Process- and Resource-Aware Information Systems

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***Abstract*—Business processes involve several perspectives that have an effect in all the phases of the business process management lifecycle. The organisational perspective addresses the way in which human resources take part in process activities. Human resources are of utmost importance as they are responsible for the correct execution of processes. However, the organisational perspective has received less attention than others and the existing support is limited. With the aim of easing the development of advances in human resource management in business processes, in this paper we present a novel framework that collects several aspects to be considered along with the existing support.**

I. Introduction

A Process-Aware Information System (PAIS) is a software system that manages and executes operational processes involving people, applications, and/or information sources on the basis of process models [1]. Classical examples of PAISs are Workflow Management Systems (WfMSs) and Business Process Management Systems (BPMSs). The explicit process awareness in PAISs introduced a number of advantages for business information systems with respect to previous task-driven systems, such as text editors or email clients [2]. The core elements in a business process are the activities and their execution order. However, there are other elements also involved in processes, which must be supported all along the Business Process Management (BPM) lifecycle [3]. These elements are called *business process perspectives*. Among them, the *organisational perspective* addresses the way in which human resources[1] in an organisation are involved in the business processes executed in it. Different process perspectives comprise a different number of aspects to be considered. For instance, the behavioural perspective merely focuses on the execution order of activities, whereas the organisational perspective must also take into account external information like organisational models.

Current PAISs support the organisational perspective but with significant limitations regarding flexibility and teamwork. For instance, a study on the usage of a workflow system in an industrial setting illustrates these problems [4]. Due to the strict mechanisms for allocating human resources to workflow activities, the system administrator had to extensively work around actual assignments of the process. In other domains like healthcare and engineering, complex team compositions have to be specified [5], which explains the low uptake of rigid PAISs in these domains.

The goal of this paper is to advance PAISs towards the concept of Process- and Resource-Aware Information System (PRAIS), which puts special attention to the management of human resources in business processes. For that purpose, we present a framework [6] for human resource management in business processes defined from the literature in the field, the characteristics found in BPMSs and our extensive experience in this research area. The research is guided by the following research questions: (RQ1) Which are the operations involved in human resource management in business processes? (RQ2) Are there other factors that affect the way in which the operations are addressed? (RQ3) Which is the existing support on the theoretical and practical sides? The result of this work is hence intended to be a starting point for process managers and researchers interested in improving the way in which human resources are handled in their business processes.

The paper is structured as follows. Section II describes the research methodology used. Section III presents the framework. Section IV sums up related work for every aspect involved in the framework. Section V discusses the existing support and challenges. Section VI reflects on potential limitations of the work. Finally, Section VII concludes the paper.

II. Research Design

The first step in this study was analysing the state of the art in resource management in business processes. As we have been actively working on this subject for the last six years, in this case it was not necessary to conduct a systematic literature review from scratch. From our experience we are aware of the main results in the field and how they are generally organised. Nonetheless, we explored the lists of references of the most recent publications as well as the proceedings of the last editions of conferences (e.g., Business Process Management, Advanced Information Systems Engineering, and the Enterprise Computing Conference) and journals (e.g., Information Systems, Information and Software Technology, and Decision Support Systems) that are relevant in this research field. We also checked the publication records of researchers that are active in the development of techniques related to human resource management in business processes.

The framework was defined from a classification of our findings taking into account the research questions RQ1 and RQ2, i.e., the operations and the factors that determine the way in which they are addressed. Once the framework was defined, a second check of literature was performed in order to answer RQ3 more precisely. In particular, specific searches were performed on the aspects identified aiming at showing

[1] We will use the terms *human resource* and *resource* indistinctly to refer to a human resource, i.e., a person.

the most recent insights of each of them. This involved a brief analysis of well-known BPMSs.

After the framework was defined and the support evaluated, a first validation was conducted by a detailed revision of our results by experts in the area, specifically three researchers that have been involved in research related to the assignment, allocation and analysis of human resources in business processes, respectively. We also held discussions on this matter with a company specialised in business process intelligence.

III. Framework

Our study led to a classification of the aspects related to human resource management in business processes in three layers. The first one refers to RQ1 and presents a classification of the operations involved in human resource management in business processes. The second and third layers respond to RQ2, i.e., they are aspects orthogonal to the operations identified which affect the way to address them. Specifically, we found that the type of activity and the type of process influence the interpretation of the operations. Fig. 1 shows the three layers of the framework along with the information necessary for operating on the organisational perspective of business processes.

As aforementioned, the first layer describes the operations involved in human resource management in business processes. Three main types of operations can be distinguished: assignment, allocation and analysis. Resource analysis can, in turn, be divided into design-time, run-time and post-execution analysis. Each of these operations can be associated with a phase of the BPM lifecycle. We use the BPM lifecycle described in [3] to frame the resource management operations. In Fig. 1, the operations identified are represented by grey boxes connected to each other, surrounded by a dashed-lined box indicating the associated phase of the BPM lifecycle.

For a specific business process identified in a process-oriented company, the first objective is to discover all the available information about the process. Despite most of the process discovery techniques are manual, automatic discovery is also possible by means of so-called *process mining*. Process mining is a type of post-processing analysis capable of extracting process models by analysing the data stored in event logs during process execution [7]. Regarding human resources, the aim is to analyse who performed a particular activity in past executions and use this information for different purposes, e.g., to check compliance with business rules or to help to improve the process design. The following example shows an excerpt of an event log with the information of two executions of a business process (a.k.a. process instances) encoded using the XES logging format [8]. In an event log, every process instance corresponds to a sequence (*trace*) of recorded entries, namely, *events*.

```
<trace>
   <event>
      <string key="org:resource" value="CC"/>
      <date key="time:timestamp" value="2013-08-06T14:..."/>
      <string key="concept:name" value="Request work trip"/>
      <string key="lifecycle:transition" value="start"/>
   </event>
   <event>
      <string key="org:resource" value="JM"/>
      <date key="time:timestamp" value="2013-08-07T12:..."/>
      <string key="concept:name" value="Approve work trip"/>
      <string key="lifecycle:transition" value="start"/>
   </event>
</trace>
<trace>
   <event>
      <string key="org:resource" value="JG"/>
      <date key="time:timestamp" value="2013-08-07T10:..."/>
      <string key="concept:name" value="Request work trip"/>
      <string key="lifecycle:transition" value="start"/>
   </event>
   <event>
      <string key="org:resource" value="AP"/>
      <date key="time:timestamp" value="2013-08-07T14:..."/>
      <string key="concept:name" value="Approve work trip"/>
      <string key="lifecycle:transition" value="start"/>
   </event>
</trace>
```

The outcome of process discovery is a process model reflecting all the information collected about the process. Resource modelling in business processes is known as *resource assignment* [9]. Specifically, it consists of defining the conditions that the resources must meet to be allowed to take part in process activities. These conditions are usually determined by the information included in organisational models as well as security policies that must be fulfiled. The first type of conditions includes, e.g., the existing roles or groups defined for an organisational unit. There are many types of organisational models [10]. Popular concepts include person, role, position, organisational unit and capability, or synonyms of them. However, despite the efforts of the W3C to define a recommendation to represent organisational structures[2], there is not yet a generalised use of any specific organisational metamodel. The second type of conditions involves, e.g., well-known access-control constraints [11] preventing the execution of two activities by the same person to avoid conflicts of interests (a.k.a. separation of duties), or obligating two activities to be performed by the same resource (a.k.a. binding of duties). The outcome of resource assignment is a *resource-aware process model*. For instance, Fig. 2 depicts the model of the process discovered from the previous event log using Business Process Model and Notation (BPMN) [12]. It comprises two activities performed by two different roles. The information about the roles involved in the process has been inferred by checking the data from the event log against the organisational model of a hypothetical research group illustrated in Fig. 3. The organisational model consists of a hierarchy of roles that are assigned to several employees.

Resource-aware process models constitute an analysis source that can help to find out problems related to the utilisation of resources in an organisation, e.g., unavailability of resources with the characteristics required. The automated analysis of the organisational perspective is the automated extraction of information from resource-aware process models about the resources that may take part in the process activities [9]. At design time, resource analysis merely relies on the information included in the process model and on existing

[2] http://www.w3.org/TR/vocab-org/

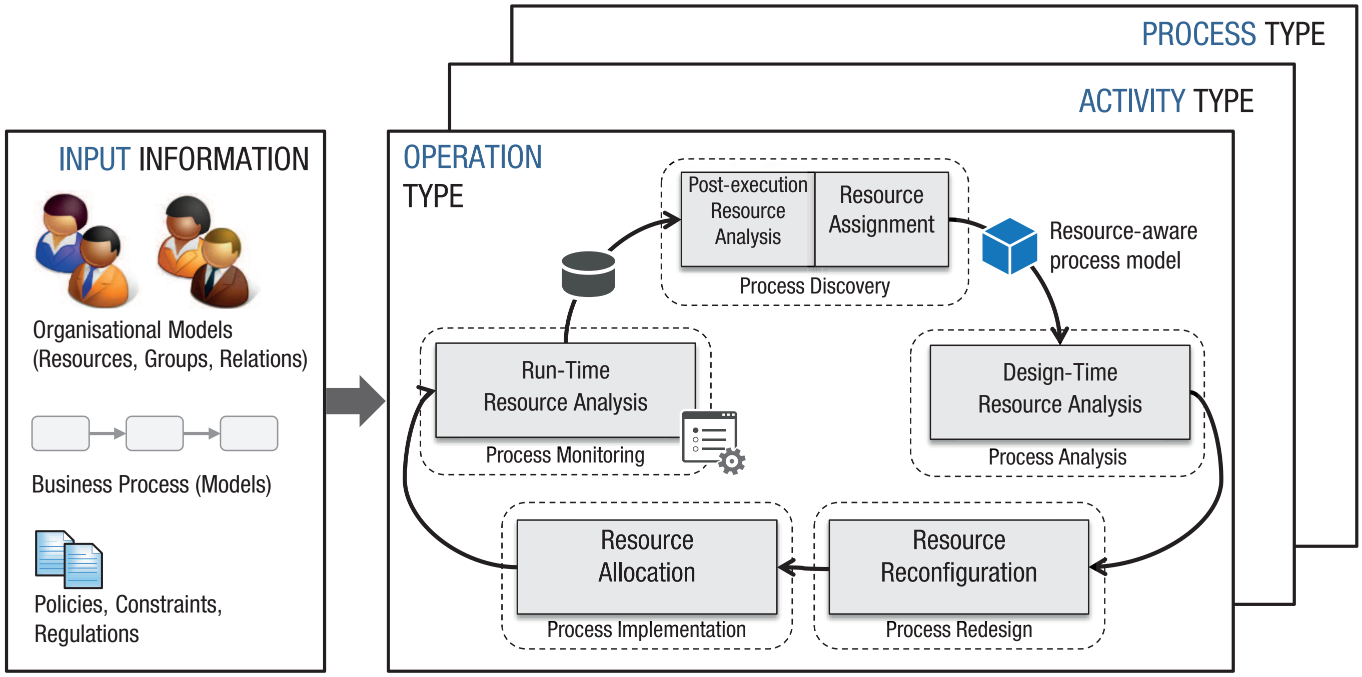

Fig. 1: A framework for managing human resources in business processes

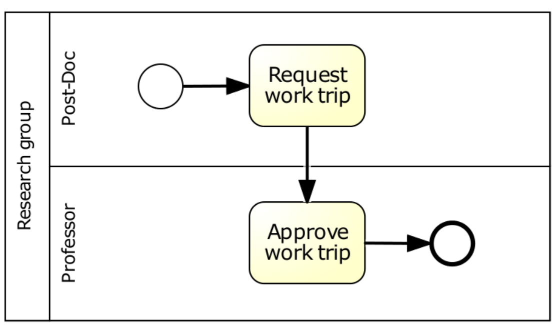

Fig. 2: Work trip management process modelled with BPMN

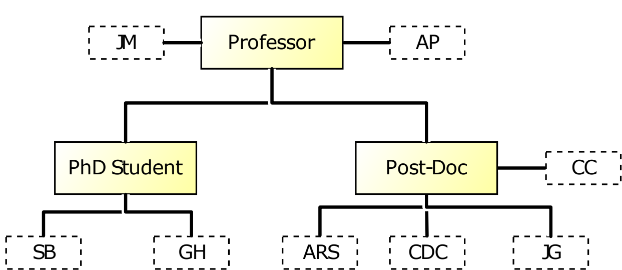

Fig. 3: Organisational model of a certain research group

information about past process executions, as well as on the background information provided by the organisational model. For instance, in our running example the question "who can be involved in this business process?" could be automatically answered by checking the resource assignment conditions defined in the resource-aware process model (cf. Fig. 2), in this case roles *Post-Doc* and *Professor*, and then checking in the organisational model (cf. Fig. 3) which human resources meet those conditions, in this case *ARS*, *CDC*, *JG*, *CC*, *JM* and *AP*.

The result of the analysis can be used, together with a set of redesign heuristics [3], for reconfiguring the resource-aware process model as well as organisational information and so obtain an improved process model and setting that can be subsequently used for process automation using a PAIS, typically a BPMS. For example, if we detected that there is no human resource available in the organisation with the characteristics required for the execution of a process activity, adaptation mechanisms should be triggered, e.g., hiring more personnel or re-distributing responsibilities among the employees of the organisation.

If a BPMS is available and the process needs to be automated, *resource allocation* techniques must be put in place for automating the distribution of activities among the available resources that meet the assignment conditions when the process is running. For instance, in our running example, deciding which person with role *Post-Doc* among the four candidates must participate in each process instance may depend on the workload of the respective resources or their expected availability. The goal is to obtain optimal resource allocations that contribute to enhancing some dimension(s) of the so-called Devil's Quadrangle [3], i.e., quality, time, cost and flexibility.

Monitoring and controlling process execution is necessary for guaranteeing that processes are operating according to the plan and, in case of problems, recovery mechanisms must be available. Run-time resource analysis provides information regarding the actual utilisation of resources and helps to detect unexpected and undesired situations, such as problems in future activity instances in a process instance due to an unplanned, temporary unavailability of a certain resource (e.g., due to an illness leave). At run time, resource analysis can use the information included in the organisational model, existing information about past process executions as well as run-time data generated during the execution of the process instance under analysis. All the run-time information that can be stored in event logs might be helpful for the post-execution analysis with which the cycle starts all over again [3].

As aforementioned, the other two layers of the framework are orthogonal to the operation types, since they apply to all the human resource management operations previously described. The second layer classifies the process activities according to the type of work that is done in terms of the number of human resources required for their completion. Instances of *individual activities* are performed by only one resource, whereas *collaborative activities* require teamwork. Our running example contains two individual activities whose instances are executed by only one person of the organisation meeting the required conditions. Domains in which collaborative work is a popular practice are, e.g., software development and healthcare. Notice that the aforementioned operations slightly differ depending on the activity type. For instance, assigning resources to an individual activity implies defining the characteristics that one specific person must have, whereas assigning a team to a collaborative activity involves defining the characteristics of the members that must compose the team as well as how these characteristics are distributed among them, e.g., two people with a certain role and at least one person with specific skills.

The last layer of the framework classifies the support according to the type of processes that need to be managed. Two different types of processes can be distinguished [13]: *routine processes* with exactly pre-described control flow, and *flexible* (a.k.a. *agile*) *processes* whose control flow evolves at run time without being fully pre-defined a priori. Agile processes are common in healthcare where, e.g., patient diagnosis and treatment processes require flexibility to cope with unanticipated circumstances. The type of process determines the type of notation that is more suitable for process modelling. Therefore, two different representational paradigms can be distinguished: *imperative* (a.k.a. *procedural*) process models precisely describe which activities can be executed next (e.g., BPMN [12] and Petri nets [14]). *Declarative process models* define execution constraints that the process has to satisfy, such that the more constraints are added to the model, the less possible execution alternatives remain (e.g., Declare [15] and Declarative Process Intermediate Language (DPIL) [16]). As flexible processes may not be completely known a priori, they can often be captured more easily using a declarative modelling approach [13]. On the contrary, imperative modelling notations are suitable for defining strict control flows but are barely capable of dealing with variations in the process behaviour. Our running example is a routine process modelled with BPMN. Nonetheless, since the process is quite simple, we exemplify how it could be modelled with a declarative modelling notation in Fig. 4. The textual notation DPIL has been used for that purpose. Similarly to the previous case, one may expect to find different requirements for operating with resources in the two types of processes. For instance, representing resource assignment conditions in imperative process models may differ from the rule-based representation characteristic in declarative process models.

```
use group Post-Doc
use group Professor

process WorkTrip {
 task Request work trip
 task Approve work trip
 ensure role(Request work trip, Post-Doc)
 ensure role(Approve work trip, Professor)
 ensure sequence(Request work trip, Approve work trip)
}
```

Fig. 4: Work trip management process modelled with DPIL

IV. Existing Support

In the following, we describe the existing support for every operation defined in the reference model considering the different activity and process types. Note that rather than pursuing completeness, we aim at showing evidence of all the aspects included in the framework and their relations.

A. Post-execution Analysis for Automatic Process Discovery

The information about resources extracted from event logs with process mining techniques can be used for different purposes. Some approaches study the performance of resources and their influence in the completion of processes [17]. Other approaches aim to extract an underlying organisational model [18] or social network [19].

However, most of the methods developed so far take into account for the analysis not only the specific individuals involved in the activities but also information from, e.g., the organisational model, for inferring knowledge relevant for resource assignment or compliance checking purposes. The type of knowledge that can be inferred is typically described with a subset of the acknowledged workflow resource patterns called *creation patterns* [20], which describe various ways in which resources can be distributed in process activities. For instance, the *Direct Distribution*, *Role-Based Distribution* and *Capability-Based Distribution* patterns assign an activity to a specific resource, organisational role and capability, respectively; and the *Separation of duties* and *Retain Familiar* patterns represent the separation of duties and binding of duties access-control constraints, respectively.

The so-called *role mining* [21] follows a Role-Based Access Control (RBAC) [22] schema and hence, it is focused on discovering direct distribution, role-based distribution and access-control constraints. The Process Mining Framework (ProM) [23] allows for extracting role-based assignments from event logs and integrates them into an existing BPMN model in the form of swimlanes. Staff assignment mining [24], [25], on the contrary, deals with the extraction of complex rules based on the capabilities and organisational relations of a resource, disregarding access-control constraints. Both role mining and staff assignment mining approaches have assumed individual activities and have discovered routine processes so far, which means that the outcome of these approaches is imperative process models represented, in general, with BPMN [12].

The shortcomings of these two types of approaches in terms of creation pattern support have recently been addressed by an approach that provides support for seven of the nine creation patterns relevant in this context [26]. However, despite the aforementioned techniques, the one in [26] aims at handling flexible processes characterised by a variety of constraints, which the authors represent with a declarative process modelling notation called DPIL [16]. An implementation of the DPILMiner is described in [27].

A conceptual and practical extension of the DPILMiner has recently been developed for extracting team compositions for collaborative process activities taking into account the Direct, Role-Based, Capability-Based and Organisational Distribution patterns [28]. To the best of our knowledge, that is the only existing support for teamwork mining in business processes.

The existing BPMSs do not yet provide support for mining the organisational perspective of business processes.

Table I summaries the existing conceptual and practical support for post-execution analysis in light of the framework introduced in Section III. In the table, a ✓ indicates that significant support has been developed; a $\sim$ indicates that partial support exists; and $-$ indicates that support is missing.

	Individual Activities		*Collaborative Activities*	
	Concept	Tool	Concept	Tool
Routine BPs	✓ [17]–[19] [21], [24] [23], [25]	✓ [18], [19] [21], [24] [23], [25]	–	–
Flexible BPs	✓ [17], [26] [19]	$\sim$ [27]	$\sim$ [28]	

TABLE I: Support for post-execution analysis

B. Resource Assignment for Process Modelling

For creating resource-aware process models, i.e., models that describe the conditions necessary to assign resources to process activities, resource assignments can be defined in three different ways: (i) they can be added directly as part of the process model, i.e., integrated with the process modelling notation. That is the case of BPMN [12], conceptual extensions of it [29], [30], as well as conceptual extensions of the Business Process Execution Language (BPEL) notation [31], among others. The BPMSs that use BPMN as process modelling notation tend to stick to this modelling style as well, e.g., Architecture of Integrated Information Systems (ARIS) [32]; (ii) they can be partially added to the process model and partially defined externally, generally for readability purposes. For instance, an extension of the UML Activity model to enable the integration with the RBAC model [11], and systems like Yet Another Workflow Language (YAWL) [33]; or (iii) they can be defined totally externally to the process model for increasing decoupling, e.g., using a so-called Responsibility Assignment Matrix (RAM) [34]. Except RAM, the aforementioned techniques are all tied to a specific process modelling notation, in all cases imperative.

Nonetheless, some resource assignment languages have been designed independent of the process modelling notation [9], [34]–[36]. This type of languages could be used with any of the three aforementioned modelling styles as well as with any type of process modelling notation, provided that the imperative and declarative modelling notations allowed for third-party language integration. As a matter of fact, for some of them, specifically Resource Assignment Language (RAL) and RALph, their practical use with BPMN has been shown in [9] and [36], respectively. However, the required support to integrate them in declarative languages is still missing.

Regarding the support for resource assignment in flexible processes, only one declarative language extensively supports the modelling of the organisational perspective, namely, DPIL [16]. This perspective is only rudimentarily implemented in Declare [15], which allows for the definition of simple organisational models based on users and roles and hence, limited resource assignment conditions.

The expressiveness of the resource assignment techniques is evaluated in terms of the creation patterns they support for the definition of the resource assignment conditions, similar to the evaluation of the approaches for process mining. There are extensive studies for the two types of processes. The study conducted in [37] focuses on routine processes and the one in [38] on flexible processes. The conclusion in both cases is that the coverage of creation patterns is greatly influenced by the organisational model used in the approach, e.g, if the model contains roles, the approach is likely to support Role-Based Distribution. Assignments based on roles and access-control constraints are largely supported. Support for capabilities and organisational relations is less common. Nonetheless, some recent approaches for routine processes provide support for all the creations patterns [9], [30], and seven out of nine patterns for flexible processes [16].

All the techniques referenced above work with individual process activities. Despite the efforts for integrating teamwork concepts in organisational metamodels [39], the existing support for modelling teamwork along with business processes is limited. Modelling teamwork in business processes means defining the teams that can participate in collaborative process activities, i.e., selecting specific already-existing teams or specifying the characteristics a team must have in terms of roles, capabilities, *etcetera*, for taking part in an activity. RALTeam [5] is a language developed as an extension of RAL [9] for describing teams, teamwork assignments and business rules related to team composition. Like RAL, it is independent of the process modelling notation. Finally, the RAMs mentioned above constitute a mechanism for assigning several types of responsibilities to a process activity, e.g., Responsible, Accountable, Support, Consulted and Informed in the case of RASCI matrices [34]. Extensions to RAMs [40] allow for a higher expressiveness while maintaining the decoupling provided by such matrices, which are defined externally to the process model. Some BPMSs offer extensions of BPMN for modelling RAM information in process models, e.g., Bizagi, ARIS and the Red Hat JBoss BPM Suite. However, this information is subsequently used only for documentation purposes and, to the best of our knowledge, there is no support for its automated execution.

Orthogonally to the process or activity types they are designed for, a resource assignment language can be further classified as textual [5], [9], [12], [31], [34], [35], graphical [12], [36] or hybrid [11], [12], [30], [32], [33]. Graphical notations for assigning teams to business process activities remain a modelling challenge.

Table II summaries the existing support for resource assignment in business processes in light of the framework introduced in Section III.

	Individual Activities		*Collaborative Activities*	
	Concept	Tool	Concept	Tool
Routine BPs	✓ [29]–[33] [9], [11], [12] [35], [36]	∼ [32], [33] [9], [11], [12] [36]	∼ [5], [34], [40]	
Flexible BPs	∼ [15], [16]		–	

TABLE II: Support for resource assignment

C. Design-Time Resource Analysis for Process Analysis

As aforementioned, a resource-aware process model might be the source of the analysis of the organisational perspective of a process, i.e., how resources are involved in its activities. A set of analysis operations related to this perspective have been defined [9], including: (i) *potential participants*, which answers the question "who can participate in this process activity?"; (ii) *potential activities*, which answers the question "in which activities can participate this resource?"; (iii) *non-potential activities*, which answers the question "in which activities cannot participate this resource?"; (iv) *non-participant*, which answers the question "which resources cannot participate in this process?"; (v) *consistency checking*, which answers the question "is there any activity in which none of the resources can participate?"; (vi) *critical participants*, which answers the question "who is critical for the completion of this process?"; and (vii) *critical activities*, which answers the question "which are the critical activities of this process?". This catalogue of operations is applicable for design-time and run-time analysis as well as for routine and flexible processes. As mentioned in Section III, at design time, resource analysis merely relies on the information included in the process model as well as on existing information about past process executions. However, run-time information (e.g., resources allocated to previous activity instances of the process instance under analysis) is not available and hence, assumptions must be made to, e.g., resolve separation of duties in the assignment conditions.

There is one complete design-time implementation of such operations based on description logics for activities executed by one single resource [9]. Partial tool support has been integrated as plug-ins in Oryx[3]. Besides that, the existing support for design-time analysis is very limited. In particular, the techniques described in [35], [41], [42] address the operations *potential participants* and *consistency checking*. The four approaches assume imperative process models. To the best of our knowledge, no support has been yet developed for analysing the organisational perspective of declarative process models.

Regarding collaborative activities, since the support for modelling teamwork in business processes is still limited, approaches specifically addressing the analysis of teamwork assignments have not yet been developed. Nonetheless, RAL-Team [5] has formally defined semantics that enables the automated resolution of the teamwork assignments, such that the teams meeting the conditions specified can be automatically identified.

As far as we know, support for design-time analysis of the organisational perspective is missing in current BPMSs.

Table III summaries the existing support for design-time resource analysis in business processes in light of the framework introduced in Section III.

	Individual Activities		*Collaborative Activities*	
	Concept	Tool	Concept	Tool
Routine BPs	∼ [9], [35], [41], [42]	–	–	
Flexible BPs	–		–	

TABLE III: Support for design-time resource analysis

D. Resource Reconfiguration for Process Redesign

The result of design-time resource analysis can help to discover an incorrect or inefficient use of resources. Resource reconfiguration may affect the resource assignments of the process (e.g., changing the type of assignment for some process activities) or the organisation itself at different levels. So far, a set of redesign heuristics have been described collecting acknowledged improvement techniques for business processes [3]. Two groups of heuristics refer to resources: The *Organisational Structure* heuristics include a reduction of the number of organisational units, roles or resources involved in a process, the composition of teams to take over certain sets of activities or process instances, and the separation of responsibilities between organisational units, among others; and the *Organisational Population* heuristics work on the organisational and workforce level and suggest to include more resources in processes and balancing the skills of the resources in an organisation, among others. In principle, these heuristics are not intended to be automated. Otherwise, the

[3]http://bpt.hpi.uni-potsdam.de/Oryx

types of activities of the processes in the company (individual or collaborative) as well as the types of processes would limit to what extent and how the heuristics can be applied.

E. Resource Allocation for Process Implementation

The push patterns and the pull patterns of the workflow resource patterns [20] describe several ways in which activities can be offered or allocated to resources in a BPMS, e.g., offered by the system randomly or on a cyclic basis. These techniques can be combined with planning algorithms responsible for optimising the utilisation of resources in the company in order to, e.g., maximise the quality of service or minimise the time for completing the ongoing process instances.

The existing work on resource allocation in business processes has focused on individual activities and has mostly relied on Petri nets [43], [44]. However, the approaches tend to use a greedy schema and do not intend to find out a global optimal solution but local optimals which in the best case lead to a feasible solution but not necessarily to the most optimal one. The same shortcoming is present in the approaches representing the resource allocation problem as a constraint satisfaction problem [45], [46]. Besides, most of the approaches for resource allocation in BPM use simplified process models that do not have, e.g., loops; as well as they assume simple resource assignment conditions (e.g., role-based distribution), disregarding, among others, typical security aspects such as access-control constraints. Nevertheless, some efforts have been recently made to optimally allocate resources to complex processes considering several concurrent process instances [47] using Answer Set Programming (ASP) on imperative process models represented with Petri nets. Ad-hoc algorithms for planning resource allocation taking into account calendar information [48] could be generalised or integrated with the aforementioned approaches. Prototypical implementations of these approaches are available and referenced in the respective publications.

As for flexible processes, the only execution engine that supports the automatic allocation of activities to resources is the DPIL Framework [27], which uses the DPIL to offer activities to available resources. Only one resource can commit to the work at run time. Planning or optimisation algorithms are not yet in place for a smarter automatic resource allocation in flexible processes.

The need for teamwork for the execution of certain activities has been recognised by the detour patterns [20]. RALTeam [5] as well as some RAM extensions [40] have been designed to support process automation. However, as mentioned in Section IV-C, teamwork analysis is not yet supported in current BPMSs and hence, teamwork allocation is not possible.

Table IV summaries the existing support for resource allocation in business processes in light of the framework introduced in Section III.

	Individual Activities		*Collaborative Activities*	
	Concept	Tool	Concept	Tool
Routine BPs	∼ [43]–[48]		–	
Flexible BPs	∼ [27]		–	

TABLE IV: Support for resource allocation

F. Run-Time Resource Analysis for Process Monitoring

As mentioned in Section IV-C, the same analysis operations that were implemented for design-time analysis can be applied at run time, taking into account new information available (i.e., ongoing process instances). Subsets of the aforementioned analysis operations have been addressed by some approaches for individual activities considering imperative process models. In particular, the approach in [42] develops conceptual support for the *potential participants* operation, and the approach in [37] develops conceptual support based on description logics for the operations *potential participants*, *potential activities*, *non-participants*, *consistency checking* and *critical participants* as well as practical support for the *potential participants* operation as an integration in Activiti[4]. However, in general run-time resource analysis has not been investigated at the same level as the rest of aspects. Notice that the results of run-time analyses could trigger the execution of recovery actions (e.g., reallocation of resources), such as those described by the detour patterns [20].

Regarding industry, the actual support provided by BPMSs nowadays is mostly limited to automating the resolution of the resource assignments of the process activities with the aim of allocating them to appropriate resources [32], [33], i.e., the *potential activities* operation. The support that may exist for other analyses is ad-hoc.

Table V summaries the existing support for run-time resource analysis in business processes in light of the framework introduced in Section III.

	Individual Activities		*Collaborative Activities*	
	Concept	Tool	Concept	Tool
Routine BPs	∼ [37], [42]	∼ [32], [33], [37]	–	
Flexible BPs	–		–	

TABLE V: Support for run-time resource analysis

V. DISCUSSION

Tables I-V depict the existing support for all the aspects involved in the framework of Fig. 1. The following conclusions can be drawn from the tables.

The most developed operations are automatic post-execution analysis (process mining) and the modelling of the organisational perspective (resource assignment). Since the outcome of both techniques is, in most cases, a resource-aware process model, the same evaluation framework for model expressiveness is used, specifically, the creation patterns [20]. However, not all the patterns that can be modelled with resource assignments can be extracted with existing process mining techniques, generally due to a lack of information in

[4]http://activiti.org/

	RAL (Routine Processes)		*DPIL (Flexible Processes)*	
	Individual	*Collaborative*	*Individual*	*Collaborative*
Supported Features	Assignment [9], [36] Allocation [37] DT Analysis [9] RT Analysis [37]	Assignment [5], [40]	Assignment [16] Allocation [27] Mining [26]	Mining [28]
Missing Features	Mining	Mining Allocation DT Analysis RT Analysis	DT Analysis RT Analysis	Assignment Allocation DT Analysis RT Analysis

TABLE VI: Collections of resource management approaches (DT: Design-Time; RT: Run-Time)

the event logs. On the contrary, process mining techniques for the organisational perspective are already mature for both routine and flexible processes, whereas the support for resource assignment focuses on the former. Teamwork is a novel feature in both operations but the current support is still limited. In addition, there is a noticeable gap between the support developed in research and in industry. Current BPMSs do not include support for process mining regarding the organisational perspective and the support for resource assignment is generally limited to specific types of conditions, e.g., role-based assignments. However, common real scenarios, such as a job application process or a bank account opening process, claim for the implementation of more complex assignments including, e.g., separation of duties, for operations that may lead to security problems due to, e.g., conflicts of interests.

The allocation of activities to a concrete resource at run time has been investigated and implemented with several formalisms, especially for routine processes. Nonetheless, the existing support is limited as the approaches either do not aim to achieve the most optimal solution or simplify the setting, which becomes less realistic. Besides, the resource allocation mechanisms present in the BPMSs tend to be simpler and adjust to some of the push/pull patterns [20], e.g., distribution by offer. Support for automatic teamwork allocation is still nonexistent.

The major deficiencies in resource management in business processes nowadays relate to design-time and run-time analysis. Several analysis operations have been formally defined but the current support is restricted to one full implementation based on description logics and partial, ad-hoc implementations; in all cases, only individual activities in routine processes have been considered. This support is only partly included in some prototypical implementations but still missing in existing BPMSs.

In addition, the existing support for the different aspects is usually scattered over a variety of independent approaches the use their own languages and formalisms. In order to provide a holistic resource management solution, integrated approaches are desired. Table VI outlines the two main integrated solutions developed so far. The names of the languages that constituted the started point for the development of related approaches (RAL [9] for routine processes and DPIL [16] for flexible processes) have been used to identify the solutions. In particular, the RAL collection includes a textual and a graphical language for resource assignment considering individual activities, an implementation of the *potential activities* analysis operation at run time that allows for resource allocation, and conceptual as well as (partial) practical implementations of most of the operations at design time and run time. Furthermore, it provides a textual language for assigning teams to collaborative activities and a hybrid approach for team assignment based on RAL and RAMs. On the other hand, the DPIL collection supports the definition of assignment conditions in a declarative way together with a mining approach capable of extracting these conditions from event logs. Moreover, the DPIL assignments can be interpreted by the DPIL Navigator to properly offer process activities to suitable resources at run time. Finally, an extension of the mining approach enables the discovery of team compositions from event logs that describe collaborative activities.

Future approaches should focus on extending the existing support for those aspects partially covered nowadays or on addressing the aspects that have been disregarded. Improving the efficiency of existing mechanisms as well as generalising or adapting them to other environments (e.g., to work with different organisational models or support different types of business rules) is also a direction for future work.

VI. Further Insights

This work may be subject to certain limitations which should be taken into account for potential extensions. First, this paper does not cite all the scientific approaches developed in the context of human resource management in business processes as well as it does not provide a detailed description of the support present in all the existing BPMSs. Instead, the techniques and tool support cited in this paper have been selected as representatives of specific functionalities developed for the problem at hand. Further references to similar approaches can be found in the cited papers. Our goal was not to present an exhaustive literature review but to design a framework that comprises all the aspects identified in the problem domain as well as how they related to each other, and to show reasonable evidence of the existing support.

Second, the framework has been designed from the state of the art in the domain of BPM. However, the analysis of close domains, such as operational management, could provide new perspectives that helped to extend the current framework.

Finally, the biggest effort towards collecting aspects involved in human resource management in business processes so far was the workflow resource patterns [20]. These patterns aim at providing a conceptual classification of resource modelling and execution techniques but disregard other operations of BPM, such as process analysis. Therefore, our framework is complementary to the workflow resource patterns and it takes them into consideration.

VII. Conclusion

In this paper, we have presented a novel framework for human resource management in business processes along with a study of the existing support for every aspect involved. Specifically, we have answered three research questions related to the operations involved in this problem, the factors that may affect the way in which the operations are addressed, and the existing theoretical and practical support. This work intends to help process managers to enhance the support for the organisational perspective in their processes by inspiring them to integrate existing approaches or to develop new ones. The aim is to extend current PAISs towards PRAISs in which resources are also treated as first-class citizens.

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