Comparing Business Process Variants using Models and Event Logs

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Abstract. Organizations realize that benefits can be achieved by closely working together on the design of their business processes. But even when there is a joint design for a particular business process, the way individual organizations carry out that process may differ – either wittingly or unwittingly. This paper proposes an analytical approach that helps to compare how different organizations execute essentially the same process. This comparison is based on the alignment of recorded process behavior with explicitly defined process models. The distinctive feature of the proposed approach is that it supports the comparison of the actual execution of a process within a particular organization with its *intended* design, as well as with the *variants* of that design by other organizations. In this way, organizations can develop a better understanding of how they can work together and further standardize a process of common interest. We include an industrial case study from the context of the CoSeLoG project to demonstrate the value of this comparison approach.

1 Introduction

All around us, we see signs of the rise of the 'sharing economy' [7]. We may primarily think of individuals who can collaboratively make use of under-utilized capacity, as in the example of Airbnb[1]. Increasingly, also professional organizations realize the benefits of sharing information, resources, and expertise among them. For example, partners in a supply chain may share market analyses to jointly arrive at better demand forecasts.

Another way of sharing knowledge for organizations is to work according to a consciously designed common plan for their operations. In this way, an autonomous organization may strike a balance between (a) reaping efficiency advantages through a standardized way of working for a particular process and (b) addressing local priorities through incorporating local deviations from that standard plan.

In this paper we focus on one of the challenges that such cooperative yet independent organizations face: Even if they execute a jointly designed process, how to identify the commonalities and differences between the ways they actually work? While some deviations may be planned for explicitly, others may be

[1] http://www.airbnb.com, last accessed on February 19, 2014

unexpected. Recent work has indicated that, for example, people can be highly creative in working around intended procedures [16].

The context for this paper is the CoSeLoG project[2] in which a group of 10 Dutch municipalities participate. Five of these have decided to start working more closely together while maintaining their legal autonomy. After having executed a commonly designed process for a prolonged amount of time, they have an interest in the type of comparison we sketch: How is each organization carrying out that process and how do they differ from each other in this respect?

Our contribution is a new analytical technique that allows for a *dual* comparison. In the first place, it allows for a comparison between the intended and the actual execution of a business process. Secondly, it supports the comparison of the execution of process variants, for example in case different organizations carry out a similar process. These comparisons are visualized through a so-called *alignment matrix*. The paper also describes a comparison framework that shows the methodic application of this aid.

This paper extends [3] by its explicit incorporation of the process model in the comparison, i.e. the intended behavior. By (a) replaying the actual behavior on that initial model, as witnessed through event logs, and (b) showing where different organizations deviate, the process model can be used as a common means to compare against. Notably, in [3] there was no means to visualize this comparison. This cross-comparison can help organizations to provide a better understanding of how a process is executed and to act upon that insight. Such actions may be diverse: It may be decided to fix the common process if it allows for too much deviation, but individual organizations may also want to imitate the practices of another partner when these seem preferable.

The remainder of this paper is organized as follows. In Section 2 we will reflect on related work that aims to analyze and compare processes. A running example is introduced in Section 3. The main contribution is provided in Section 5, which is preceded by an explanation of fundamental concepts in Section 4. The overall comparison approach is applied in a case study, which is described in Section 6. Section 7 concludes our paper.

2 Related Work

For a considerable time now, organizations seek to learn from others on how to adapt their own processes towards improved competitiveness [18]. Process *benchmarking*, however, is primarily a manual process, requiring the involvement of experts to collect and interpret process-related data [19]. A main problem that has been recognized is that processes across different organizations are often modeled on different levels of granularity and for different purposes. This makes their comparison hard. Previous research in the area of process benchmarking has mainly focused on semantic approaches to overcome these types of barriers, e.g. [6, 9, 19].

[2] `http://www.win.tue.nl/coselog/wiki/start`, last accessed on February 19, 2014

In the context of our work, the processes that are to be compared can be considered *variants* of each other [12]. This means that the processes are different, but share essential characteristics through their conformance to a shared set of constraints [13] or their derivation from a common template [8]. Because of this starting point, their semantical matching is not really an issue. Yet, the emphasis of existing work on model variants is on the management, specification, and comparison of *models*, i.e. the design-time perspective on these processes. Our paper widens this scope by incorporating the actual *behavior* of these variants, i.e. the run-time perspective. In other words, we extend process model variant management with analytical approaches that allow for comparing the supposed/intended behavior of processes with their actual execution.

Two categories of approaches with respect to comparing the supposed or intended behavior with the actual behavior of a process can be identified. The first of these encompasses approaches that pursue delta analyses between a *predefined* process model on the one hand and the *discovered* model derived from event logs on the other [5, 10]. Here, also generic approaches play a role that relate to process model matching, cf. [21]. The second category aims to project the actual behavior of a process *onto* the predefined process model, as in [11]. The aim is then to show how individual instances relate to pre-defined process model parts. Our research is most related to the latter category. In contrast to existing work, however, it will specifically build on the notion of *process alignments* [1], which we will discuss in more detail in Section 4. Another innovative angle in this context is our interest in the comparison of multiple, related processes.

Since our work also strongly emphasizes the visualization of the analysis results, it also relates to other approaches that help to better make sense of process models. These cover the usability aspects of the employed notation [15], ways to emphasize the logical relations between model elements [17], and bringing in new perspectives [2], to name a few.

In summary, our work is at the intersection of the streams of *analytical* and *visualization* research to support *process benchmarking* across *process variants*. We extend existing work by taking both the *supposed behavior* and the *actual behavior* of the process variants into account.

3 Running Example

Throughout this paper we use a running example to illustrate our approach. The running example consists of four process model variants, shown in Figure 1, and four corresponding event logs, as shown in Table 1. All four variants describe the process for handling loan applications. Even though the processes differ slightly, each process sends an e-mail (activity `A`) and in the end either accepts (activity `E`) or rejects (activity `F`) the application. The order in which the activities can be executed, however, differs. Moreover, each variant differs as to which activities are included. For instance, whether activity `B` is part of the variant or both activities `B1` and `B2`, which are more fine-grained. The corresponding event logs describe possible executions of the corresponding process model. Please note

Table 1: Four event logs for the four different variants of the loan application process of Figure 1.

(a) Event log for variant 1

Trace	#
A B C D E G	6
A B C D F G	38
A B D C E G	12
A B D C F G	26
A B C F G	8
A C B E G	1
A D B C F G	1
A D B C E G	1
A D C B F G	4
A C D B F G	2
A C B F G	1

(b) Event log for variant 2

Trace	#
A B1 B2 C D2 E G	20
A B1 B2 C D2 F G	50

(c) Event log for variant 3

Trace	#
A C B E	120
A C B F	80

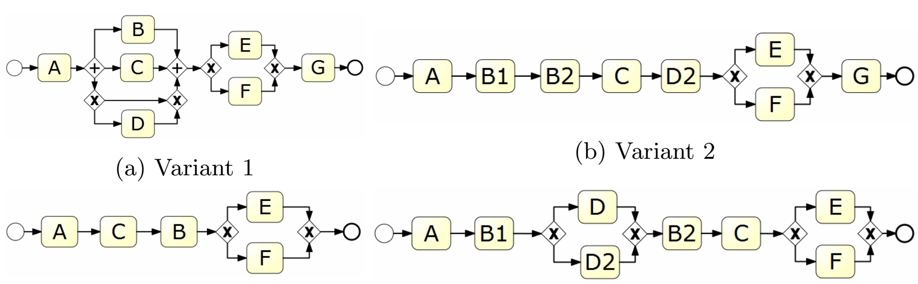
(d) Event log for variant 4

Trace	#
A B1 D B2 C E	45
A B1 D2 B2 C F	60

that in this example the traces align perfectly with the corresponding process model. This is generally not the case for real-life processes.

4 Preliminaries

In order to relate the observed behavior to the modeled behavior, so-called *alignments* [1] between cases in the event log and a single run through the process model can be created. Since an observed execution of the process may not always fit the described behavior of the process model, deviations need to be detected. However, often multiple solutions to align a deviation are present. Adriansyah et al. [1] propose a technique to assign cost to particular deviations and to then



(a) Variant 1

(b) Variant 2

(c) Variant 3

(d) Variant 4

Fig. 1: Four variants of a loan application process. (`A` = send e-mail, `B` = check credit, `B1` = send check credit request, `B2` = process check credit request response, `C` = calculate capacity, `D` = check system, `D2` = check paper archive, `E` = accept, `F` = reject, `G` = send e-mail).

find the alignment between the observed and modeled behavior with the least cost. This technique has been proven to be robust to different variations of deviation and provides detailed insights in the (mis)alignment between observed and modeled behavior.

An example of an alignment between the modeled and observed behavior is shown in Figure 2a. Here, the trace $\langle A, B1, D, B2, C, E\rangle$ from event log variant 4, as shown in Table 1d, is aligned with process model variant 2 of Figure 1b. The first two activities `A` and `B1` can be observed in both the trace and the process model. Since both the trace and the process model move synchronously, we call this a *synchronous move*: This indicates that there is no error and the observed behavior matches the modeled behavior. Next, activity `D` occurs in the trace, but the process model prescribes activity `B2` to take place. In order to obtain an optimal alignment, the best option is to move forward on activity `D` in the trace, and to do nothing in the process model. This results in a *log move only* alignment step, which indicates that behavior is observed that is not described by the process model. The two following activities `B2` and `C` can be again performed synchronously. Now the process model "expects" activity `D2`, while in the trace activity `E` is recorded. The best option is to perform activity `D2` in the process model, resulting in a *model move only.* This type of move indicates that certain behavior was expected according to the process model, but was not observed in the trace. Next, activity `E` can be observed in the trace and executed according to the process, which is again a synchronous move. However, even though the trace is finished, the process model does not yet describe a final state. Therefore, the last alignment step consists of performing a model move only on activity `G`.

Alignments provide the connection between the expected, modeled behavior of a process to its observed behavior as recorded in an event log. This connection is crucial when using event logs and process models, since deviations between these are commonplace. As we indicated in our discussion of related work, currently only the setting where one event log is aligned with one process model has been investigated. In this paper, we apply this technique to different combinations of event logs and process models, which stems from our motivation to study a process that is commonly designed and used by different organizations. Unfortunately, the existing ways of visualizing alignments, i.e. by showing the traces and process models in detail, is not applicable in such a cross-organizational setting.

5 Facilitating Cross-Organizational Comparison

In order to facilitate the comparison of process models and behavior across organizations, we will first propose a comparison framework in Subsection 5.1. This framework allows to compare different statistics between the organizations. In order to provide more insights into how the behavior of one organization behaves in relation to the way another organization intends to execute that process, we will propose a new artifact, i.e. the alignment matrix visualization in

Table 2: Application of the comparison framework on the running example, with event log statistic set to number of traces, process model statistic is number of nodes in the model and the comparison statistic is the replay fitness.

	Config 1	Config 2	Config 3	Config 4	Log Stat
Event Log 1	1.000	0.644	0.575	0.580	100
Event Log 2	0.622	1.000	0.488	0.745	70
Event Log 3	0.933	0.618	1.000	0.656	200
Event Log 4	0.579	0.795	0.553	1.000	105
Model Stat	15	11	9	14	

Subsection 5.2. The alignment matrix can hence be used within the comparison framework to get a more detailed insight into the commonalities and differences of process executions between organizations.

5.1 The Cross-Organizational Comparison Framework

In order to compare processes between organizations we proposed a cross-organizational comparison framework in [3]. The framework aims at facilitating a comparison of business processes by usage of both the process models *and* the observed behavior. An example of the comparison framework as presented in [3] is shown in Table 2. The comparison framework distinguishes three types of metrics: process model (quality) metrics, event log metrics, and comparison metrics.

Process model metrics are metrics calculated using only the process model. Some common examples would be the various structural and complexity metrics that exists for process models [14].

Event log metrics are generally related to different performance indicators that can be defined on the process. Simple examples include the number of traces and events recorded, the number of people working on the process, the average trace duration, etc.

The third category of metrics are *comparison metrics*. These relate to comparisons between an event log and a process model. The alignments discussed in Section 4 are an example of a comparison metric.

The comparison framework has been implemented as a plug-in in the ProM framework [20]. ProM is a process mining framework which allows for a simple implementation of different analysis techniques on event logs and/or process models. All results of the comparison framework, including the alignment matrices we discuss later in this section, have been implemented in the 'Comparison-Framework' package. This package is available from the nightly build package repository which can be used by installing the ProM nightly edition[3].

An application of the comparison framework on the running example is shown in Table 2. The specific process model metric chosen here is the number of nodes

[3] ProM 6 nightly can be obtained from `http://www.promtools.org/prom6/nightly/`.

in the process model. The number of cases in the event log defines the event log metric. Each event log-process model comparison cell displays the replay fitness score [1], calculated on the alignments. Higher values indicate better alignments, which are emphasized by increasingly darker shades of green as background color.

Comparing the size of the event logs, one can see that event log 3 has the most traces, and event log 2 contains the fewest traces. The process model statistic indicates that organization 3 with 9 nodes has the smallest process model, while organizations 1 and 4 have the biggest process models, with 15 and 14 nodes respectively. When we investigate the replay fitness scores, we can see that the diagonal has a perfect score of 1.000. This means that the process model of each organization perfectly explains the observed behavior. Furthermore, the process model of organization 1 describes the observed behavior of organization 3 quite well. However, the process model of organization 3 does not explain the observed behavior of any of the other organizations very well. Organizations 2 and 4 have reasonable replay fitness scores on each other's process models, which might allow these organizations to start a collaboration.

The simple replay fitness scores give some preliminary insights, but do not provide a deep understanding of the (dis)similar behavior between the different organizations. To provide more in-depth insights we propose the alignment matrix visualization as a comparison metric.

5.2 Visualizing Alignments: the Alignment Matrix

The purpose of the *alignment matrix visualization* is to visualize the alignments, as calculated using both the process model and the event log, in a concise but clear way. However, we do not project alignments on either the event log or the process model. Instead, we want to exploit the utilization of the available space, whether this concerns a display or a physical canvas, to allow for a wider exploration. Furthermore, we synchronize the settings of the different alignment matrices to ensure all matrices are indeed comparable.

The input for the alignment matrix consists of the alignments for the traces of the event log. Figure 2a shows such an alignment between a trace and a process model. The alignment consists of several *alignment steps*. Each alignment step contains information as to which trace and process model it relates. It also

Trace	A	B	C	$\gg$	D	E	G
Model	A	$\gg$	C	B	$\gg$	E	$\gg$

(a) Alignment between the trace $\langle A, B, C, D, E, G \rangle$ from Table 1a and the process model of Figure 1c.

	A	B	C	D	...
Trace 1	(A,A)	(B,-) (-,B)	(C,C)	(D,-)	...
⋮	⋮	⋮	⋮	⋮	⋱
Trace 100	(A,A)	(B,B)	(C,C)		...

(b) A concrete instance of the alignment matrix with alignments steps shown in the cells.

Fig. 2: Alignments and the construction of the alignment matrix.

contains a relation to an event in that trace or a relation to an activity in the process model or both.

Within the alignment matrix, alignment steps are assigned to one or more cells, which are distributed over columns and rows. An example is shown in Figure 2b. Here, the columns are defined to be the activities, while each row is an alignment instance[4]. In this way, each cell contains those alignment steps which for a particular alignment are related to a certain activity. In the example, most of the time there is one alignment step in each cell. An exception is the cell for trace 1 and activity `B`. Since the alignment contained both a log move and a model move on this activity, this cell contains two alignment steps. Furthermore, since trace 100 (the last trace of event log Table 1a) did not contain activity `D`, and the process model did not enforce the execution of this activity, the corresponding cell is empty.

Since in general there can be many alignment steps in a cell, we do not show these individual steps. Instead, we aggregate them and express them by various colors:

- If the cell is empty, i.e. there are *no alignment steps*, we color the cell white;
- In case the cell mainly contains *log move steps*, we color the cell black;
- If the cell mainly contains *model move steps* we color that cell gray;
- In case the cell mainly contains *synchronous steps*, we color the cell according to a pre-defined color that is assigned to that activity (red, yellow, green, blue, purple, etc).

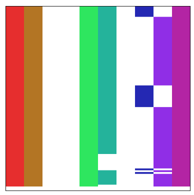
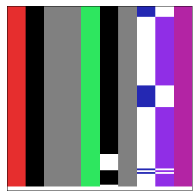
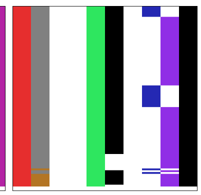
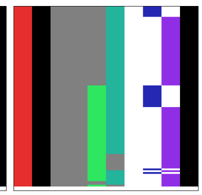
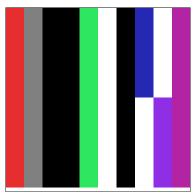
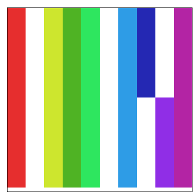
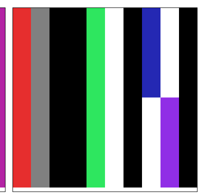
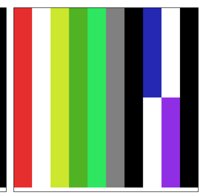
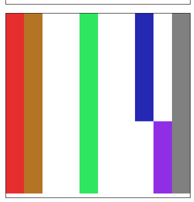
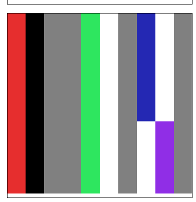
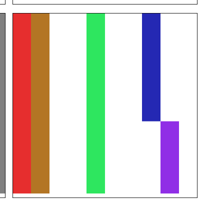
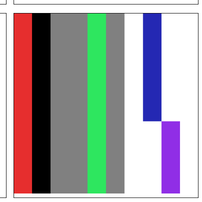
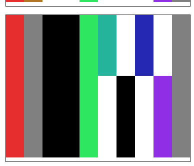
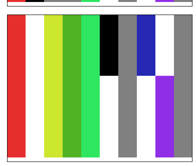
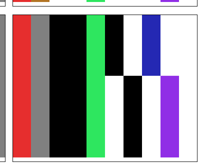
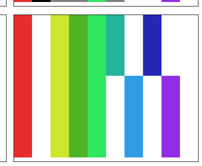
An application of the comparison framework using exactly the settings as discussed is shown in Table 3. Here, the four event logs of Table 1 are replayed on the four process models of Figure 1. Each of these replays is visualized using the alignment matrix. The columns in the alignment matrix represent the activities (`A` through `G`), while each row is a single alignment of a trace.

Let us examine, for the example, the replay of event log 1 on process model variant 3. It shows both black and gray cells, which indicate mismatches, log move and model move steps respectively. It can be seen that activity `A` can be replayed correctly, as indicated by the red color. The gray column, however, indicates that activity `B` cannot be replayed correctly, except in the last couple of traces as visualized by the orange color in that column.

We can now also further investigate the previous observation that the process model of organization 1 seems to match quite well with the observed behavior of organization 3. The alignment matrix of this combination shows mainly colored columns, but the last column for activity `G` is completely grey. This indicates that activity `G` is always a move on model. Therefore, if the process model of organization 1 simply allows the option to skip activity `G`, the same process model can be used without any problems by organization 3. In other words,

[4] Other settings for the column and row definition are possible. One could, for instance, change the rows to represent the different users in the process, and the columns to represent a day or week each. This visualizes when certain users are active and if they execute the activities according to the process model.

Table 3: Application of the comparison framework on the running example. Each column of the comparison framework represents a process model variant from Figure 1 and each row an event log from Table 1. Inside each cell an alignment matrix is shown where the columns are activities, the rows are traces and the color is determined by move type and activity.

	Variant 1	**Variant 2**	**Variant 3**	**Variant 4**
Event log 1				
Event log 2				
Event log 3				
Event log 4				

these organizations basically work in the same way, which could be exploited in various ways.

6 Case Study

In order to validate our comparison framework we applied it on a building permits process. Five municipalities from the CoSeLoG project are collaborating on the building permits process and jointly selected and configured an information system to support this process. However, the five municipalities use their own instance of the system with slightly different settings for each. Moreover, the system allows for some flexibility during the execution of the process. Because of these reasons, several differences still exist in the way the municipalities execute the process. The long-term goal of the municipalities is to centralize and standardize the process to reduce the costs, but this goal can only be attained by making gradual steps. For this reason, it is crucial for the municipalities to understand individual differences between these processes and address them one by one.

In this section we describe the set-up of the case study and how it was executed. We will also provide the insights that we extracted from it.

6.1 Setup

We planned a meeting in February 2014 and invited representatives of each of the five involved municipalities. The meeting was set up to consist of two parts. The aim of the first part is to present general information (number of cases and average throughput time), together with dotted chart and social network visualizations of cases from 2013, detailed along different case types. No process models or activity details are given in that part. Roughly one hour is devoted to this first part.

In the second part, planned to cover approximately another hour, we set out to explain the global idea of the comparison table, i.e. comparing the behavior of a municipality with the discovered model from the behavior of another municipality. The idea for this part is to show the comparison table with the replay fitness scores, as shown in Figure 3a. This is then followed by an example of the alignment matrix (the matrix of event log 1 on variant 4 from Table 3). During a small break of 5 minutes we would lay out the 25 (5 by 5) printouts of the alignment matrices on a table. After the break the idea is then to gather everyone around the table and provide each participant with an individual color marker. In this way, each participant can mark observations on the printouts. During this part, participants are stimulated to make observations and initiate discussion.

We invited seven representatives for the meeting, of which six eventually joined. The expertise from all participating municipalities was present except for municipality 2, whose representative was unable to attend. Fortunately, the representative of municipality 5 also had knowledge about the process in municipality 2. Two representatives were present for municipalities 1 and 3. For each of these two municipalities a coordinator of the process within their respective municipality was present, who both also collaborated in the process. For municipality 4 a building permits expert working in the process was present. As such, these three people had a very good understanding of the whole process. The remaining three representatives were a coordinator of automation and internal affairs (municipality 1), a specialist on internal control and electronic services (municipality 3), and a policy officer for the environmental law (municipality 5). As such, these three people had a more high-level understanding of the whole process, but also detailed knowledge of parts of the process.

The event logs used in the case study contain those cases that were started at some point in 2013 within either of the five municipalities. The logs cover between 150 and 300 cases for each of the municipalities. Both the event logs and the process models contain the 47 most frequent activities across all municipalities. The process models used were automatically discovered using the ETM algorithm [4] based on the data of the event logs. The reason for this is that the municipalities in question immediately configured the information system to their individual preferences without the use of an explicit process model. While the logic of a configuration setting in principle could be translated into a process model, we chose for the use of the discovered model as a reasonable proxy for it.

6.2 Execution

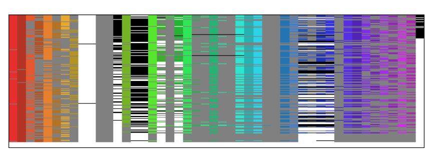
First, before showing the alignment matrices, we showed the replay fitness table as shown in Figure 3a. We first explained that each number roughly corresponded to the number of correctly explained events. The participants quickly noticed that these ratios were not overly high, and in many combinations even very low. They also noticed differences between municipalities. After asking if they could identify distinct clusters of municipalities they replied they could recognize a group consisting of municipalities 1, 3 and 4 which is likely to display highly similar behavior.

Next a small break was introduced and the 25 alignment matrices were distributed on the table, where municipality 2 was moved between municipalities 4 and 5, so that 1, 3 and 4 (as a group of similar municipalities) were close together.

One of the first things that was noticed on basis of the alignment matrices was that there were a considerable number of black cells, which the participants understood to be ‘bad’. One of the representatives of municipality 3 contributed that he noticed that each municipality has significantly less black cells on their own models, which can be expected.

	M1	M2	M3	M4	M5
M1	0.800	0.530	0.764	0.694	0.560
M2	0.482	0.567	0.431	0.458	0.560
M3	0.761	0.511	0.829	0.724	0.551
M4	0.736	0.482	0.752	0.854	0.535
M5	0.477	0.567	0.419	0.459	0.631

(a) Comparison table shown with replay fitness scores.



(b) Example of one of the 25 alignment matrices shown, more specifically of the behavior of municipality 5 on the model of municipality 1.

Fig. 3: Two of the analysis results shown to the case study participants.

Another observation made was that one municipality had a lot of white cells in the alignment matrix. From this, the participants concluded that the specific case types dealt with by this municipality could be different than that of the others, since they show different activities in their behavior.

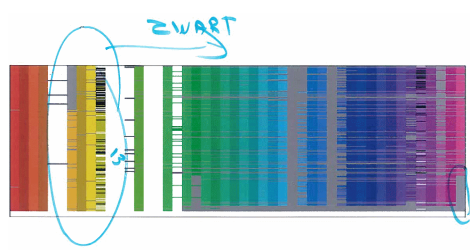
Based on the alignment matrix of municipality 4 on its own model two observations were made, as is shown in Figure 4b. The first observation, denoted by the bigger blue circle on the left, is that first of all there is not much black ('zwart' in Dutch) visible in this matrix. A second observation, made by two of the participants, was that in two of the columns there was a mix of color and black. They correctly concluded that this was caused by sometimes correctly executing this activity, and sometimes deviating from the process model.

The other observation made on this matrix, as indicated by the blue circle in the bottom-right, is that the last activity shows a lot of grey for the last few traces. A brief remark by us that the cases were sorted from old in the top rows to the newer cases in the bottom rows, quickly resulted in the correct conclusion that these cases did not reach that particular activity in the process just yet. Quickly after this, the participants observed that some of the newer cases actually were further along in the process. They expected a diagonal line from bottom left to upper right. They also noticed that this was not the case for all municipalities.

All-in-all, 22 observations were counted. Each of these triggered a discussion and an exploration of explanations for it between the participants. In the end, one participant remarked that he would like to rearrange the alignment matrices and only show the matrices of the replay on the municipalities' own process models. In this set-up, another 11 observations were made.

We then gently ended the discussion and asked the participants if they thought this approach was easy to understand and use. Although we noticed that the participants seemed somewhat overwhelmed during the introduction of the rather colorful pictures in the beginning, this was not mentioned during the evaluation by themselves. All people involved noted that detecting the grey and

(a) Photo of the set-up and the participants. Participants faces are obstructed, the third person from the left is the first author.



(b) The alignment matrix of municipality 4 on its own model, shown with annotations.

Fig. 4: A photo and an annotated alignment matrix with some observations made during the case study.

black, and also white, worked well. Furthermore, the colors helped participants in relating parts of the process across alignment matrices. A further remark that was made is that the colors made it easy to distinguish between irregular behavior and more structured executions of the process: This was considered highly useful.

From a content perspective, the participants expressed satisfaction with what they could observe using the alignment matrices. From the various insights that were obtained on basis of observing the alignment matrices of each others processes, we provide two striking examples. The first of these relates to the observation that one municipality actually did not execute certain steps, while their products still adhered to the regulations. All people involved mentioned that it would be valuable to investigate whether this way of working could be adopted by all municipalities. Secondly, the participants could recognize the effect of a change of personnel within a particular municipality. They expressed that it would be interesting to keep on following the execution of the process to see if the caused behaviorial differences would stabilize over time.

Improvement suggestions with respect to the comparison approach were also made. One suggestion was to add more *visual anchors*, which could help to better determine the location in the alignment matrices. This would help to remember which column represented which part of the process, and for the rows in which month the case arrived. Also, the participants would favor additional features for increased interactivity with the data. They were particularly interested to select specific case types for comparison to see how these compared across municipalities. Another interactive feature they proposed was to select only certain users, since they had the intuition that certain users performed well (or badly), in particular municipalities.

6.3 Results

The goal of our visualization is to provide insights in the commonalities and differences in behavior between organizations. After a brief explanation of the alignment matrix, we let all participants observe and discuss based on alignment matrix printouts. We noticed that some picked-up how to read the figures quicker than others, but after a few minutes almost all participants joined in the discussion. All but one of them regularly made observations, supported other observations or came with possible explanations for observations. Moreover, only very few times was actual input from the organizers required to clarify certain things after the initial explanation of the alignment matrix. Overall, we counted over 30 observations in about half an hour of discussion, which underscores how helpful the approach is to compare the involved processes.

One of the main comments we noted was that the participants would favor more interaction opportunities with the visualization. By hovering over a cell they would like to see more details of that cell, such as the activity, resource and case involved. They also showed real interest in the ability to filter on case types and resources, in order to validate certain assumptions they would have.

However, the main thing we noticed was that the alignment matrices, and the comparison of process executions in general, triggered a lot of discussions between the participants. Participants often asked each other questions of the type "But how do you do this?", or "Why are you faster?", or "Does this role perform this type of activity?". We see these as an indication that the comparison approach triggers a meaningful discussion based on actual analysis results.

7 Conclusion

Organizations increasingly pursue ways to share knowledge about the design and execution of their business processes. In this paper, we presented an analytical approach for the comparison of *similar* business processes across *different* organizations. Since the execution of a business process can deviate from the prescribed way as recorded in the process model, we use both the *observed* behavior as stored in an event log and the *described* behavior as specified in a process model. In order to provide more detailed insights into the way the observed and modeled behavior inter-relate, we proposed the *alignment matrix* visualization. Using a case study, we demonstrated the applicability of the alignment matrix visualization as part of an encompassing comparison framework.

Based on the feedback obtained during the case study we plan to follow up on the presented work by improving the interactivity that interested parties can have with the alignment matrix. Although the rows and columns of the matrix can be flexibly configured, the representatives of the municipalities indicated their wish for further filtering features on the visualized cases. In particular, we received the request to emphasize information on the time and resource perspectives. It would be interesting anyway to focus more on the commonalities and differences between processes on other dimensions than control flow. Additionally, more information about particular cells can be provided, for instance by selecting them and providing on-demand, aggregated information.

On a more abstract level, we plan our future work to focus on the development of additional analytical techniques that help organizations to synchronize and standardize their operations. We believe there are still various opportunities to improve on this highly beneficial but as-of-yet laborious endeavor.

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References

1. A. Adriansyah, B. van Dongen, and W.M.P. van der Aalst. Conformance Checking using Cost-Based Fitness Analysis. In *Proceedings of EDOC*. IEEE Computer Society, 2011.

2. S. Betz, D. Eichhorn, S. Hickl, S. Klink, A. Koschmider, Y. Li, A. Oberweis, and R. Trunko. 3D Representation of Business Process Models. In *MobIS*, 2008.
3. J.C.A.M. Buijs, B.F. Dongen, and W.M.P. Aalst. Towards Cross-Organizational Process Mining in Collections of Process Models and Their Executions. In *Business Process Management Workshops*. 2012.
4. J.C.A.M. Buijs, B.F. Dongen, and W.M.P. van der Aalst. On the Role of Fitness, Precision, Generalization and Simplicity in Process Discovery. In *On the Move to Meaningful Internet Systems: OTM 2012*. 2012.
5. E. Esgin and P. Senkul. Delta Analysis: a Hybrid Quantitative Approach for Measuring Discrepancies between Business Process Models. In *Hybrid Artificial Intelligent Systems*. Springer, 2011.
6. H.G. Fill. Using Semantically Annotated Models for Supporting Business Process Benchmarking. In *Perspectives in Business Informatics Research*. Springer, 2011.
7. T. Friedman. Welcome to the 'Sharing Economy'. `http://www.nytimes.com/2013/07/21/opinion/sunday/friedman-welcome-to-the-sharing-economy.html`, 2013. Last accessed on February 19, 2014.
8. A. Hallerbach, T. Bauer, and M. Reichert. Configuration and Management of Process Variants. In *Handbook on Business Process Management 1*. Springer, 2010.
9. Y.C. Juan and C. Ou-Yang. A Process Logic Comparison Approach to Support Business Process Benchmarking. *The International Journal of Advanced Manufacturing Technology*, 26(1-2), 2005.
10. N. Kleiner. Delta Analysis with Workflow Logs: Aligning Business Process Prescriptions and their Reality. *Requirements Engineering*, 10(3), 2005.
11. S. Kriglstein, G. Wallner, and S. Rinderle-Ma. A Visualization Approach for Difference Analysis of Process Models and Instance Traffic. In *Business Process Management*. Springer, 2013.
12. R. Lu and S. Sadiq. Managing Process Variants as an Information Resource. In *Business Process Management*. Springer, 2006.
13. R. Lu and S. Sadiq. On the Discovery of Preferred Work Practice through Business Process Variants. In *Conceptual Modeling-ER 2007*. Springer, 2007.
14. J. Mendling. *Metrics for Process Models: Empirical Foundations of Verification, Error Prediction, and Guidelines for Correctness*, volume 6 of *Lecture Notes in Business Information Processing*. Springer, 2008.
15. D.L. Moody. The "physics" of Notations: Toward a Scientific Basis for Constructing Visual Notations in Software Engineering. *Software Engineering, IEEE Transactions on*, 35(6), 2009.
16. N. Outmazgin. Exploring Workaround Situations in Business Processes. In *Business Process Management Workshops*. Springer, 2013.
17. H.A. Reijers, T. Freytag, J. Mendling, and A. Eckleder. Syntax Highlighting in Business Process Models. *Decision Support Systems*, 51(3), 2011.
18. A. Rolstadås. *Performance Management: A Business Process Benchmarking Approach*. Chapman & Hall, 1995.
19. F. Teuteberg, M. Kluth, F. Ahlemann, and S. Smolnik. Semantic Process Benchmarking to Improve Process Performance. *Benchmarking: An International Journal*, 20(4), 2013.
20. H.M.W. Verbeek, J.C.A.M. Buijs, B.F. van Dongen, and W.M.P. van der Aalst. XES, XESame, and ProM 6. In *Information System Evolution*, volume 72. Springer, 2011.
21. M. Weidlich, R. Dijkman, and J. Mendling. The ICoP Framework: Identification of Correspondences between Process Models. In *Advanced Information Systems Engineering*. Springer, 2010.