A Systematic Review and Assessment of Aspect-oriented Methods Applied to Business Process Adaptation

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***Abstract*— Today's ever-changing business environments, comprised among other things of customer expectations, market demands, and legal obligations, require dynamic and adaptive business processes. Hence, enterprises need to monitor and improve their business processes against their business goals and constraints. Aspect-oriented development is known to have helped designers cope with changing concerns in software, even dynamically. In this paper, we perform a systematic literature review of aspect-oriented approaches for business process adaptation. We observe that current methods focus on i) composing and swapping services based on Quality of Service (QoS), cost, rules, policies, and constraints, as well as in the event of failure, ii) extracting roles and crosscutting concerns from composite services, iii) customizing process instances based on user profiles or Service Level Agreements, iv) adapting service composition and collaboration policies, and v) using monitoring aspects to detect undesired situations. This review also suggests that our own aspect-oriented process modeling and adaptation framework is novel because none of the other approaches considers organization goals, performance and constraints as a whole when improving business processes. In addition, given much prior research on aspect-oriented service composition is available, we are confident that our modeling framework is realizable.**

***Index Terms*—Aspects, Business Process, Adaptation, Modeling, Service Composition.**

I. INTRODUCTION

Adaptive business processes and service-based systems are gaining a lot of attention in both academia and industry because businesses have to react quickly to changes in the market place. Customers now expect custom and personalized services while competitors offer new services every day that businesses have to keep up with. Furthermore, when considering suppliers of different services, especially electronic ones, there are many options available to choose from. Meanwhile, businesses have to constantly monitor and evolve their processes to reduce their costs and increase customer satisfaction. Finally, businesses have to deal with new constraints including standards, Service Level Agreements (SLAs), and legal requirements. Unless a reliable infrastructure is provided to allow businesses to constantly monitor their processes using best practices and to constantly react to changing situations, businesses will find it difficult to keep up with competition and react promptly to market demands.

Research has proposed many different solutions for process adaptation. Among others, aspect-oriented methods have recently attracted much attention. Aspect-Oriented Programming (AOP) [18] has been around for 15 years and has proven to be a useful modularization approach for improving separation of concerns and for composing features and services dynamically. However, only in recent years has research started applying the same ideas to the business process adaptation area.

Although many surveys and literature reviews on business processes were published, to our knowledge no review that specifically targets the application of aspect-oriented methods to business process adaptation currently exists. To validate this claim and to evaluate the extent to which aspect-oriented methods are applied to business process adaptation, we have performed a two-step systematic review. The first step of our study shows that among the 40 survey/review papers on business processes we examined, none focuses on aspect-oriented process adaptation. Yet, the second step of our research illustrates that aspect-oriented methods have been significantly applied to business process adaptation and service-based systems adaptation. This motivates the need for a new systematic review of the literature in this area.

Finally, another motivation for this new literature review is the validation of our own aspect-oriented process modeling adaptation framework [26], introduced in Section I.C. This review suggests that our proposed framework is not only novel but also realizable. Indeed, much of the research we found in our review focuses only on specific elements of adaptation while our proposed approach has a more comprehensive view and takes goals, performance, processes, and constraints of the organizations into consideration. In addition, given the availability of much prior research in terms of aspect-oriented implementations of business process execution and service composition infrastructures, we are confident that our

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proposed modeling framework will be realizable in the near future.

The rest of the paper is organized as follows. In Section II, we provide some background on aspects and summarize the work we have done on the application of the Aspect-oriented User Requirements Notation (AoURN) [22] to adaptive business process modeling. In Section III, we elaborate on our research method and summarize the highlights of our studies. Section IV presents a review of the most pertinent papers in this research area, as discovered by our systematic review. Finally, Section V discusses important threats to the validity of this work while Section VI states the conclusions and lessons learned from this study.

II. Adaptive Business Process Modeling with AoURN

This section introduces our aspect-oriented process modeling adaptation framework. The framework uses the User Requirements Notation (URN) and Aspect-oriented URN as its base. Therefore, we first give a brief overview of these techniques before providing further details of the framework.

A. User Requirements Notation

The User Requirements Notation (URN) [2][13] is an International Telecommunication Union standard published in 2008. URN facilitates the elicitation, specification, analysis, and validation of early requirements expressed in the form of scenarios with the Use Case Maps (UCM) notation and in the form of goals with the Goal-oriented Requirement Language (GRL).

GRL captures business goals of many stakeholders, alternative solutions that are to be considered for a system and how they impact stakeholder goals, decisions that were made, and rationales that helped make these decisions. UCM, on the other hand, focuses on the specification of the causal flow of behavior optionally superimposed on structural elements.

URN's unique capabilities for modeling both processes with UCM and goals with GRL in a unified way are a significant advantage over other process modeling notations. The integrated view of UCM and GRL not only answers the where, what, who, and when questions of process models, but also answers *why* a particular part of a process exists. Furthermore, URN's analysis capabilities can be used to evaluate the goal model for trade-off analysis among stakeholder goals and to establish a test suite for the scenario model.

B. Aspect-oriented URN

Aspect orientation provides separation of concerns for a particular class of concerns called crosscutting concerns. These concerns exist because of the tyranny of the dominant decomposition [35], which states that a chosen modularization technique inevitably will cause unwanted side-effects such as scattering and tangling leading to significant maintenance problems. Scattering means that a concern is not encapsulated in its own module but spread over many different unrelated modules. Tangling, on the other hand, refers to one module containing elements of many concerns. Typically, an aspect encapsulates the properties of a crosscutting concern and then defines one or more composition rules that systematically apply these properties to other parts of the system. In recent years, research emphasis has shifted from AOP [18] to Aspect-Oriented Modeling (AOM) at earlier phases of the software development process such as requirements and design [7]. The Aspect-oriented User Requirements Notation (AoURN) [22] is one such example.

AoURN extends URN with aspect-oriented concepts to enable the encapsulation of crosscutting concerns, which cannot be achieved with URN alone. AoURN allows for the grouping of all modeling elements that belong to a concern, i.e., aspectual properties such as goals, behavior, and structure as well as patterns called pointcut expressions.

An AoURN aspect is applied to an AoURN model wherever the aspect's pointcut expression is matched in the AoURN model. AoURN's matching technique takes the semantics of URN into account to improve the accuracy of matching results. As AoURN uses standard GRL and UCM diagrams to describe pointcut expressions, it is only limited by the expressive power of URN itself as opposed to a particular composition language. Furthermore, since both URN sub-notations may be used for the definition of one pointcut expression, it is possible to specify an aspect that is applied only if a pattern in the scenario model and a pattern in the goal model is matched at the same time.

C. Adaptive Business Process Modeling with AoURN

The AoURN framework for adaptive business process modeling consists of the process view, goal view, performance view, and validation view [26]. The process view describes the business process with UCM models, from very high levels of abstraction to the task level where atomic parts of the process are described. The goal view captures the business goals related to the process with GRL models, from high-level strategic goals of the business to low-level operational goals and even tasks. Typically, tasks are shared in both the low-level process view and the low-level goal view, enabling the specification of which part of a process impacts which business goals. Furthermore, the performance view illustrates how processes perform with respect to the business goals using key performance indicators (KPIs) in GRL models. KPIs are measurements derived from real-world data that indicate how well one or more business processes are performing. Furthermore, several KPIs may be aggregated using mathematical expressions allowing for the creation of complex cause-effect analytical models [25]. Finally, the validation view defines the requirements and restrictions such as corporate policies, laws, or SLAs against which the process view should be validated [33].

The framework is based on a set of process redesign patterns [29] that capture common improvement approaches for business processes. A redesign pattern is a crosscutting concern, because each redesign pattern may be applied multiple times to a business process and also because each redesign pattern may impact not only the

process view but also the goal, performance, and validation views. Furthermore, aspects are often viewed as model transformations and the purpose of a redesign patterns is also to transform the current business process. Consequently, an AoURN aspect describes a redesign pattern, where and in what circumstances it should be applied, and its impact – if it is applied – on the business process, business goals, performance, and validation. With AoURN, a redesign pattern can more easily be encapsulated and selectively applied to the existing process.

The framework allows the best applicable redesign patterns among several possibilities to be selected, utilizing the built-in evaluation mechanisms of URN. For example, monitoring a process yields process measures that are translated into KPIs. These values are then propagated to high-level stakeholder goals by the evaluation mechanism. This allows for an assessment of the high-level stakeholder goals, which forms the basis for subsequent decisions about the state of the business process.

The framework advocates an iterative and incremental approach for business process improvement. First, the target processes for improvement are selected based on the priorities of the organization. Second, artifacts including the four views and their association links are modeled as required for the improvement. Third, the dimensional data sources used for monitoring are prepared and the performance of the processes is monitored. In the alignment step, the views are modified based on automated suggestions of redesign patterns given the monitoring results. As redesign patterns are modeled with aspects which can be added to and removed from process models automatically, what-if scenarios may be explored more easily. It is not necessary anymore to make changes to process models that are difficult to undo in case the adaptation has to be reverted. Hence, for the selection of the most appropriate patterns, several applicable patterns may be applied and their results compared in terms of their impact on the business process and the business goals before committing to an actual change to the business process.

III. Research Method

In our research, we followed the approach proposed by Kitchenham [19] for systematic literature reviews. We designed a two-phase systematic review. In both phases, we first selected the related work using search engines and cited references. Afterwards, we performed an analysis on the related work. In the second phase, we also conducted a detailed review of a selected subset of initial results.

A well-established body of knowledge exists for the business process arena. Therefore, to assure there is not already a literature review answering our research questions, in the first phase, we looked at existing survey and literature review papers. In the second phase, we focused on studying the existing work on applying aspect-orientation to business process adaptation. This second phase is also used to validate our research agenda from the novelty and feasibility points of view.

A. Research Questions

We define four main research questions for this study: 1) Is there any existing survey or systematic review related to adaptive business processes? 2) Have aspect-oriented methods been used for business processes adaptation? If yes, 3) what are the main applications of aspect-oriented methods in the area of adaptive business processes? 4) Is our proposal for an AoURN-based framework novel and realizable given prior research and existing infrastructures?

B. First Phase Queries

In the first phase of the review and to answer the first question, we used three queries (i.e., *("Business Process" AND Survey)*, *("Business Process" AND "systematic review")*, and *("Business Process" AND "literature review")*) and performed the search on Google Scholar for each query individually. The initial result just for the first query was 54,300 papers. As studying all these paper would be impractical, we limited the search to titles of articles. This reduced the search results significantly to a total of 72 papers.

C. First Phase Results

After finding the 72 papers, we started the review process by selecting a subset of the search results using two main criteria. First, we defined six keywords (i.e., adaptation, adaptive, redesign, improve, enhance, and reengineering). We searched for these keywords in the papers and reviewed the papers with any of those keywords. The intention was to make sure we would only review the papers relevant to the research question we were interested in. Furthermore, we also excluded any paper that was published before the year 2000. Since there has been much research and industry evolution in this area and since using automated methods to evolve business processes is a relatively new concept, we believe any earlier survey is no longer relevant to the our topic. Following this exclusion, we reviewed the 40 remaining papers. Finally, we did not find any survey/review on the application of aspect-oriented methods to business process adaptation. Therefore, we decided to continue with the second phase of the systematic review.

D. Second Phase Queries

In the second phase of the review process, we used two queries (i.e., *("aspect oriented" AND "business process adaptation")* and *("aspect oriented" AND "adaptive business process")*) and performed the search on the Google Scholar, SpringerLink, IEEE Explore, and ACM search engines. 45 papers were returned in total, including 11 duplicates (i.e., 34 unique papers). Furthermore, when reviewing the papers, we also added 22 other papers from the references to our result set. These were papers commonly cited among the 34 papers in the initial list. Therefore, the total number of papers we analyzed in the second phase was 56.

E. Second Phase Results

In this phase, we used refined criteria (Table I) to select a subset of the papers for a deep review that can help

us answer the second and third research questions but also to compare the selected papers with our previous work, which exploits aspect-oriented adaptation, process measures (Key Performance Indicators – KPIs) and redesign patterns [29] for process improvement. We did not find any match that uses all the concepts we have used in our previous research on process improvement.

TABLE I.
SECOND PHASE STUDY CRITERIA

Criteria
Is the focus on adaptive processes / systems?
Is an aspect-oriented technique used?
Is the focus on process improvement?
Are process redesign patterns used?
Are business goals and KPIs used?

We observed that the papers using aspect-orientation mainly focus on the techniques summarized in Table II. In Section IV, we review those papers that help us answer our research questions.

IV. SUMMARY OF SECOND PHASE PAPERS

In this section, we review the final set of papers selected using the criteria listed in Table I. We first focus on papers using aspect-oriented methods for business process adaptation. Then, we turn our attention to papers that use other methods (these papers come from the additional references collected manually). Finally, we review papers that have a more generic look at service-based adaptive systems.

A. Aspect-oriented Methods

A review of the first group of papers shows that current research using aspect-oriented methods for business process and service adaptation is mainly focused on using the (non-mutually exclusive) techniques summarized in Table II.

In [11], Hermosillo *et al.* discuss challenges of process adaptation using BPEL and process execution engines including 1) the lack of specification in BPEL to force execution engines to implement a consistent monitoring API, 2) the addition of unnecessary code to the core business process definition, and 3) downtime caused by process redeployment. The authors propose a framework called CEVICHE (Complex Event processing for Context-adaptive processes in pervasive and Heterogeneous Environments) to address the mentioned problems. CEVICHE uses the CEP (Complex Event Processing) engine to trigger the adaptation aspects after detecting a pre-defined adaptation situation. Furthermore, they use an AO4BPEL engine to perform the adaptation. This approach supports *before*, *after*, and *around* advice types that allows one to execute a task before, after, and both before and after a process step. In the example used in the paper, the adaptation is used in an online car rental store to eliminate optional steps of the renting process when store traffic is high. In [12], the same authors discuss the same framework, but this time they use a healthcare process as the example and argue that in different situations, different levels of information may need to be gathered about the patient that cannot always be anticipated. Therefore, their framework could help with the adaptation of such processes according to the detected situations. This approach shows a significant enhancement in the process execution infrastructure in terms of adaptation of business processes. However, the adaptation points and the adaptation rules should be predefined in the business process model and can only handle known specific cases. In other words, this is not a generic framework that can be used to improve the design of the process models, but rather execute already known alternative processes after detecting pre-defined situations.

TABLE II.
ASPECT-ORIENTED METHODS SUMMARY

Papers	Techniques
[11][12] [1][24][9]	Composing and swapping services based on QoS, cost, rules, and in the event of failure
[27][24] [32] [34]	Extracting roles and crosscutting concerns from composite services
[37]	Customizing process instances based on user profiles or SLAs
[9]	Adapting service composition and collaboration policies
[5][36]	Using monitoring aspects to detect undesired situations

Furthermore in [1], Algahtani and Zedan aim to solve several problems with service-based technologies using a combination of an event-driven architecture and aspect-oriented methods. The targeted problems are the lack of design-time adaptability, lack of testability for composition correctness, lack of behavioral features, and lack of runtime adaptability. Similar to CEVICHE, the proposed system intercepts the events that trigger behaviors based on a set of pre-defined rules. Then, the appropriate behaviors are weaved into the system to address the situation raised by the events.

Similar to the two previous research contributions, Rahman *et al.* [27] propose an Event-Condition-Action (ECA) based architecture using aspect-oriented methods to adapt rule-based service-oriented systems. The goal of this architecture is to increase the adaptability of rules and use of rules in the composition of web services. Rule-based operations are extracted as aspects and applied to join points at run-time. Therefore, when rules are changed, workflows are easily adapted to the new rules.

Narendra *et al.* [24] focus on run-time adaptation of non-functional features (e.g., security and scalability) of composite web services. They propose an aspect-oriented approach and a language for specifying the non-functional properties of composite services. This approach allows for the adaptation of web services without impacting user experience or QoS.

In [32], Sánchez and J. Villalobos use AOP to define dynamic and flexible executable workflow definitions. The main argument the authors make for using an aspect-oriented technique in process modeling is the existence of

process parts that are not necessarily domain related but play a more supportive role in the process model. They argue that process definitions are often tangled with extra tasks that are meant to support the main activity. Some examples of such tasks are recurring tasks like data storage, resource allocation or restrictions (e.g., maximum time allotted to complete a task). Although the paper focuses on the dynamicity of process models, the intention is the reuse of common tasks and services and easier extension of the process model, not the monitoring and improvement of the models.

Stearns and Piccinelli [34] describe the cross-cutting nature of business transactions in terms of organizational boundaries. A business process (e.g., order process), when executed in an e-business environment, usually involves several functional units of the organization as well as other external organizations (e.g., suppliers) to fulfill the requirements of the process. Furthermore, the paper discusses the increased challenges in terms of process adaptability due to business environment changes or customer circumstances. According to the authors, processes within the boundaries of the organization are easier to adapt than processes that go beyond the organization's boundaries. To address this problem, the authors suggest capturing the processes in form of aspects that can be automatically projected depending on the requirement. They suggest the separation of role from the actual function (e.g., transfer of the merchandise). They discuss an example showing that a transport function can be assigned to three different roles (buyer, seller, or a third party supplier). Depending on the business model or customer requirements, the business process structure and flow remain the same, but the role that executes the delivery part of the process changes.

In addition, Wen *et al.* [37] discuss an approach for using aspect-oriented technology to provide personalization and customization in IP Multimedia Subsystem Networks. The authors argue that existing solutions are not flexible enough for today's agile and dynamic environments. Service providers need to be able to react to changes more rapidly and be able to customize services more dynamically using a service control layer proposed in this paper. The approach suggested by this paper achieves this control using the AOP paradigm to model service control requirements (e.g., authorization or event based charging) and apply them to the appropriate points in the services without changing and redeploying the core composite service.

In [9], Erradi *et al.* discuss an ongoing effort regarding the development of an aspect-oriented service composition method with the goal of increasing configurability and dynamicity of web services. The framework will help with the adaptation of business rules, collaboration policies between web services and the addition of functional and non-functional extensions to core services. The motivation for this work is the shortcoming of existing approaches in terms of adding optional extensions as well as applying crosscutting concerns. Furthermore, there is a lack of proper approaches for responding to new requirements and changes in business rules. To address all these challenges, the authors augment existing frameworks with aspect-oriented features so that core functionalities can be easily extended. The new proposed framework is called AdaptiveBPEL. Likewise, Charfi *et al.* [5] also provide a good infrastructure, complementary to ours, in terms of the adaptation of business processes execution environments. However, it lacks the holistic view of the organization and looks at the building blocks of the composite services as opposed to the overall performance with respect to organization goals and performance views.

In [4], Charfi and Mezini introduce a container for AO4BPEL, which is a well-known work in the research community and is considered the basis for several subsequent publications by these authors. In [5], Charfi *et al.* build on their previous work, using aspects, to achieve web service composition and propose a flexible plug-in based architecture allowing self-adaptation logic to be deployed on the running process instances. The authors argue that manual fault management in the unstable web services environment is not the right approach, because the process instances executing important business transactions using composite services could be interrupted. In addition, the cost of manual intervention is high. Furthermore, the authors believe other suggested approaches based on extensions to orchestration engines as well as BPEL processes consisting of self-healing logic are not satisfactory in terms of extensibility, flexibility, and scope. The authors suggest two types of aspects to address the shortcoming of other approaches: monitoring aspects and adaptation aspects. While the former is used to detect the faulty situations, the latter addresses the detected problems. The authors have developed three generic plug-ins including one for replacing faulty services, one for detecting and reacting to service policy updates, and a third one for monitoring of services SLA and changing services when they do not satisfy the requirements. Although the flexibility is impressive in terms of providing modifications to composite services, the work is limited to monitoring the service SLAs as opposed to the process as a whole with respect to the organization goals. The objective of this work and of any other work at this level is immediate reaction to the run-time problems whereas our work mainly focuses on monitoring and improving the business process in the long term. However, this work and all the related work at this level demonstrate that the implementation of our suggested approach is feasible at the process execution level.

Finally, Verheecke *et al.* [36] propose an aspect-oriented method for the dynamic selection and swapping of web services using several criteria including their QoS, cost, and availability. The services selection can be done based on new incoming application requirements or based on the monitoring results and performance of the current web services as measured by dynamically added measure points. Similar to the other research in this category, this work is also focused on atomic level of service composition. In this case, the focus is even narrower and is on the selection and swapping of specific services as required. An interesting part of this research, though, is the dy-

namic monitoring aspects, which allows monitoring of services based on the defined selection policy. For instance, if the selection policy requires the fastest service, the performance of the service will be measured using the measurement points added to steps in the service on the fly. Although, much of the research in this area uses aspects for service swapping and making modification to composite services, this work as well as Charfi's [5] are among the few that discuss the use of monitoring aspects to monitor and detect undesirable situations.

B. Other Methods

The next group of papers consists of papers returned in our systematic search results that attempt to address the process adaptation issue but do not use aspect-oriented technology. We learned the lessons summarized in Table III by reviewing these papers. Although these papers do not directly help us answer the research questions, reviewing them allowed us to look at this research area from different angles and to realize some of the downsides of aspect-oriented approaches.

In [10], Graml *et al.* propose a method to extract business rules from process definitions to make processes more agile and adaptive. They believe in the separation of rules from the actual process definitions. Putting rules in a rule engine enables the adaptation of business processes at run-time just by changing the rules. Their suggested approach relies on a web-services based integration of a process execution engine and rule engine. Although they use aspect-oriented concepts to integrate constraints with business processes, they do not use any AOP technology for implementation.

Ramakrishnan [28] suggests an approach to provide self-adaptive, process-based web service composition. The main goal of the paper is proper handling of fault situations, especially failures of partner services. The authors achieve this goal by instrumenting existing BPEL processes so that when the satisfactory service is not provided, an alternative service provider is used. The authors review some of the aspect-oriented approaches in their related work and argue that aspect-oriented based approaches require extensions to standard BPEL engines.

TABLE III.
OTHER METHODS SUMMARY

Papers	Highlights
All papers in this part	System adaptation is an important problem and many researchers are trying to address this problem. While policy-based approaches are gaining the attention of several researchers, much research has been done on this topic from various angles and using different approaches.
[15][31]	Process adaptation should be considered at all levels, not just at the process design level.
[30][38]	The migration of running process instances to a newly improved process model can be challenging and needs special attention.
[20][8] [17][21]	Some authors believe aspect-oriented based methods are complicated and could have a longer learning curve for the practitioners. In addition, the higher level of abstraction of policy-based approaches may be more suitable for capturing management information.
[28]	While aspect-oriented based approaches always require infrastructure supporting aspect-oriented technology, other types of approaches can achieve some level of adaptation (e.g., fault handling) without extending the process execution engines.
[28][23] [31]	Many of the suggested approaches only use QoS and focus on a very narrow view of adaptation (e.g., fault handling, service replanning or replacement, and requirements) and forget about the business value.

In addition, Na *et al.* [23] suggest a method for adaptive replanning (changing the service bindings) of service-based systems. Their main goal is to improve the replanning process from three points of view: 1) trigger, 2) service selection, and 3) cost and effect. According to the authors, most of the approaches that have been suggested for replanning of service-based systems use an exclusive strategy for replanning and do not consider the effectiveness of the replanning based on the current state of the system. Therefore, in the proposed system, they focus on a closer relationship between replanning and the system situation using a quantitative evaluation method to estimate the impact of the change on the system and a solution space management model to identify the search scope in which the best solutions can be found. Most of the related work as well as the approach suggested in this paper rely on QoS to trigger the adaptation process while, in a business environment, using only QoS is not the perfect measure for changing the composition. We believe the business context, including the outcome of the process and KPIs defined to measure the overall performance of the business as well as the satisfaction level of business goals, needs to be considered in order to achieve a good results that contributes to the bottom line of the business.

Ruy *et al.* [30] present a framework that allows businesses to evolve executing process instances to newly defined protocols if possible. In this paper, business protocol definitions are equivalent to business processes. The framework also provides tool support for detecting the process instances that can be migrated to the new protocols. The main goal of the paper is to provide the supporting environment for ever-changing services in a composite services environment. The authors use finite state machines to model the business processes and illustrate the Australian citizenship application process as an example in the paper. This framework does not use aspect-oriented approaches to perform the modification on the process models, but instead use protocol change operators including AddTransition, RemoveTransition, AddState, and RemoveState to perform modifications on the service models.

From a different angle, Erradi *et al.* [8] take a policy-based approach on business process adaptation and propose a middleware architecture called MASC to implement that approach. The main goal of the authors is separation of concerns between process definition and the monitoring and control of the process. Furthermore, a

new language, WS-Policy4MASC, is used to define the policies and monitoring rules. The authors suggest that adaptation can be studies from three different dimensions: 1) adaptation target (i.e., at a class or instance level), 2) adaptation approach (i.e., dynamically / at run-time or statically / at design time) 3) adaptation goal (i.e., customization, correction, optimization, prevention). This paper mainly focuses on dynamic customization and correction processes, which is mainly adding, removing, and replacing tasks and fixing the faults reported during the execution. Furthermore, the authors argue that the policy-based approach to adaption is easier to understand compared to alternatives like aspect-oriented programming.

Likewise, Lu takes a policy-based approach in [21] and proposes an autonomic business-driven method to maximize business value while considering several policies and constraints. This method also uses WS-Policy4MASC to define the business metrics and policies that need to be taken into account during the adaptation process. Lu claims that the proposed approach, unlike the existing aspect-oriented approaches, not only considers QoS but also business value and goals into account. In addition, it provides better abstraction for specifying management information compared to aspect-oriented approaches.

Similarly, Xiao *et al.* discuss a policy-based approach for process adaptation in [38]. This method mainly relies on pre-defined process fragments that can be used to compose a process defined at a higher level of abstraction. The high-level process is defined using a process template and the process fragments are selected using defined policies and constraints. Although this approach seems promising for having a flexible pre-defined process infrastructure, it is not ready yet to be used for adapting live processes on the fly.

Furthermore, Kalavathy *et al.* [17] propose a policy-based architecture for self-adaptation of service-oriented media services. The architecture is not generic but is meant to be used for media services only. The authors suggest that in any service adaptation framework, separation of the adaptation policies from the base process is important, and their architecture supports this approach. Similar to [20] and [8], the authors also believe their approach is better than the aspect-oriented programming alternative because it deals with the problem at a higher level of abstraction and is easier and more understandable by the users of the system.

In [20], Lian *et al.* propose an agent-based, context-aware framework that helps with the adaptation of business processes. The framework mainly focuses on handling fault and error situations and takes a proactive approach in addressing exceptions. The designed architecture sets an agent layer on top of the process execution layer to monitor and adapt the processes, as well as react to unexpected events. The authors do not use any aspect-oriented technique, but reference many aspect-oriented research contributions as related work. They argue that while aspect-oriented methods can be used to insert rules into processes, these methods could also increase complexity in terms of managing conflicts between different rules.

In [15], Kazhamiakin *et al.* break down service-based applications into several layers and argue that monitoring and adaptation in each layer independently is not the right approach. For instance, if a business process is improved but the underlying services used to execute the process still uses low quality services, the improvement will not be maximized. Furthermore, they illustrate a conceptual model of an architecture to help address the mentioned problem.

In [31], Sawyer *et al.* use an *i** based modeling approach to handle dynamic changes of a system at the requirements level. In their method, a visual model of dynamically adaptive system requirements is created. The requirements for the system when it works in a stable environment are separated from the adaptive requirements. Although the suggested method uses a goal modeling language, it covers only the system requirements level and does not address the need for monitoring and improving on the process models.

C. Generic Studies

The last group consists of papers that have performed a more generic study on adaptive systems and processes. While studying these papers, we learned the lessons summarized in Table IV.

TABLE IV.
GENERIC STUDIES SUMMARY

Papers	Highlights
[14]	Current process modeling notations are not good enough for defining flexible business processes.
[3][6]	Adaptation could be performed at different levels, have different goals, and use different approaches. In addition, most of the existing approaches only target this space partially and it is hard to come up with a framework to cover everything.
[16]	Current adaptive systems have several issues including a focus on process instances as opposed to classes, being reactive as opposed to proactive, the use of rigid and inflexible specifications, requiring human intervention, and not considering the business context.

Kapuruge *et al.* performed a survey [14] on the current approaches for providing flexibility in business modeling and service composition. The focus of the paper is mainly on defining the flexibility requirements and assessing the current work considering those requirements. The flexibility requirements specified by this paper are in three groups: 1) process definition flexibility including: configurable design, built-in context awareness, ease of understanding, late specification, automated change verification, and merging business process definitions; 2) process instance flexibility including: process instance deviation, process instance handling as a case, process instance migration to a new process class design, and ease of human understanding and intervention; and 3) services relationship flexibility including: ability to change service interfaces, ability to change service bindings, and ability to change inter-service relationships. According to this paper, one of the problems of current

graphical modeling languages is the use of strict sequences of atomic level tasks to form a process. This approach, while helpful with understandability of the process for humans, reduces the flexibility of the process model dramatically.

In [3], Cheng *et al.* discuss a software engineering research roadmap for self-adaptive systems from four points of view, including modeling dimensions, requirements, engineering, and assurance. The paper suggests that an adaptive system has to support methods for expressing goals and monitoring changes, mechanisms to perform change, and also evaluations of effects on the system.

In [6], Courbis and Finkelstein argue that adaptation can be 1) static or dynamic, 2) manual or automatic, and 3) proactive or retroactive. The paper suggests that aspect-oriented approaches must be used in all layers of process-based systems to achieve maximum flexibility and adaptability. The three layers suggested by this paper are semantic analyzers, BPEL engines, and BPEL processes.

Finally, Kazhamiakin *et al.* [16] discuss the adaptation of services from several points of view, including personalization based on user preferences, changes to address QoS requirement, and changes in functionality. A taxonomy is also presented that defines the adaptation arena by answering why, what, and how questions in this context. In addition, the authors suggest AOP in related work as a good approach for the adaptation of software systems due to the flexibility and dynamicity that it brings to the table. The paper also presents a summary of the adaptation approaches proposed by other researchers in this body of knowledge. This summary looks at adaptation from five different angles:

- Usage of adaptation: the authors suggest that adaptation is mostly used for recovery, optimization, and customization. They believe the use of contextual factors (e.g., business context) as well as proactive approaches can be enhanced in adaptation frameworks.
- Subject of adaptation: according to the authors, there are few researchers focusing on adaptation at the class level. The majority of research focuses on adaptation at composition or instance level. Our systematic review also confirms this result. The authors regard more holistic approaches at the class level as proposed in our framework to have better long-term impact on businesses.
- Adaptation strategy: according to the authors, the existing approaches have several issues. As these approaches are usually not proactive, future issues cannot be easily prevented. Furthermore, most of the frameworks do not have a distribution and coordination module for the adaptation activities.
- Adaptation specification: most of the existing adaptation specifications lack flexibility and are defined at design-time for specific situations. Therefore, it is hard to use them in more generic situations.
- Decision and autonomy: researchers address the adaptation decision problem differently, at design-time in a predefined way or dynamically. Furthermore, in some cases, human intervention is required for the final decisions on the modifications.

V. Threats to Validity

There are several main threats to the validity of our research. One may argue that the scope of our research in both phases one and two was not wide enough. In addition, one may suggest that we could have biased the selection of publications.

In the first phase, because of a very high number of search results, we have limited our publication selection scope significantly (i.e., we only searched on article titles and we only used one meta-search engine). Therefore, there is a risk that our answer to the first research question is not correct, which means there could be existing literature reviews focusing on the application of aspect-oriented methods to business process adaptation. This was mitigated to some extent by the use of the Google Scholar engine, which is fairly global and up to date.

In the second phase of our study, we could have used several more queries, for example (*"aspect oriented" AND "dynamic business processes"*), to increase the scope of our research. However, to make the research feasible, we chose a targeted set of queries. We believe we have mitigated this risk in two ways: first, by looking at commonly cited articles by the papers we found, and second, by comparing our conclusions with some more generic surveys and studies (i.e., [3], [6], [14], and [16]).

Finally, considering that this paper is also used as a validation of our own research agenda from feasibility and novelty points of view, one may argue that we could have biased the selection of articles used in the second phase of the research. We have addressed this threat in three ways. First, we have systematically selected the papers and documented all steps, allowing them to be redone by any independent party. Second, some of the conclusions we reached are confirmed by other higher-level studies on the topic of adaptive service-based systems (i.e., [3], [6], [14], and [16]). Third, we took a very neutral position by applying the lessons learned from the study to our own research and criticizing the downsides of our own proposed framework in the conclusion section and throughout the paper.

VI. Conclusions

In this paper, we conducted a systematic review on the application of aspect-oriented techniques to business process adaptation. The review was done in two phases. In the first phase, we looked at 72 existing surveys/reviews on business processes to assure ourselves no one had already performed a systematic review on our topic of interest. In the second phase we focused on finding papers that apply aspect-oriented methods to process adaptation to answer three main questions: i) have aspect-oriented methods been used for business processes adaptation? If yes, ii) what are the main applications of aspect-oriented methods in the area of adaptive business processes? iii) Is our proposal for an AoURN-based frame-

work novel and realizable given prior research and existing infrastructures?

After analyzing 56 papers and performing a deep review of a subset extracted using the criteria listed in Table I, we can answer the aforementioned research questions. For several years, mainly after 2005, significant attention was devoted to the application of aspect-oriented techniques to business process and service-based system adaptation. Much of the research is focused on adaptation at the process execution level and in the following areas: i) composing and swapping services based on QoS, cost, rules, policies, and constraints, as well as in the event of failure, ii) extracting roles and crosscutting concerns from composite services, iii) customizing process instances based on user profiles or Service Level Agreements, iv) adapting service composition and collaboration policies, and v) using monitoring aspects to detect undesired situations.

Although the results may convey that this area of research is mature enough, we believe there is still much work that can be done. However, the underlying research in this area makes us confident that our proposed framework is realizable in practice.

As also indicated in [16], much current work focuses on instance-level adaptation as opposed to considering the overall performance of the process and improving the process model. Most existing approaches do not take the context of the business into consideration. As illustrated in Table V, this is where our framework exceeds other research by considering processes, business goals, performance models (KPIs), constraints, and even redesign patterns (for process improvement), to provide a more comprehensive framework.

Furthermore, current techniques are more reactive as opposed to proactive. They mainly use pre-defined rules, policies, or hard-coded situations that are hard to use in a more generic way. Moreover, most of the existing frameworks require some level of human intervention for the final decision-making. The other aspect that could be improved in the existing research is the lack of focus on all layers of service-based systems. While adaptation could be done at many different levels of a system, many proposed approaches only focus on one specific layer. This is true for our proposed framework as well, which only focuses on process adaptation at the business process model level. Although this is still beneficial, a process that is improved to perfection but still uses poor services during the execution will not perform as expected. Therefore, to have a better picture and feedback loop, even when we are focused on improving business process models, we have to monitor the service composition and process execution layers as well.

TABLE V.
REVIEWED PAPERS COMPARED WITH OUR PROPOSED FRAMEWORK [25] USING THE CRITERIA SPECIFIED IN TABLE I

		Ref.	Author - Year	1	2	3	4	5
A	CS	[1]	Algahtani *et al.* - 2009	Y	Y	Y	N	N
		[11]	Hermosillo *et al.* - 2010	Y	Y	Y	N	N
		[12]	Hermosillo *et al.* - 2010	Y	Y	Y	N	N
		[24]	Narendra *et al.* - 2007	Y	Y	N	N	N
		[9]	Erradi *et al.* - 2005	Y	Y	N	N	N
	E	[27]	Rahman *et al.* - 2008	Y	Y	N	N	N
		[24]	Narendra *et al.* - 2007	Y	Y	N	N	N
		[32]	Sánchez *et al.* - 2008	Y	Y	N	N	N
		[34]	Stearns - 2002	Y	Y	N	N	N
	CP	[37]	Wen *et al.* - 2008	Y	Y	N	N	N
	MA	[4]	Charfi *et al.* - 2005	Y	Y	Y	N	N
		[36]	Verheecke *et al.* - 2003	Y	Y	N	N	N
O		[10]	Graml *et al.* - 2007	Y	N	N	N	N
		[31]	Sawyer *et al.* - 2007	Y	N	N	N	N
		[30]	Ruy *et al.* - 2007	Y	N	N	N	N
		[15]	Kazhamiakin *et al.* - 2009	Y	N	Y	N	N
		[8]	Erradi *et al.* - 2006	Y	N	N	N	N
		[17]	Kalavathy *et al.* - 2010	Y	N	N	N	N
		[20]	Lian *et al.* - 2010	Y	N	N	N	N
		[23]	Na *et al.* - 2010	Y	N	N	N	N
		[28]	Ramakrishnan - 2009	Y	N	N	N	N
		[21]	Lu - 2011	Y	N	Y	N	N
		[38]	Xiao *et al.* - 2011	Y	N	N	N	N
G		[14]	Kapuruge *et al.* - 2010	Y	N	N	N	N
		[3]	Cheng *et al.* - 2009	Y	N	N	N	N
		[6]	Courbis *et al.* - 2005	Y	Y	N	N	N
		[16]	Kazhamiakin *et al.* - 2010	Y	N	N	N	N
P		[26]	Pourshahid *et al.* - 2011	Y	Y	Y	Y	Y

Column headers:
1: Is an adaptive System?
2: Aspect-oriented approach is used?
3: The goal is to improve business processes?
4: Redesign patterns are used?
5: Business goals and KPIs are considered?

Row headers:
A: Aspect-oriented-based methods
G: Generic studies
O: Other methods
P: Proposed method
CS: Composing and swapping services based on QoS, cost, rules, etc.
E: Extracting roles and crosscutting concerns from composite services
CP: Customizing process instances based on user profiles or SLAs
MA: Using monitoring aspects to detect undesired situations

We also learned that there are concerns in the research community regarding the complexity of aspect-oriented approaches. Some authors claim that the learning curve in aspect-oriented approaches from the point of view of the end user could be (too) high. In addition, managing the interaction between aspects when multiple aspects are applied to a process could increase the complexity of the system. Some authors argue that policy-based approaches are easier since they deal with the adaptation / rule definition at a higher level of abstraction that is closer to the language users often understand. We also had a similar experience with our aspect-based redesign patterns. They can become very complex and hard to explain to an audience without prior experience in Aspect-oriented URN.

Considering the lessons learned from this research, in our future work, we are going to extend our framework to at least support monitoring of the process models adaptation impact on all layers of the system including process execution layer. Since there has been much research in this area and since the existing work will likely make our proposed holistic modeling framework realizable in the future, we are going to continue on this research. However, we have to address the complexity issues associated

with aspect-oriented methods to make the framework usable by business people. A potential solution to address this problem is to hide the complexity of aspect-oriented models behind a layer of abstraction that simplifies the interaction of the users with the system.

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