process development and allowing even nonprogrammers to develop business processes using visual tools. jBPM engine is based on open source software, providing infrastructure to developers who have access to a variety of supplementary software tools with which they can easily design and analyze business processes in a graphical environment.

In order to assess and compare the capabilities of these modeling techniques, the authors investigated the patterns that each supports when it comes to business process modeling. A pattern, according to Riehle and Zuillinghoven [59] is "the abstraction from a concrete form which keeps recurring in specific nonarbitrary contexts." The reason pattern support is essential for a process modeling because patterns enable the standardization of solutions to commonly recurring problems within business processes and the reuse of these standardized process parts across different process models. Table II presents a selection of patterns from van der Aalst and ter Hofstede [77] that are considered as the basic constructs for any business process model and identifies which business process modeling techniques support these patterns. Most of the business process languages are implemented taking into account the process patterns of Table II. For example, YAWL supports all these patterns since it was created primarily for this purpose [77]. BPEL also supports most patterns [28], [84] and also BPML [28]. According to Koenig [37], jBPM's jPDL was also implemented to cover all the patterns presented here. Therefore, business process languages prove a reliable tool to formally model and visualize a business process in terms of constructing standardized and reusable models.

TABLE II
PROCESS PATTERNS SUPPORTED BY BUSINESS PROCESS LANGUAGES

Pattern	BPEL	BPML	YAWL	jPDL
1. Sequence	✓	✓	✓	✓
2. AND-split & join	✓	✓	✓	✓
3. XOR-split & join	✓	✓	✓	✓
4. OR-split & join	✓	×	✓	✓
5. Discriminator	×	×	✓	×
6. Arbitrary cycles	✓	✓	✓	✓
7. Cancel activity	✓	✓	✓	✓
8. Cancel case	✓	✓	✓	✓

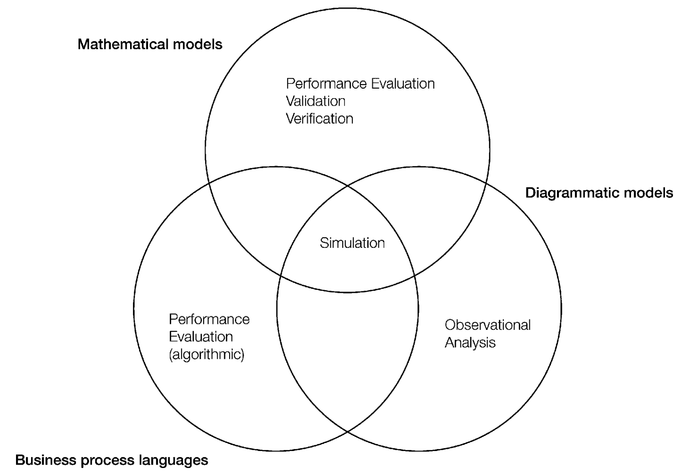

Fig. 2. Types of process analysis against the business process modeling sets.

III. BUSINESS PROCESS ANALYSIS: AN OVERVIEW

According to Irani *et al.* [31], businesses should not be analyzed in terms of the functions in which they can be decomposed to or in terms of the products they produce, but in terms of the key *business processes* that they perform. Due to the complexity of process design and control encountered in modern businesses, there is a need for the development of suitable analysis techniques [73]. However, *business process analysis* is a term used with a rather broad meaning including a range of different tactics such as simulation and diagnosis, verification, and performance analysis of business processes. van der Aalst *et al.* [79] underline that business process analysis should aim at investigating properties of business processes that are neither obvious nor trivial. Boekhoudt *et al.* [11] justify the necessity for analysis of business process models in order to clarify the business process characteristics, identify possible bottlenecks, and compare any potential process alternatives. Yet most of business process analysis approaches are based on subjective rather than objective methods [70]. In line with van der Aalst *et al.* [79], Boekhoudt *et al.* [11] also report that among the modeling techniques, those that have formal semantics and mathematical basis are the most suitable for analysis. Irani *et al.* [31] citing Davenport [14] state that to understand and analyze a business process helps to recognize the sources of problems and ensure that they are not repeated in the new process, thus providing a measure of value for the proposed changes. This approach opposes the radical attitude toward business process redesign introduced by Hammer and Champy [25]. This section presents the different types of business process analysis and presents a variety of representative approaches found in literature.

A. Different Analysis Types: From Observational Analysis to Performance Evaluation

There are different *types* of analysis related to business process. Fig. 2 presents these different analysis types in a Venn diagram. It matches the types of process analysis to each of the three business process modeling sets introduced in the previous section. For the first set of business process modeling (i.e., diagrammatic models), only *observational analysis* is at hand. Observational analysis, which primarily entails altering the process structure via inspection of the diagrams [3], is the most common analysis approach using visual models of business processes [52]. The observational analysis technique offers a set of options to redesign a process that includes eliminating nonvalue-added activities (e.g., redundant, rework, and supervisory activities), simplifying activities, combining activities, increasing the concurrency of activities and automating activities [39]. However, this analysis approach can be time-consuming and heavily dependent upon the experience of the modeler whose conclusions are frequently based upon his knowledge of the particular business domain and his skills [50]. Zakarian [85] recognizes that diagrammatic process models have qualitative notation, and this results in the lack of analysis tools, thus making the application of quantitative methods very unusual [82] and also unattractive. Making business process analysis meaningful and attractive is not only linked to the construction of ever-more detailed maps, which use increasingly sophisticated representational techniques, but also the willingness to combine seemingly irreconcilable strategies for analysis [10].

When analyzing a business process, it is necessary to have mechanisms more sophisticated than simple qualitative analysis of static diagrammatic models. Authors such as Aguilar-Saven [2] and Zakarian [85] stress the need for formal techniques for analysis of process models, in order to make process modeling methodologies more attractive and meaningful. The need for quantitative analysis of the business process models is one of the major reasons for the evolution of process models with formal underpinning (i.e., mathematical models set). These formal approaches to modeling of business processes provide a sound basis for setting performance indicators that measure the attainment of strategic goals and objectives by relating these goals and objectives to the core processes [42]. For these to occur, analyses types that present both dynamic and functional aspects of the process are required. According to van der Aalst [73], most of the techniques that are used for the analysis of formal business process models originate from operations research.

Fig. 2 demonstrates that the three different types of business process analyses proposed by van der Aalst [75] (having workflows—and in particular Petri nets—in mind) belong to the mathematical models set:

1) *validation*, i.e., testing whether the business process behaves as expected in a given context;
2) *verification*, i.e., establishing the correctness of a business process;
3) *performance analysis (or performance evaluation)*, i.e., evaluating the ability to meet requirements with respect to throughput times, service levels, and resource utilization or other quantitative factors.

It is obvious that none of the aforementioned analysis types can be applied to a visual diagram only; formal underpinning of the process model is required. Validation checks whether the system behaves as expected in a particular context, while verification checks whether the business process model is free of logical errors [73]. Verification, unlike validation, is context independent; it detects, for example, deadlocks in process designs a logical error independent of the purpose of the process. Performance evaluation aims to describe, analyze, and optimize the dynamic, time-dependent behavior of systems [29], [55]. Validation can be done by interactive simulation: a number of fictitious cases are fed to the system to see whether they are handled well. However, verification and performance analysis require more advanced analysis techniques [75]. Li *et al.* [44] present another classification of business process analyses. This classification is very similar to that proposed by van der Aalst [75]. According to Li *et al.* [44], workflow model analysis is conducted mainly at three levels—the logical, the temporal, and the performance levels that deal with different aspects of a workflow model. Logical level focuses on the correctness of the various process events (i.e., verification), and temporal level focuses on the interval dependency relations of a workflow model with imposed timing constraints (i.e., validation). The logical and temporal levels ensure only a functionally working workflow but not its operational efficiency. The performance level focuses on evaluating the ability of the workflow to meet requirements with respect to some key performance indicators. Although performance analysis of business processes is recognized as a significant step toward quantitative analysis of business processes, it has not captured the attention of many researchers [63].

The concept behind business process languages is to make a process executable, and hence, amenable to quantitative analysis. However, for business process languages set, only simulation is proposed in literature explicitly. Simulation is a software-assisted technique for analyzing business process; it is discussed later in a separate section. Although formal languages have been exploited in order to define and model business processes, the use of formal languages to handle the performance evaluation of workflows has received little coverage [1]. However, some process languages have associated analysis techniques that can be used for investigating process properties. These techniques can then be relied upon to provide insight into the behavior and characteristics of a business process model specified in the language [79]. According to the authors' opinion, this level of modeling and execution of business processes (i.e., using a process language) is the most suitable for the application of any analysis technique. These can be in the form of algorithmic expressions that can be expressed using the process language, and thus, be integrated within the process model. However, it is not sufficient to just develop these techniques. It is important to look at methods and tools to make them applicable in the practical context [73].

B. Simulation of Business Process Models

Simulation is a popular technique for analyzing business processes, and it can involve other types of analyses mentioned before. According to Volkner and Werners [82], many problems of business processes have similarities to problems in project management or production process planning that have already been solved successfully using simulation. Simulation provides a structured environment in which one can understand, analyze, and improve business processes [23]. Business process simulation is used to assist decision-making by providing a tool that allows the current behavior of a system to be analyzed and understood. It is also able to help predict the performance of the system under a number of scenarios determined by the decision maker [22]. Process simulation facilitates process diagnosis (i.e., analysis) in the sense that by simulating real-world cases, what–if analyses can be carried out [73]. The advantage of simulation is that it is a very flexible technique [74] because it can be used to obtain an assessment of the current process performance and/or to formulate hypotheses about possible process redesign [1].

Modern simulation packages allow for both the visualization and performance analysis of a given process [74] and are frequently used to evaluate the dynamic behavior of alternative designs [3]. Visualization and graphical user interface are important in making the simulation process more user friendly. According to Fathee *et al.* [18], simulation is most useful for the analysis of stable business processes and less useful for dynamic systems that do not reach equilibrium. The main advantage of simulation-based analysis is that it can predict process performance using a number of quantitative measures such as lead time, resource utilization, and cost [22]. As such, it provides a means of evaluating the execution of the business process to determine inefficient behavior [19]. Thus, business process execution data can feed simulation tools that exploit mathematical models for the purpose of business process optimization and redesign [1]. Dynamic process models can enable the analysis of alternative process scenarios through simulation by providing quantitative process metrics such as cost, cycle time, serviceability, and resource utilization [23]. These metrics form the basis for evaluating alternatives and selecting the most promising scenario for implementation [41]. However, these analytical models (mostly mathematical), according to Gunasekaran and Kobu [23], have not received much attention due to their complexity despite their ability to play a greater role in measuring performance and in conducting experiments.

The advantages of applying simulation are: 1) the possibility for the quantitative analysis of business processes with consideration to their dynamic characteristics; 2) the possibility for a systematic generation of alternatives by modifications in identified weak points; and 3) the high flexibility in modeling as

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TABLE III
BUSINESS PROCESS ANALYSIS APPROACHES BASED ON MODELING SETS AND ANALYSIS TYPES

business process MODEL	**modelling SET(S)**	**business process analysis TYPES**	**business process analysis APPROACHES**
–IDEF	–Diagrammatic models	–Observational –Simulation	– (Kusiak and Zakarian, 1996a) – (Kusiak and Zakarian, 1996b) – (Zakarian and Kusiak, 2001) – (Zakarian and Kusiak, 2000) – (Zakarian, 2001) – (Badica *et al.*, 2003a) – (Peters and Peters, 1997) – (Shimizu and Sahara, 2000)
–RADs	–Diagrammatic models	–Observational –Performance analysis	– (Phalp and Shepperd, 2000) – (Badica *et al.*, 2003b)
–Petri–nets	–Diagrammatic models –Mathematical/formal models	–Observational –Validation –Verification –Performance analysis –Simulation	– (van der Aalst, 1998) – (van der Aalst *et al.*, 1994) – (van der Aalst and van Hee, 1996) – (van der Aalst, 1995) – (van der Aalst, 2003) – (Kiepuszewski *et al.*, 2003) – (Li *et al.*, 2004b) – (Donatelli *et al.*, 1995) – (Gao *et al.*, 2003) – (Raposo *et al.*, 2000) – (Peters and Peters, 1997)
–Mathematical models	–Mathematical/formal models	–Performance analysis –Simulation	– (Powell *et al.*, 2001) – (Valiris and Glykas, 2004)
–Business process languages	–Business process languages	–Performance analysis (algorithmic) –Simulation	(none reported in literature)

well as an adequate consideration of stochastic influences [82]. However, simulation has some weak points as well. Some authors [22], [82] report the large costs involved and the large amount of time to build a simulation model due to the complexity and knowledge required building such models. van der Aalst [74] underlines that simulation supports only "what–if" analysis and does not suggest any process improvements. Basu and Blanning [8] also claim that while process simulation can provide useful insight into process behavior, it does not address questions about the interrelationships among process components.

C. Compilation of Approaches Regarding Business Process Analysis

After identifying the main analysis types for business process, the most relevant approaches found in literature are discussed. Table III presents the analysis types and approaches for a selection of business process modeling techniques. For each process modeling technique, the table cites the modeling set(s) it belongs to (Fig. 1), the types of analyses applicable based on these sets (Fig. 2), and a selected number of related approaches (references). According to Table III, most analysis approaches reported in the literature are based on models that belong to the diagrammatic models set. Also, no analysis approach is reported for the business process languages set.

IDEF models have been a starting point for business process analysis for authors such as Kusiak and Zakarian who have published a series of papers (refer to Table III for references) exploring and analyzing various aspects of IDEF models. The most representative is Zakarian's [85] where the author is using an IDEF3 model attempting to model and analyze/quantify a business process using a combination of fuzzy logic and rule-based reasoning. Using—although not explicitly mentioned—observational analysis, he extracts IF–THEN fuzzy rules from the IDEF3 model and defines a number of linguistic variables. The linguistic variables are categorized into fuzzy sets that are defuzzified by assigning precise boundaries. The process is accurately executed, and its output is quantified and predicted by eliminating the values of each variable. Combinations of different values for each variable can be applied to analyze and test the process and its outputs. Peters and Peters [51] also present a tool to simulate an IDEF0 model by making dynamic transformations. Other IDEF-based analysis approaches come from Badica *et al.* [5] and Shimizu and Sahara [65]. Another group of analysis approaches is related to the quantification of RADs. Phalp and Shepperd [52] attempt to quantify RADs. The authors extract a metric (coupling ratio) to measure the correlation between actions (sole activities of a role) and interactions (involvement of another role). By reducing coupling, roles can become more autonomous within the process because they do not need to synchronize. Badica *et al.* [6] attempt to map and quantify RADs using a similar approach.

When it comes to process models with formal underpinnings, two main approaches are identified: those built around Petri nets and those that use mathematical models of business processes. van der Aalst has produced a series of papers focusing on different aspects of Petri nets and workflow analysis (refer to Table III for references), but he tends to focus more on validation, verification, and correctness of workflows rather than on performance analysis. Other analysis approaches include that of Donatelli *et al.* [16] that involves process algebra and stochastic Petri nets, and Gao *et al.* [21] that applies fuzzy reasoning to Petri nets. In terms of mathematical models, Powell *et al.* [54] propose a

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series of mathematical formulations and ratios to measure, analyze, and control business processes. Valiris and Glykas [71] propose a framework that contains a series of metrics for business processes. As mentioned previously in this section, as of now, there are no reported analysis approaches explicitly for business process languages. This gap and its potential are discussed later in this paper.

IV. Business Process Optimization Beyond Reengineering

As the previous section discussed, business process modeling does not add much value without further inspection and analysis of the business processes model. Likewise, process analysis has little value, unless it helps in improving or optimizing a business process [79]. Process improvement can occur through associated formal techniques [79] that support both the modeling and the analysis of business processes [80]. A holistic approach toward business processes should capture a business process (business process modeling), provide the necessary means for bottleneck identification and performance analysis, and—eventually—generate alternative improved business process(es) in terms of specified objectives. But often this last part (business process optimization) is overlooked—if not completely neglected—in business process literature. This section discusses the difference between process improvement and optimization, and provides a classification of the current business process optimization approaches.

A. Improvement Is Not Enough

Business process improvement started as part of business process redesign and/or reengineering efforts that promised exceptional results. Gunasekaran and Kobu [23] claim that a business process has to undergo fundamental changes to achieve significant performance improvements. According to Soliman [66], the objectives of business process reengineering are to improve the business processes and reduce costs. However, although most of the business process reengineering (or redesign) attempts in literature claim to support business process improvement, there are scarce cases that describe with sufficient details the actual improvement steps that need to be undertaken. Jaeger *et al.* [32] is a typical case where business process improvement is limited to a broad description of steps that need to be undertaken. The steps according to these authors are as follows.

1) Specify the system.
2) Identify the performance bottleneck(s).
3) Choose among the possible modifications to resolve the performance bottlenecks.

These—almost obvious—guidelines are not sufficient for a structured process improvement as they do not provide the necessary insight and level of detail for the actions that lead to process improvement. Another similar approach is presented by Aldowaisan and Gaafar [3], and it is based on observational analysis. Their technique has a set of options to redesign a process. This includes eliminating nonvalue-added activities (e.g., redundant, rework, and supervisory activities), simplifying activities, combining activities, and increasing the concurrency of activities; but again, the improvement process is not transparent. This approach does not guarantee an optimum redesign as it manually derives alternative process maps starting from the current process map.

A methodology for business process improvement is only as good as the tools and techniques that support it [7]. Unfortunately, the literature restricts itself to descriptions of the "situation before" and the "situation after," giving very little information on the redesign process itself [57]. Valiris and Glykas [71] criticize this perspective, stating that most of these reengineering methodologies lack the formal underpinning to ensure the logical consistency of the generation of the improved business process models. This leads to a lack of systematic approach that can guide a process redesigner through a series of (repeatable) steps for the achievement of process redesign [71]. While there are several methodologies for structuring business process redesign projects, the task of developing optimal designs of business processes is left to the designer's intuition [30]. Business process optimization is the automated improvement of business processes using prespecified quantitative measures of performance (objectives), and as discussed in the next section, it is the appropriate systematic approach to fill in this gap.

B. Two Perspectives for Business Process Optimization

Business process optimization can espouse techniques from relevant disciplines. Gunasekaran and Kobu [23] claim that, within the business process context, there is a need for a wider use of decision support systems based on artificial intelligence and expert systems. They also support the need for developing queuing, linear programming, and simulation models to represent business processes and to select the optimal design. In this section, we discuss and relate two other disciplines with business processes: scheduling and evolutionary computing. Scheduling shares a range of common topics with business processes, and evolutionary computing is an already successful optimization approach in other areas.

1) Business Processes and Scheduling: Scheduling problems are similar to business process optimization problems. Both disciplines share common topics such as the optimal allocation of resources to tasks [72]. Having this in mind, a range of already successful optimization approaches from scheduling can become available to business processes taking into account what Ernst *et al.* [17] claim; that optimization capabilities are generally targeted at a specific application area and cannot be easily transferred toward another discipline.

According to Bellabdaoui and Teghem [9], the development of optimization models for planning and scheduling is one of the most useful tools for improving productivity in a large number of companies. There is a range of review papers regarding scheduling optimization approaches. Mathematical programming, especially mixed integer linear programming (MILP), has become one of the most widely explored methods for process scheduling problems because of its rigor, flexibility, and extensive modeling capability. Floudas and Lin [20] present an overview of the developments of MILP-based approaches for scheduling and observe increasing application of the formal MILP optimization framework to real scheduling problems in process and related industries. Kallrath [33] gives an overview of the current state-of-the-art of planning and scheduling problems and reaches to similar conclusions. According to this author, the state-of-the-art technology based on mathematical, especially mixed-integer optimization for planning, is quite advanced and appropriate for solving real-world planning problems. The reason is that mixed integer optimization can provide a quantitative basis for decisions, and it has proven itself as a useful technique to reduce costs and to support other objectives. Rommelfanger [60] presents another scheduling optimization approach that involves fuzzy mathematical programming. While in the case of classical models, the vague data are replaced by "average data," fuzzy models offer the opportunity to model subjective judgment of a decision maker as precisely as the decision maker is able to describe it. In contrast to classical systems, in fuzzy systems combined with an interactive solution process, the information can be gathered step by step. Another advantage of fuzzy models is the fact that mixed integer programming problems can be solved easily because the boundaries are not crisp.

These scheduling problems are inherently combinatorial in nature because of the many discrete decisions involved, such as equipment assignment and task allocation over time. Shah [64] examines different techniques for optimizing production schedules with an emphasis on formal mathematical methods. Pinto and Grossmann [53] also present an overview of assignment and sequencing models used in scheduling with mathematical programming techniques. A recent review comes from Mendez *et al.* [48] that present an extensive classification of scheduling problem types that demonstrates their great diversity. Addressing this diversity, these authors also present a general classification of optimization models as a framework for describing the major optimization approaches that have emerged over the last decade regarding scheduling.

From the aforementioned information, one can conclude that scheduling optimization is an established research area reporting successful approaches. These approaches can inspire relevant applications in business process optimization. However, business processes model other elements not covered by scheduling problems, such as decisions, business rules, etc., that are hard to be expressed mathematically. Ernst *et al.* [17] report that mathematical programming formulations can only be applied when constraints and objectives can be expressed mathematically. Hence, relevant approaches can be applied to simplified versions of business processes. As it is later discussed, there are optimization approaches on mathematically formulated business processes from authors such as Hofacker and Vetschera [30]. These approaches, although consistent, are overly complicated, and still deal with simplistic business processes. Taking into account that scheduling is solely based on mathematical models, it is questionable whether business process optimization should follow the same path or investigate alternative ways that express a business process using a variety of components.

2) Business Processes and Evolutionary Computing: Evolutionary techniques use the principles of evolution to guide the optimization process, and they have been successfully applied to several combinatorial problems. Genetic algorithms (GAs), for example, have already been used to find solutions to scheduling problems and their variants [30]. Hart *et al.* [27] present a review of applied evolutionary computing methods to scheduling problems, and they report the existence of evolutionary algorithms that are capable of tackling large and hard real-world problems and are competitive with traditional techniques. There are a number of benefits in using evolutionary-based optimization. One significant advantage lies in the gain of flexibility and adaptability to the task in hand, in combination with robust performance and global search characteristics [4]. According to Moon and Seo [49], the most attractive feature of evolutionary algorithms is the flexibility of handling various kinds of objective functions with few requirements on fine mathematical properties. Wang *et al.* [83] note that process optimization is a difficult task due to the nonlinear, nonconvex, and often discontinuous nature of the mathematical models used.

Regarding business processes, the evolutionary approaches reported are rather limited. Hofacker and Vetschera [30] have attempted to transform and optimize a business process model using GAs, but they report nonsatisfactory results. The model is based on a series of mathematical formulations and is highly constrained, thus making it hard for the algorithm to locate solutions. Tiwari *et al.* [69] and Vergidis *et al.* [81] extended their mathematical model and applied multiobjective optimization algorithms, such as the Non-Dominated Sorting Genetic Algorithm 2 (NSGA2) and the Strength Pareto Evolutionary Algorithm 2 (SPEA2), and report satisfactory results that provide encouraging opportunities for further investigation. These and other approaches toward business process optimization are further discussed in the following section.

In general, evolutionary optimization could benefit business processes by discovering process designs that are perhaps overlooked by a human designer. Also, these techniques can evaluate a significant number of alternative designs based on the same process and determine the fittest based on specific objectives. GAs could also be related with a new concept, the one of automatic process generation. A process design could be either generated or modified in an automatic way based on different paths of execution and different objectives each time. It is a quite new and intriguing area of process optimization where evolutionary techniques can significantly contribute.

C. Current Business Process Optimization Approaches

Zhou and Chen [88] suggest that business process optimization should aim at reducing lead time and cost, improving quality of product, and enhancing the satisfaction of customer and personnel so that the competitive advantage of an organization can be retained. Reijers [56] suggests that the goals of business process optimization are often the reduction of cost and flow time. However, Hofacker and Vetschera [30] underline that the concept of "optimality" of process designs is not trivial, and the quality of processes is defined by many, often conflicting criteria. Both in application and theory, great importance is attached to the optimization of business processes, mostly without explaining the criteria and the alternatives considered for optimization [82]. But Zhou and Chen [87] remark that there is

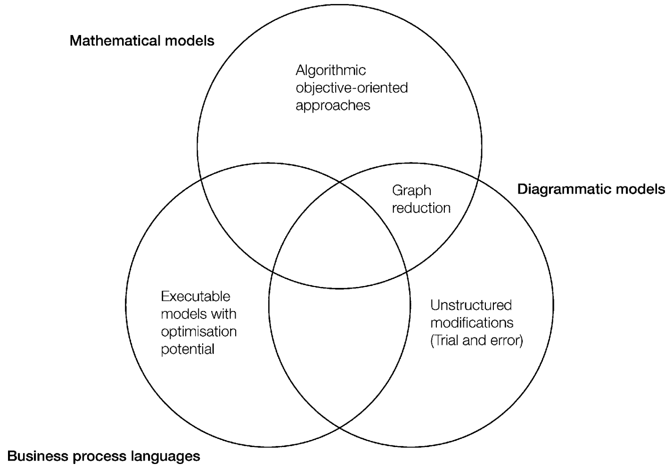

Fig. 3. Improvement/optimization capabilities of the business process modeling sets.

still no systematic optimization methodology for business processes. Fig. 3 classifies the improvement and the optimization capabilities of business process models using the same sets like Figs. 1 and 2.

As mentioned previously, optimization is not an option for diagrammatic process models. This is because optimization requires quantitative measures of process performance that cannot be produced in diagrammatic models. However, there are many qualitative improvement approaches applied to diagrammatic process models such as that by Zakarian [85] and Phalp and Shepperd [52] to name a few. But these techniques are limited as they develop the existing diagrammatic models based on trial-and-error approach. Graph reduction technique is another systematic approach for business process optimization applicable to models that have elements from both the diagrammatic and the mathematical models. Current optimization approaches are related almost exclusively to the formal modeling techniques on the mathematical models set. This is because the formality and quantitative nature of these models allows for systematic optimization. Quantitative criteria are considered essential in order to evaluate the improvements in a business process through modifications to the basic structure [82]. Business process languages set could accommodate executable models of process optimization, but to the authors' knowledge, there is no literature reference in this area.

Table IV summarizes the main business process optimization approaches found in literature; mostly related to Petri nets and mathematical process models. Taking into consideration the emphasis that has been put on Petri nets for their analysis capabilities, one would expect that they would also fit for optimization purposes. But, according to Lee [40], Petri nets are not adequate to solve optimization problems except using graph reduction techniques. Although they can capture system dynamics and physical constraints, they are not suitable for optimization problems with combinatorial characteristics and complex precedence relations.

Li *et al.* [43] suggest that another way of analyzing and improving a business process is graph reduction technique for structural conflict identification or deadlock removal. Graph-reduction techniques have also engaged the attention of a series of authors. These are algorithmic techniques that modify a diagrammatic model of a process. Sadiq and Orlowska [62] identify and try to analyze and resolve two structural conflicts in process models: deadlock and lack of synchronization. van der Aalst *et al.* [76] regard the previous approach as incomplete and propose a new algorithm. A similar approach is also followed by Lin *et al.* [45], who present a complete and minimal set of rules and a novel algorithm to implement the identification of structural conflicts in process models. In this case, the correctness and completeness of the algorithm are proved. Again, graph reduction techniques are not related with quantifiable performance measures although they have algorithmic foundation.

The majority of optimization techniques are related to algorithmic approaches. Soliman [66] provides a typical description of an optimization problem. According to this author's approach, business processes may be considered as a complex network of activities connected together with decision variables and an objective function subject to a number of constraints. Similar approach to the optimization problem is proposed by Hofacker and Vetschera [30], who provide analytical support for optimizing the design of (mainly administrative) business processes. Their paper introduces formal models of the business process design problem, which can be used to analytically determine optimal designs with respect to various objective functions subject to a number of constraints. It is perceived to be the most complete paper in the area of business process optimization because along with the formal business process model, three different optimization techniques are examined: mathematical programming, a branch and bound method, and GAs. Tiwari *et al.* [69] present an extension of the same formal model by applying multiobjective optimization for business process designs and Vergidis *et al.* [81] demonstrate the optimized alternatives. Optimization of a business process under multiple criteria is quite attractive since business processes often have conflicting criteria [30].

Gutjahr *et al.* [24] present a stochastic branch-and-bound approach for solving hard combinatorial business process related problems. Jaeger *et al.* [32] also provide an optimization framework based on performance evaluation that makes both resource and process changes to improve a system's performance. Han [26] develops an algorithmic framework to design business processes using decision models. The aim of this methodology is to reduce the total cost of implementing decisions by creating a quantitative model and using four design change patterns: 1) simple automation for process streamlining; 2) linear sequencing; 3) resequencing involving process parallelization; and (4) radical process integration that is implemented algorithmically.

Zhou and Chen [86]–[88] have published three papers regarding business process optimization. Zhou and Chen [88] introduced the concept of assignment quality and developed multiobjective evaluation, combining optimization models for intra- and interenterprise business processes, and they use the NSGA to solve this problem. Zhou and Chen [86] focus more on time, cost, and resource constraints of a business process model and attempt to optimize it by utilizing a GA to minimize

TABLE IV
OPTIMIZATION APPROACHES FOR FORMAL BUSINESS PROCESS MODELS

MODEL of business process	modelling SET(S)	TYPES of business process optimisation	APPROACHES to business process optimisation
–Petri–nets (and workflows)	–Diagrammatic models –Mathematical/formal models	–Graph reduction techniques	– (Sadiq and Orlowska, 2000) – (van der Aalst *et al.*, 2002) – (Lin *et al.*, 2002)
–Mathematical models	–Mathematical/formal models	–Algorithmic approaches	– (Han, 2003) – (Gutjahr *et al.*, 2000) – (Jaeger *et al.*, 1995) – (Hofacker and Vetschera, 2001) – (Soliman, 1998) – (Tiwari *et al.*, 2006) – (Vergidis *et al.*, 2006) – (Volkner and Werners, 2000) – (Zhou and Chen, 2003a) – (Zhou and Chen, 2002) – (Zhou and Chen, 2003b)
		–Activity/Task consolidation	– (Dewan *et al.*, 1998) – (Rummel *et al.*, 2005)

the process cost. Lastly, Zhou and Chen [87] develop a systematic design methodology for business process optimization from strategic, tactical, and operational perspectives using structured and quantitative methods that support the design. This optimization optimally assigns resource capabilities, organizational responsibilities and authorities, and organizational decision structure.

Another approach to optimization is the consolidation of the activities (or tasks) of a business process. Rummel *et al.* [61] propose a model that focuses on shortening the cycle time of a business process by consolidating activities—assigning multiple activities to one actor—thereby eliminating the coordination and handoff delay between different activities that occurred when assigned to different actors. As this approach is activity (or task) focused, it ignores interactivity delay that may contribute significantly to overall process cycle time. Dewan *et al.* [15] claim that there is no systematic methodology to determine the optimal rebundling of information-intensive tasks. They present an approach to optimally consolidate tasks in order to reduce the overall process cycle time. The authors present a mathematical model to optimally redesign complex process networks but a limitation of the paper is that it refers to business processes with information flows only. Its main contribution is the effective business process restructuring and the reduction of the overall task time using handoff delay reduction or elimination as a result of a unified methodology applicable to multiple task-based business processes.

Although formal languages have associated analysis techniques that can be used for investigating properties of processes [79], an optimization approach based on executable process languages was not observed in the literature. Since most of the optimization approaches—as discussed before—are based on algorithmic approaches, these could be easily translated to executable software programs. Analysis and optimization of business processes can be done best using an approach based on explicit and executable process models. Such models would allow evaluating performance in terms of flows, calculating costs against objectives, recognizing constraints, and evaluating the impact of internal and external events [58]. The idea is that, by being able to assess the process execution quality and costs, it is possible to take actions to improve and optimize process execution [12].

V. OVERVIEW AND DISCUSSION

This paper presented and classified a wide selection of references regarding business process modeling, analysis, and optimization. The review was based on a novel classification of the existing business process modeling techniques using a grouping of three sets according to their modeling capabilities. The analysis and optimization approaches were also related to the same classification scheme. These classifications resulted in visually highlighting a number of interesting observations, and especially, the lack of certain approaches. Table V summarizes the main business process models that were discussed in this paper along with their associated modeling, analysis, and optimization capabilities.

It is evident from Table V that business process optimization has not received as much attention in comparison to business process modeling and analysis techniques. Business process modeling has always attracted attention of researches from a variety of fields. This resulted in a variety of modeling approaches that are used for business processes. Each of these diverse modeling approaches has distinctive advantages but still what is missing is a holistic approach that will involve elements from all the three sets presented in this paper. There is a need for defining operational and reusable business process models within different types of enterprises, in different contexts, and at the required level of detail. These models should be able to address the complexity of the design and identify problems encountered in modern business processes. Therefore, there is an increasing need for formal methods and techniques to support both the modeling and the analysis of business processes. However, despite the existence of many formal process modeling notations, the majority of the business process community still uses simple diagrammatic modeling techniques that have no potential for performance analysis and/or optimization.

Table V demonstrates this gap in the lack of reported performance analysis and optimization approaches. For most of the business process models, there is no structured and repeatable

TABLE V
OVERVIEW OF BUSINESS PROCESS MODELS, MODELING SETS, ANALYSIS, AND OPTIMIZATION TYPES

MODEL of business process	modelling SET(S)	TYPES of business process analysis	TYPES of business process optimisation
– Flowcharts	–Diagrammatic models	–Observational	
–IDEF	–Diagrammatic models	–Observational –Simulation	
–RADs	–Diagrammatic models	–Observational –Performance analysis	
–Petri–nets	–Diagrammatic models –Mathematical/formal models	–Observational –Validation –Verification –Performance analysis –Simulation	–Graph reduction
–Mathematical models	–Mathematical/formal models	–Performance analysis –Simulation	–Algorithmic approaches –Activity/Task consolidation
–Business process languages	–Business process languages	–Performance analysis (algorithmic) –Simulation	

improvement technique reported. In terms of process analysis, there should be a trend to focus on performance analysis as it can be directly used for decision-support and further improvement of the process. Performance evaluation needs to be integrated into the design process from the very beginning so that the objectives of the process can be rationalized from an early stage. Performance indicators are critical for the control and monitoring of a business process. The knowledge extracted from performance analysis should be fed back to the process in order to improve it. However, there are very few attempts reported in the literature to combine performance evaluation and process optimization. Regarding the latter, there are some successful attempts reported, they are highly complicated, and yet, address only simple sequential business processes. The lack of optimization approaches can be attributed not only to the static and complex models but also to the unwillingness of business analysts toward "black box" process improvement.

Business process languages combined with diagrammatic depictions of business processes and associated analysis techniques can be used for investigating the properties of processes. These techniques can be used to provide a useful insight into the behavior and characteristics of a business process model specified using such a language. As these languages support process execution, process models can be executed a number of times (i.e., simulated) for their properties to be properly investigated. This can prove a distinctive advantage of business process languages for optimization as the simulation results of multiple executions can provide a guide for optimum definition of the process properties.

With process modeling techniques such as IDEF and Petri nets still popular, what is missing is a modeling technique that involves elements from all the three modeling sets, and thus, supports analysis and optimization. This hybrid modeling technique could: 1) support a visual diagrammatic representation of the process (thus having all the advantages of visualization); 2) have a formal mathematical underpinning so that quantitative measures can be extracted; and 3) can be expressed using a software-based process language, and thus, allow optimization extensions. These features are provided individually by existing modeling techniques; thus, the proposed novel technique could incorporate these features and implement the remaining. This could result in a software-based process language with a graphical editor to design the process and the necessary tools to support process analysis and generation of optimized process designs. Having these capabilities and being supported by a holistic modeling language, business process optimization can take on new tracks. Apart from scheduling-like resource allocation problems, business process optimization can move toward the direction of flow optimization and automatic process modification. Flow optimization is the notion of defining the optimum path for a business process during execution and according to different objectives at a time. Automatic process modification is the real-time construction of a business process design according to specific needs. The optimum process design is created based on the selection and combination of different alternative activities. Business process optimization has a potential growth with direct benefit to the business process community, and there are still a lot remaining to be done.

VI. CONCLUSION

In this paper, a grouping of three sets provided a classification for business process models based on their mathematical, diagrammatic, and language characteristics. The advantage of this classification is that it allows a modeling technique to be positioned based on several features simultaneously. The current trend in business process modeling is the use of diagrammatic models that only visualize the business process. These three sets also provided a framework for the classification of analysis and optimization approaches. The different analysis types were identified and classified into the three sets. Then, distinctive references were discussed to demonstrate the link between the business process models and their analysis capabilities. Business process analysis has not yet embraced quantitative performance analysis as a way to assess a business process. Simulation can provide the necessary means to analyze a business process and identify its bottlenecks providing a solid basis for improving the process. Lastly, business process optimization (as a concept of automated improvement) was discussed. What was demonstrated is the lack of support provided by most business process modeling techniques for structured process improvement. The few business process optimization approaches reported in literature were classified and discussed. Although there are some successful attempts recorded, they are highly complicated, and yet, address only simple sequential business processes. This paper highlights the necessity for developing business process languages with diagrammatic depictions and associated analysis techniques. The future trend would be these hybrid modeling techniques that would support performance analysis and enable process optimization.

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