Machine-Assisted Design of Business Process Models Using Descriptor Space Analysis

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Abstract. In recent years, researchers have become increasingly interested in developing methods and tools for automating the design of business process models. This work suggests a method for machine-assisted design of new process models, based on business logic that is extracted from real-life process repositories using a linguistic analysis of the relationships between constructs of process descriptors. The analysis enables the construction of a descriptor space in which it is possible to define new process sequences. The suggested method can assist process analysts in designing new business processes while making use of knowledge that is encoded in the design of existing process repositories. To demonstrate the method we developed a software tool ("New Process Design Assistant" - NPDA) that automates the suggested design method. We tested our tool on the Oracle Applications ERP process repository, showing our approach to be effective in enabling the design of new activities within new business process models.

Keywords: New process model design, Business process repositories, Business process integration and management, Process choreographies.

1 Introduction

In recent years, researchers have become increasingly interested in developing methods and tools for automating the design of business process models. Process modeling is considered a manual, labor intensive task, whose outcome depends on personal domain expertise with errors or inconsistencies that lead to bad process performance and high process costs [12]. Hence, automating the reuse of constructs, gathered from predefined process models does not only save design time but also supports non-expert designers in creating new business process models. Research in this field encapsulates topics from the areas of software design and data mining [19,15,6,4], and is focused on structured reuse of existing building blocks and pre-defined patterns that provide context and sequences [5].

While most previous work focused on supporting the design of alternative process *steps* within *existing* process models, less work has been carried out on the design of *new* process models. We only identified a few works that address the design of new models [12,14,7]. This work aims at filling this gap by suggesting a generic method for designing new business process models related to any

R. Hull, J. Mendling, and S. Tai (Eds.): BPM 2010, LNCS 6336, pp. 128–144, 2010.

functional domain. The suggested method guides business analysts that opt to design a new business model, by suggesting process steps (activities) that are relevant to the newly created process model. The business logic for such suggestions is extracted from process repositories through the analysis of existing business process model activities. Each activity is encoded automatically as a *descriptor*, using the "PDC" notation, suggested first in [11] and further elaborated in this work for supporting the field of new process model design. The collection of all descriptors formulates a descriptor space, and distances between every two space coordinates are calculated in terms of business process conduct proximity. We show through an empirical evaluation that by utilizing the descriptor space it is possible to effectively support the design of new process models.

As a motivating example consider an airport process model of check-in related processes. Now, suppose that the airport management desires to offer to its customers a new service: "check-in from home". In addition, it is also desired to outline the "check-out" process model as an extension of the current repository. Although these process models are new, the existing repository encapsulates know-how and business logic that are relevant and useful for their creation (*e.g.*, passenger check-in policies and procedures regarding security, luggage handling, passenger handling, and document validation). In the above scenario, it would have been helpful for the process designer to design the new processes using a supporting system that relies on the reuse of previous know-how instead of doing this manually from scratch. To illustrate our methodology in this work we use a real-world case study for airport process design. Based on a "check-in" process that already exists in the repository, we demonstrate how it is possible to design the two, above mentioned, new business processes.

This work proposes an innovative method for assisting designers in designing brand new business process models while making use of knowledge that is encoded in the design of existing, related process models. Our work presents the following innovations: (a) it provides generic support to the design of new business process models; (b) it equally utilizes objects and actions for business content analysis: we make use of all activity linguistic components (object, actions and their qualifiers) concurrently, without special focus on objects (as object centric methods do) or on actions (as activity-centric methods do); (c) it extends the PDC model [11] to enable the extraction of business logic from business process repositories.

The suggested method was implemented within a software tool, that was demonstrated using the aviation industry case study and the Oracle Applications ERP process repository.

The rest of the paper is organized as follows: we present related work in Section 2, positioning our work with respect to previous research. In Section 3 we present an extended model for representing process activities based on the process descriptor notion, presented first in [11], and extended in this work to support new process model design. In Section 4 we define and discuss the descriptor space and explain how to navigate in it. Then, we describe our method for designing new business process models in Section 5. Section 6 introduces the software tool and our empirical analysis. We conclude in Section 7.

2 Related Work

Most of the efforts invested in developing methods and tools for designing process models focus on supporting the design of alternative process steps within existing process models. Such a method is presented in [16] aiming to provide next-activity suggestions during execution based on historical executions and optimization goals. Recommendations are generated based on similar past process executions as documented in event logs. Similarly, [5] suggests an approach for helping business users in understanding the context and consequences of applying pre-defined patterns during a new process design. Other works extend this research domain by adding both generalization and formalization layers [7,1]

Few works were devoted to the design of brand new process models within specific and predefined domains. The work presented in [12] utilizes the information about a product and its structure for modeling large process structures. [14] presents a method, named "the product-based workflow design," for designing new process models based on product specification and required design criteria.

A requirement for the support of business process design involves the performance of a structured reuse of existing building blocks and pre-defined patterns that provide context and sequences [5]. The identification and choice of relevant process components are widely based on the analysis of linguistic components - actions and objects that describe business activities. Most existing languages for business process modeling and implementation are activity-centric, representing processes as a set of activities connected by control-flow elements indicating the order of activity execution [20]. In recent years, an alternative approach has been proposed, which is based on objects (or artifacts/entities/documents) as a central component for business process modeling and implementation. This relatively new approach focuses on the central objects along with their life-cycles. Services (or tasks) are used to specify the automated and/or human steps that help move objects through their life-cycle, and services are associated with artifacts using procedural, graph-based, and/or declarative formalisms [8]. Such object-centric approaches include artifact-centric modeling [13,2], data-driven modeling [12] and proclets [17]. Further analysis of the object-centric model in terms of computing the expected coupling of object lifecycle components is presented in [20].

Although most works in the above domain are either object or activity centric, only a few works combine the two approaches in order to exploit an extended knowledge scope of the business process. The work in [9] presents an algorithm that generates an information-centric process model from an activity-centric model. The work in [11] presents the concept of business process descriptor that decomposes process names into objects, actions and qualifiers.

In this work we take this model several steps forward by: (a) describing the relationships between the model components; (b) showing how the descriptor model can automatically be generated (using NLP methods); and (c) utilizing the qualifiers for identifying the relationships between descriptor components within a process repository.

3 The Activity Decomposition Model

This section describes a model of business process decomposition that supports process design. To illustrate the model components we make use of the aviation example from Section 1.

3.1 The Descriptor Model

The Workflow Management Coalition (WFMC) [3] defines business process as a **"**set of one or more linked procedures or activities which collectively realize a business objective or policy goal.**"** An example of such business process model is the "Passenger check-in" process model, presented in Fig. 1. This figure is based on YAWL [18] with two slight visual representation modifications, convenient for our needs: (a) roles were added at the top of each activity; and (b) predecessor and successor processes are presented as nested activities at the beginning and at the end of the workflow.

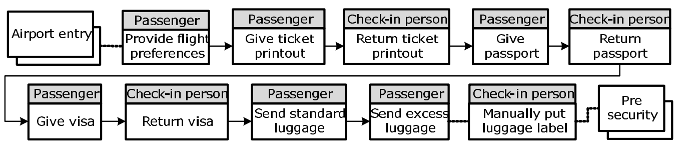


Fig. 1. An example: the "Passenger check-in" process model

In the Process Descriptor Catalog model ("PDC") [11] each activity is composed of one action, one object that the action acts upon, and possibly one or more action and object qualifiers, as illustrated in Fig. 2, using UML relationship symbols. Qualifiers provide an additional description to actions and objects. In particular, a qualifier of an object is roughly related to an object state. State-of the art Natural Language Processing (NLP) systems, *e.g.*, the "Stanford Parser,"[1] can be used to automatically decompose process and activity names into *process/activity descriptors*.

For example, in Fig. 1, the activity "Manually put luggage label" generates an activity descriptor containing the action "put," the action qualifier "manually," the object "label" and the object qualifier "luggage."

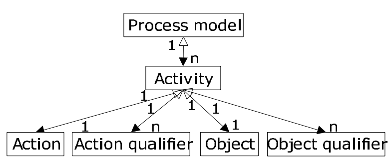


Fig. 2. The activity decomposition model

[1] `http://nlp.stanford.edu:8080/parser/index.jsp`

3.2 A Descriptor Model for Process Design

We now enhance the PDC model of [11] to support process design. Our model has two basic elements, namely objects and actions, and we delineate four taxonomies from them, namely an *action hierarchy model*, an *object hierarchy model*, an *action sequence model* and an *object lifecycle model*. The business action and object taxonomy models organize a set of activity descriptors according to the relationships among business actions and objects both longitudinally (hierarchically) and latitudinally (in terms of execution order), as detailed next.

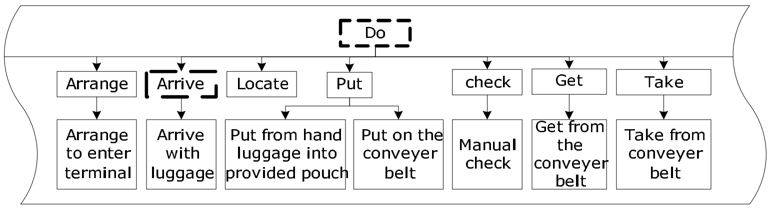


Fig. 3. A segment of the action hierarchy model extracted from the aviation processes

The longitudinal dimension of actions and objects is determined by their qualifiers. To illustrate the longitudinal dimension of the aviation workflows, a segment of the action hierarchy model is presented in Fig. 3 and a segment of the object hierarchy model is presented in Fig. 4. Consider the complete action (the action and its qualifier) “Manual check.” It is a subclass (a more specific form) of “Check” in the action hierarchy model, since the qualifier “Manual” limits the action of “Check” to reduced action range. It is worth noting that some higher-hierarchy objects and actions are generated automatically by removing qualifiers from lower-hierarchy objects and actions. For example, the action “Arrive” was not represented without qualifiers in the aviation processes repository, and was completed from the more detailed action: “Arrive with luggage” by removing its action qualifier (“with luggage”) (see Fig. 3). In Section 5 we will show how such elements assist in designing new processes by enriching the underlying process repository range. This type of objects and actions are marked with a dashed border. In addition, a root node “Do” is added to any action hierarchy model and a root node “Object” is added to any object hierarchy model, effectively generating a single object and action tree from what would have been, in graph theoretic terminology, a forest.

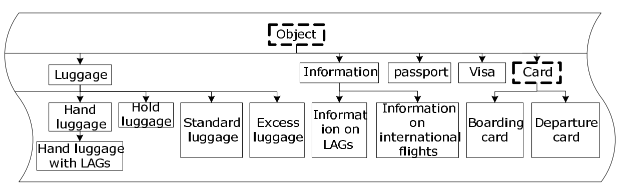


Fig. 4. A segment of the object hierarchy model extracted from the aviation processes

To illustrate the latitudinal dimension of the aviation process repository, a segment of the action sequence model is presented in Fig. 5 and a segment of the object lifecycle model is presented in Fig. 6. Latitudinally, each object holds: (a) a graph of ordered actions (an "action sequence") that are applied to that object. For example, the object "Luggage" is related to the following action sequence: "Arrange" followed by "Send" (see Fig. 5); (b) a graph of ordered objects that expresses the object's lifecycle, meaning - the possible ordering of the object's states. This sequence is built by locating the same object with different qualifiers along the process diagram. For example, the object "Luggage" is part of the following object lifecycle: "Luggage" –> "Standard luggage"/"Excess luggage" –> "Labeled luggage" (see Fig. 6).

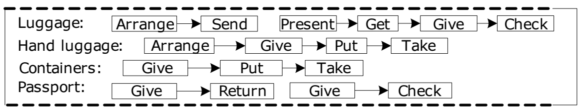


Fig. 5. A segment of the action sequence model extracted from the aviation processes

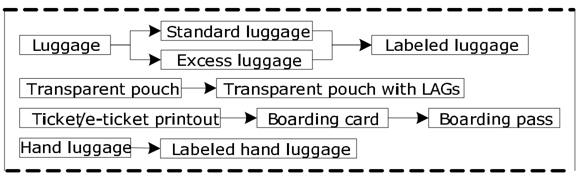


Fig. 6. A segment of the object lifecycle model extracted from the aviation processes

4 The Quad-Dimensional Descriptor Space

Based on the activity decomposition model, it is possible to visualize the operational range of a business process model as a descriptor space comprised of related objects and actions. The descriptor space is a quad-dimensional space describing a range of activities that can be carried out within a process execution flow. The coordinates represent the object dimension, the action dimension, and their qualifiers. Therefore, each space coordinate represents an activity as a quadruple $AC = \langle O, OQ, A, AQ \rangle$, where O is an object, OQ is a set of object qualifiers, A is an action, and AQ is a set of action qualifiers.

For example, the activity "Arrive at appropriate terminal with luggage" can be represented by the following coordinate: ⟨arrive, with luggage, terminal, appropriate⟩. This coordinate represents an actual activity in the business process model: "Airport entry." Once constructed, the descriptor space includes all the possible combinations of descriptor components, forming a much larger and diversified set of possible descriptors. Hence it includes several "virtual" combinations- that did not originally exist in the original process repository.

These virtual combinations, together with existing activities, form an expanded repository that is used for the design of new business processes.

For every two coordinates in the descriptor space we define a *distance function* that is tailored to our method. The proposed distance function in the descriptor space represents a linear combination of changes within each of its dimensions. Therefore, we define four specific distance measures using the structures that were gathered from existing business processes repositories (Section 3).

Definition 1. ***Object distance (*****OD*****):*** *Let O_i and O_j be two objects, OD_{ij} is the minimal number of steps connecting O_i and O_j in the object lifecycle model.*

In a similar way we define *Action distance*, AD, calculated based on the action sequence model. For example, the action distance between "Present" and "Check" when acted on "Luggage" is 3 (see Fig. 5).

Definition 2. ***Object hierarchy distance (*****OHD*****):*** *Let O_i and O_j be two objects, OHD_{ij} is the minimal number of steps connecting O_i with O_j in the object hierarchy model.*

In a similar way we define *Action hierarchy Distance*, AHD, calculated based on the action hierarchy model.

OD, AD, OHD and AHD are combined to generate a specific distance function between any two activities AC_i and AC_j, as follows:

$$Dist\,(AC_i, AC_j) = OD_{ij} + AD_{ij} + OHD_{ij} + AHD_{ij} \tag{1}$$

It is worth noting that the hierarchy distances (OHD and AHD) can always be calculated since the hierarchy models that they rely on are bidirectional trees. However, the distances OD and AD can be undefined in some cases (*e.g.*, when the two objects are not connected in the object hierarchy model, or when the two actions are not acted upon the same object and therefore do not take part in the same action sequence). In these cases the above distance components contribute a *no-connection* distance to the overall distance function. This distance is an application specific tunable parameter.

As an example for the use of this distance function consider the two descriptors (luggage, hand, check, null) and (luggage, null, get, from the conveyer belt). To navigate from the first descriptor to the second, we first move one step up in the object hierarchy ($OHD = 1$) from the object "Hand luggage" to the object "Luggage" (see Fig. 4). Then, we recede two steps from the action "Check" in the action sequence ($AD = 2$), resulting with the action "Get" (See Fig. 3). Finally, we drill down one step within the action hierarchy ($AHD = 1$), and retrieve the action "Get from the conveyer belt", and by that we reach the target descriptor. In total, the distance between the two above coordinates is 4.

In general, it is possible to navigate within the descriptor space (hence, move from one descriptor to another) in a meaningful way. This navigation enables us to move up to more general or drill down to more specific action and object scopes as well as to navigate to: (a) preceding and succeeding actions that act on the descriptor's object and (b) advance to a successor (more advanced) state of the object's current state or recede to a predecessor (less advanced) state. A more elaborated discussion regarding the navigation within the descriptor space is presented in [10].

5 The *Process Delineator* Method for Assisting the Design of Process Models

The *process delineator* method relies on an underlying process descriptor space and at any phase it either refines an existing process activity or suggests a next process activity. Since the descriptor space has a large number of elements, a general search within this space may be very expensive. Therefore, we will hereby suggest a more efficient navigation method that is tailored for our specific target.

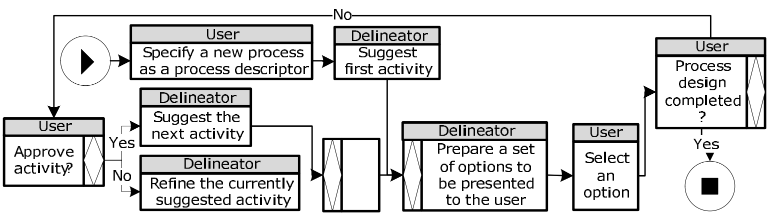


Fig. 7. The process delineator mechanism

The process delineator is illustrated in Fig. 7. The design process starts when a process designer defines the name of the new process model. This name is decomposed into a process descriptor format. For example, a new process named: "Send luggage from home," will be transformed into the following process descriptor: object="luggage," action= "send," object qualifier="null," action qualifier="from home."

Based on the process descriptor input, the process delineator produces options for the first process activity (see Section 5.1). The process designer reviews the output option list, and either selects the most suitable first activity for the newly designed process, or suggests an alternative. At any next phase the designer either requests to refine the current activity (see Section 5.2) or advance to design the next activity (see Section 5.3). Each time the process delineator is requested to suggest activities as part of the design process it outputs a list of options, sorted and flagged according to the option's relevance to the current design phase (see Section 5.4).

After selecting the most suitable process activity from the suggested list, the designer examines the newly designed process model to determine if it achieves the process goals. If goals are achieved, the design is terminated; else - the design procedure continues until the process goal is achieved.

It is worth noting that the process delineator also uses virtual activities (see Section 4). These activities can enrich and improve the design process by expanding the optional range of available building constructs.

5.1 Suggesting the First Process Activity

To suggest the first process activity, the process delineator searches the target object and its more specific objects within the object hierarchy model. It then creates first activity suggestions in the format of activity descriptors comprised of the retrieved objects and the first action that acts upon them in the action sequence model. Continuing the example above, the following first activity options will be suggested (see Fig. 5): “Arrange luggage” and “Give hand luggage.”

5.2 Refining the Currently Suggested Process Activity

A refinement can be performed by five orthogonal methods. To illustrate each of these methods we will show how the action “Get luggage” can be refined.

Action and Object Refinement. To refine the reference action, the process delineator navigates the descriptor space by drilling *down* the action hierarchy to more specific actions. It then combines the retrieved, more specific, actions with the reference object. The refinement of objects is done in a similar manner. By applying an action refinement to our example’s reference activity, the refinement option: “Get luggage from the conveyer belt” is retrieved (see Fig. 3).

Action and Object Generalization. The generalization method is similar to the action and object refinement method, only this time the process delineator navigates the descriptor space by moving *up* the action and the object hierarchal dimension, respectively.

Advance an Action or an Object State. To advance the object’s state within an activity, the process delineator navigates the descriptor space by moving *forward* in the object lifecycle sub-dimension. In a symmetrical manner, to advance an activity’s action, the process delineator moves forward in the action sequence sub-dimension of the descriptor space. In our example the objects “Standard luggage” and “Excess luggage” represent more advanced states of the object “Luggage” (see Fig. 6) and the action “Give” follows the action “Get” in the action sequence applied on “Luggage” (See Fig. 5). Therefore, the following three refinement suggestions are constructed: “Get standard luggage”, “Get excess luggage” and “Give luggage”.

Recede to a Less Processed State of the Object or to a Former Action. The receding method is similar to the advancing method, only this time the process delineator navigates the descriptor space by moving *backwards* in the object lifecycle and action sequence sub-dimensions. For example, the action “Present” is acted on “Luggage” before this object is taken (before the action “Get” is applied) (see Fig. 5), hence creating the option: “Present luggage.”

Move to a Sibling Action or Object. In order to move to a sibling action, the process delineator moves horizontally within the action hierarchal sub-dimension. By fixing the reference action’s level, it retrieves sibling actions for this action. Moving to a sibling object is conducted in a similar manner. Continuing our example, a navigation to sibling actions to "Get" retrieves a list of activities that includes: "Check luggage" and "Take luggage" (see Fig. 3).

5.3 Suggesting the Next Process Activity

This step can be achieved in two alternative ways: either by advancing to a later action that acts on the currently accepted (reference) object, or advancing to a sibling object combined with the reference activity's action. The rationale behind the last directive is that in some process flows the same action is operated on sibling objects in order to fulfill a certain process goal. For example, in the aviation processes, the "Check-in" process includes the two consecutive activities: "Send standard luggage" and "Send excess luggage."

To demonstrate this step, consider the activity following "Give passport." The process delineator finds in the action sequence model two options: "Check passport" and "Return passport" (see Fig. 5). In addition, sibling objects to "Passport" are also retrieved from the object hierarchy model, creating additional options such as "Give visa," "Give luggage," and "Give information" (see Fig. 4).

5.4 Preparing a Set of Output Options

The process delineator assesses the output options in each navigation phase and combines an ordered option list to assist the user in selecting the most suitable option. The process delineator sorts the options according to their relevance to the current design phase based on two considerations. First, on proximity to the design phase reference coordinate - which represents the last selected activity when suggesting a refined or next activity, or to the targeted process descriptor when suggesting the first process activity. Second, the process delineator considers to what extent was it changed comparing to actual activities that were part of the underlying process repository. Therefore, the construction of the ordered option list is conducted according to the following four stages: (a) sort by proximity to the reference activity; (b) internally sort by similarity to processes in the repository; (c) add a random option to avoid getting stuck in a local optimum; and (d) flag each option, as further detailed below.

Sort by Proximity to the Reference Activity. The process delineator calculates the distance between the reference coordinate and each of the list options (see definition 1), and sorts the list in an ascending order - from the closest to the most distant option.

Internally Sort by Similarity to Processes in the Repository. The process delineator also takes into account the extent to which a proposed activity was changed in comparison to actual activities in the underlying process repository. For this purpose the process delineator distinguishes between three change levels: (a) *No change*- the suggested activity is represented "as is" within the underlying business process repository. These options are not marked by any flag;

(b) *Slight modification* - there is an actual activity in the underlying business process repository containing the same object and action with different qualifiers. These options are marked with "~"; (c) *Major change* - the object and action within the suggested activity were not coupled in any of the activities within the underlying business process repository. These options are marked with "M".

Therefore, after sorting the options by their proximity to the reference activity, each group of options with equal distances is internally sorted in an ascending order - presenting the "no change" options at the beginning of the list, since these options posses a higher level of credibility, continuing with the "slight modification" options and terminating the list with the "major change" options. According to the example presented in Section 5.3, several options were generated as candidates for next activities to be conducted after the activity "Give passport." Most of these options were produced by combining the action "Give" with siblings of the object "Passport," hence having the same distance from the reference activity. Nevertheless, these options can further be differentiated. For example, "Give visa" is an actual activity in the aviation process repository, and therefore is flagged as such. Nevertheless, "Give luggage" has no representation in this repository, but since "Give hand luggage" does, this option is flagged by "~." Since there is no descriptor that combines the action "Give" and the object "Information" in this repository, the option "Give information" is flagged by "M."

Add a Random Option. To avoid getting stuck in a local optimum, the process delineator adds at any stage a random activity from the descriptor space, that shifts the reference activity to a new random coordinate, in a similar manner as in simulated annealing (or mutation in genetic algorithms). Thus, the process delineator can provide new suggestions that are based upon a proximity sort to this new reference activity.

Flag Each Option. After assessing each option's relevance to the current navigation phase and sorting the option list accordingly, the process delineator tags each option with both the numerical distance value and the change level. For example, the option "Give luggage" from the example above will be flagged "[2,~]."

6 Implementation, Case Study and Experiments

6.1 Implementation

We have developed a system that implements the suggested method for designing new process models. We named this software system: "New Process Design Assistant" (NPDA). Given a process name, and based on an existing process repository, the NPDA guides users in creating new process models. The system implements a client-server architecture. Server side logic is implemented in PHP using a MySql database. It uses a Natural Language (NL) parser - the "Stanford Parser" - as a web service for decomposing sentences into linguistic components (see Section 3.1). The client runs within an Internet browser and is implemented in HTML and JavaScript, with AJAX calls to the server. The server side high-level architecture is further detailed in our technical report [10].

6.2 Case Study: An Example for Designing a New Process Model

To illustrate the proposed framework we present two short examples from the field of aviation. The full extended case-study can be found in the technical report[10]. The aviation process repository covers airport activities starting from the passenger's entry to an airport, through document handling and security checks and terminating as the passenger boards the airplane. The newly designed processes are related to the aviation field, but are not covered by the process repository. The first new process, "Passenger checkout," extends the process repository by handling passenger related activities conducted *after* an airplane arrives at its destination. The second new process, "Send luggage from home," extends the process repository by offering an additional service to passengers *before* their arrival at the airport.

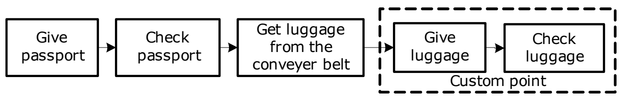
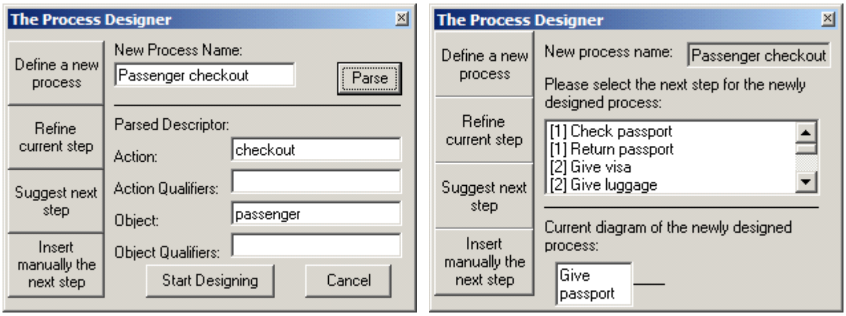


Fig. 8. The new designed process diagram for "Passenger checkout"

The first example supports the design of a new business process for: "Passenger checkout." The generated output (new process model) of this example is illustrated in Fig. 8 as a YAWL diagram. The design process starts when the (human) process designer inserts the following process descriptor: (action="checkout", action qualifier=null, object="passenger", object qualifier=null) to the process delineator (see Fig. 9a) and determines that the first activity is: "Give passport." Respectively, the process delineator searches the descriptor space, looking for next activity possibilities. The result set includes the following activities (see Sections 5.3 and 5.4): "[1] Check passport," "[2] Give visa" and "[2,M] Give information" (see Fig. 9b). The designer selects the option "Check passport" and decides that this activity is suitable.

The design process continues with four more design phases. The 2nd phase required a refinement for the option "Get luggage" - which was suggested as the next activity after "Check Passport." The resulted refined option list includes the option: "[1,~] Get luggage from the conveyer belt," (see Section 5.2), and this option was selected by the designer. Note that this activity was not represented "as is" in the business process repository.

The designer now wishes to design the new business process: "Send luggage from home." An interesting observation in this design process is that the designer selects more often next step activities that share the same action applied on sibling objects. For example, the the activity "Give passport" was followed by "Give flight ticket" and "Give boarding pass;" and the activity "Check flight ticket" followed the activity "Check passport" (see resulted process model diagram at [10]). The business logic behind this phenomenon is that this process expresses a more interactive business conduct in which one party (the passenger) exchanges items with the other party (the airport representative).



(a) The designer's request for designing the new process: "Passenger Checkout"

(b) The third phase in designing the new process: "Passenger Checkout"

Fig. 9. The designer's request for designing the new process: "Passenger Checkout"

6.3 Experiments

We now present an empirical evaluation of the proposed method effectiveness. We first present our experimental setup and describe the data that was used. Based on this setup we present the implemented methodology. Finally, we present the experiment results and provide an empirical analysis of these results.

Experiment Setup. The "New Process Design Assistant" software (NPDA, see Section 6.1) was installed on a workstation running Windows XP, IIS6, PHP 4.8 and MySQL 5.0. This workstation served both as the server and the client, running Internet Explorer 7 as the application container and presentation layer. The "no-connection" distance (defined in Section 4) was set to 500.

Data. We chose a set of 14 real-life processes from the Oracle Business Model (OBM),[2] comprising: (a) nine business processes from the "Procurement" category, with 96 activities altogether; and (b) five business processes from the "Inventory" category, with 31 activities altogether. The "Procurement" data set contains related, sequential activities and therefore represents a focused operational area. The "Inventory" data set represents an extended business area, featuring loosely coupled business logic. Using the selected 14 processes we created a "process repository database" (see Section 6.1).

Evaluation Methodology. To evaluate the suggested method we conducted 14 experiments. At each experiment, a single process was removed from the database and then reconstructed using the NPDA software. This "machine assisted reconstruction" enables us to objectively measure the method's effectiveness.

Each experiment was conducted according to the following steps: (a) preparation: remove one of the processes from the database so that the database will not contain any of its descriptor components; (b) run the NPDA in a stepwise

[2] `http://www.oracle.com/applications/tutor/index.html`

manner. At each phase we try to identify an activity ("goal activity") that is compatible with the removed process, according to the following steps: (1) if the goal activity's linguistic components are represented in the Process Repository Database, run the "find next activity" algorithm (see Section 5.3). If the output list contains the goal activity - continue to reconstruct the next goal activity. Else, run the "activity refinement" algorithm (see Section 5.2). If the option list produced by the refinement step does not include the goal activity, choose the activity that shares the largest amount of common descriptor components with the goal activity as a basis for an additional refinement. If, after 10 successive refinements, the required activity is still not represented by one of the output options, it is inserted manually as the next process activity and the design process is continued by locating the next activity; (2) else (the goal activity's linguistic components are not represented in the Process Repository Database), the next goal activity is inputted manually by the experimenter.

Results and Analysis. Table 1 presents a summary of the experiment results. Each experiment of creating a new process model was based on a database with the set of all activity descriptors in all process models, excluding the set of activity descriptors of one goal process. This means that we aim at recreating the goal activities from a partial set of activity descriptors. On average, for 89% of the goal activities, all descriptor components were contained both in the goal process and in another process (see column #3). This was the case despite the relatively small experiment size (13 processes, whereas the entire OBM includes around 1,500 processes), highlighting the amount of similarity one would expect when designing new processes based on an existing repository. For the remaining 11%, at least one descriptor component was missing. In such a case, the activity was inserted manually during the design process. It is worth noting that for the 89% of activities that had the potential of reconstruction from the database, 100% were reconstructed successfully using our method (see Table 2).

In addition, Table 1 shows that on average, two iterations are required for reconstructing a goal activity (see column #4). The design of Procurement

Table 1. Experiment results

Column #	1	2	3	4	5	6	7
Column name	# of total processes in DB	# of total activities in DB	% of goal activities represented in the DB	Avg. # of steps per design phase	Avg. location of correct option in 'next activity'	Avg. location of correct option in 'refine activity'	Avg. location of the correct option per design phase
Avg.-all	14	127	89.0%	2.0	1.2	2.8	2.6
Avg.-Procurement	9	96	90.6%	1.9	0.8	3.0	2.8
Avg.-Inventory	5	31	83.9%	2.1	1.9	2.4	2.3

processes required slightly less steps than the design of Inventory processes (1.9 vs. 2.1 steps on average, respectively). It should be noted that the location of the goal activity was very high in the ranked list of suggested activities (average location: 2.6, see column #7). This location was even higher at phases that did not involve refinement (average location: 1.2, see column #5); and was a little lower in steps in which a refinement was required (2.8 on average, see column #6). This may be due to the fact that refinement steps include a much larger amount of alternatives. Again it should be noted that results within the Procurement category were better than results within the Inventory category - probably due to the larger database representing Procurement processes. Another reason may be the consecutive nature of procurement processes vs. the loosely coupled business logic of the Inventory processes.

Table 2. Distribution of successful predictions vs. the number of required refinements

# of refinements	0	1	2	3	4	5	6	7	8	9
% of successful predictions	12%	35%	27%	12%	4%	2%	2%	1%	1%	3%
Cumulative	12%	48%	75%	88%	92%	94%	96%	96%	97%	100%

Table 2 analyzes the number of refinements that are needed to design the correct goal activity. For each number of refinements, we record the percentage of cases where this number of refinements was needed. We also record, for each number of refinement i, the cumulative percentage of cases where up to i refinements were needed. We observe, for example, that in 88% of the cases the system can reconstruct the goal activity after a maximum of three refinements. These results clearly demonstrate the speed and efficiency of the suggested method. Moreover, in all experiments the refinement process converged into a maximal number of nine refinements in the worst case. As hypothesized earlier- a larger database would probably yield even better results.

To summarize, we have shown the usefulness of using a descriptor repository in identifying activities for a new business process. We also showed the method to be effective in the given experimental setup, both in terms of the number of design steps and in the number of refinements that are needed.

7 Conclusions

We proposed a mechanism to automate the reuse of constructs gathered from predefined process models. Such a mechanism saves design time and supports non-expert designers in creating new business process models. The proposed method, software tool, and experiments provide a starting point that can already be applied in real-life scenarios, yet several research issues remain open, including: (1) an extended empirical study to further examine the quality of newly generated processes; (2) an extended activity decomposition model to include an elaborated set of business data and logic (*e.g.*, roles and resources); and

(3) defining a learning mechanism that will take into account previous designer preferences and adjusting (in real time) the process delineator mechanism.

As a future work we intend to investigate further language semantics by using more advanced natural language processing techniques, as well as semantic distances between words. Finally, we intend to apply the techniques we have developed to create new methods for workflow validation.

Acknowledgments

Many thanks to Samia Mazhar and the BPM Group at QUT for providing access to the aviation process data. Also thanks to Roman Kushnarenko for supporting the experiments.

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