Exposing Delays in Multi-Step Processes by Retrospective Analysis

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ABSTRACT

Multi-step processes are common in healthcare, software development, and other dynamic environments. Managers who monitor processes are overwhelmed by information, and have limited time to investigate data from different viewpoints. We propose the interactive Multi-Step Process Visualization (MSProVis) for retrospective analysis, to expose delays in multi-step processes, and support the comparisons between steps or between actors executing those steps. A usability study with seven users showed that all participants could use MSProVis effectively and rapidly gain insights.

Author Keywords

Visualization; Monitoring.

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation: User Interfaces Graphical user interfaces (GUI)

General Terms

Design

INTRODUCTION

A multi-step process is composed of a number of steps, where each step is executed by one or more actors from an organization. Examples include the management of orders and their results in healthcare, the paper-review process in academic journals, the return merchandise authorization process in the electronics industry, the internal supplier agreement process in IT companies, etc.

According to the "Bounded Awareness" theory, the limited cognition of humans and large volume of available information can harm the decision-making process [2]. The bounded awareness challenge in multi-step processes can be addressed by introducing information visualization. Retrospective analysis using a visual approach can support managers who need

to obtain an overview, identify bottlenecks, and highlight the root causes and contributing factors.

This paper presents the interactive *Multi-Step Process Visualization (MSProVis)* that combines several *Process Completion Diagrams* (PCD); MSProVis aims at exposing delays so as to promote timely completion of multi-step processes and support managers in decision-making (e.g. dropping a vendor who is not performing well). We evaluated MSProVis using a scenario from the medical domain and report the results from a study with two physicians and five other participants.

MOTIVATION

Patients' lives can be threatened when there are errors in the management of the results of medical orders (e.g. labs, imaging, referals to specialists) [4]. Several studies show that there is room for improvement [8, 10, 13]. A medical order, such as a blood chemistry test, can be completed in-time, late or never completed. Each step in this process is triggered when the previous is completed. A delay in one step may cause a delay in the whole process. The performance of an actor affects the duration of the step and the entire process. There is a need for identifying the delays in different situations [9] to support managers in decision-making, which can improve healthcare delivery [13].

RELATED WORK

Process Management: A multi-step process can be modeled using one of the several business process management notations, for example using Petri Nets[3], Business Process Modeling Notation [15], Yet Another Workflow Language [12], etc. These models assist in defining the workflow of the process in an ideal environment, which may fall far from reality [11]. Process management models do not provide information about what is actually happening or happened in practice, because these models are not bound to data [6].

Information Visualization: Several interactive visualizations have been developed to present event-log data [7, 14, 16, 5]. However, all these visualization tools share the same limitation: they do not categorize and provide a summary of event-log data to allow users to identify new insights regarding the process, step, and actors performances. To the best of our knowledge, there is no previous literature describing work on exposing delays in multi-step processes using a visual approach.
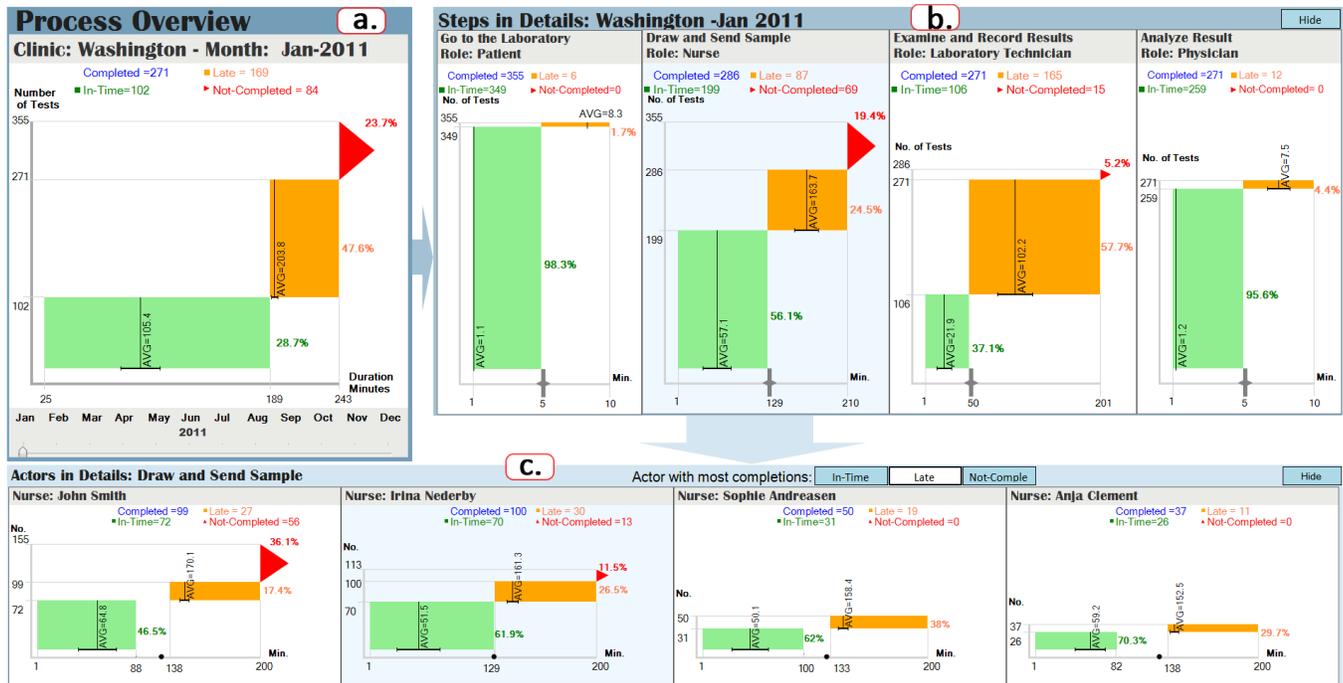
Figure 1. MSProVis combines three views: (a.) *Process Overview* shows the summary of the entire process, **(b.)** *Steps in Details* shows each individual steps of the process (here 4 steps), and **(c.)** *Actors in Details* shows the performance of the individual persons who performed the selected step (here the Draw and send sample step). The green and orange rectangles represent in-time and late performance respectively. Height is the number of tests, width corresponds to the min and max completion time. The red triangle reflects the number of never-completed tests at each point. A time slider in the *Process Overview* gives access to different months. Here we can see a data for a blood-test and almost half of tests were performed late in January. The second step of the process has the highest number of not-completed, and step one has barely any (i.e. most patients went to get their blood drawn). In c) we see that the first two actors have done most of the work in that step. The first actor (John) caused the highest number of never-completed tests.

MULTI-STEP PROCESS VISUALIZATION (MSPROVIS)

MSProVis (Figure 1) is an interactive visualization composed of three views: *Process Overview*, *Steps in Details*, and *Actors in Details*. It aims at facilitating review and comparison at different levels of detail. Each view uses one or more Process Completion Diagrams (PCDs). Typically users start by looking at the Overview PCD, then click on it to see the completion diagrams for each step individually, then click on those steps as needed, to compare the performance of individual actors.

In the header of each view the font size decreases with the depth in the hierarchy, and the header color becomes more pale.

MSProVis computes default thresholds that define lateness based on analysis of historical performance data for each step, and allows managers to adjust those thresholds interactively.

Process Completion Diagram (PCD): The PCD uses a specialized chart to aggregate logs into in-time, late and lost categories; using color, shape and position. It provides a summary of performance. It is composed of two rectangles - one for the in-time and one for the late completions, and a triangle for the never completed orders. A different shape is used to distinguish the count of never completed orders which by definition do not have a completion time. By default green, orange, and red is used for in-time, late and never-completed because it is a familiar scheme, but users can use other colors.

Labeling of the different parts use the same consistent color scheme.

The shapes are placed on a plot, where the X-axis corresponds to completion time and the Y-axis corresponds to the number of orders. Classifying completions into in-time and late is realized using the threshold of lateness (defined later in the Process Overview section).

To facilitate understandability, the PCD is enriched with detailed information. It shows the minimum, average, and maximum duration for the in-time and late groups of completions (X-axis). It has a visual representation of the average duration (the vertical line inside a rectangle) and the standard deviation (the horizontal line at the bottom of a rectangle) for the in-time and late completions. Showing the average and the standard deviation indicates to managers the distribution of completions.

Process Overview: The *Process Overview* summarizes the overall process performance using one PCD. The process duration is computed using all the process steps' durations. The threshold of lateness for the process is calculated using the threshold of lateness defined in each of the steps of the process (described below). Figure 1.a shows the overview of a blood test process using data from January 2011 (see the time slider at the bottom). Users can use the time slider at the bottom to view specific month and rapidly compare the overall performance over time.

Steps in Details: A click on the overview gives information about the four steps of that particular process. The *Steps in Details* view shows four PCDs (Figure 1.b). The in-time and late completions of a step do not affect the performance of the other steps, but they impact the performance of the overall process. Never completed tests at one step have a direct impact on the next one, as the total number of completed tests in the next step also decreases. Positioning PCDs in order, using the same normalized scale for the number of completions and aligning them with the Y-axes of the *Process Overview*, allows managers to quickly view how the number of completions evolves through steps, and compare them with the overall process performance. Different steps may have different lengths of execution time (in Figure 1.b, 10 minutes for step one, 210 minutes for step two). Therefore, the timescales used for the X-axis differ from one step to another. All time-oriented visualizations face the challenge of presenting data in different timescales and using different granularity of time [1]. In the *Step in Details*, the PCDs use consistently the same granularity of time (e.g. minutes), but as space is limited and time span may differ significantly, we decided to divide the space based on the number of steps and slightly adjust the width based on the time spans. This helps managers realize that different timescales may be used.

When the visualization is opened for the first time, the threshold of lateness in each step has a default value. Default values can be set by statistical analysis of the data (e.g. the average time, or the average time plus one or more standard deviation). Still, managers can adjust the thresholds interactively by moving the threshold slider, shown as a thicker gray line with two small arrows over the X-axis. When the threshold value changes, the *Process Overview* and *Actors in Details* (described below) are updated accordingly. This feature allows the manager to see the effect of the threshold adjustment on performance summaries (i.e. PCDs). Adjusting thresholds can be useful to manage changing conditions but also to adjust the number of alarms generated. Some systems may alert the physician who ordered a test when it is late or deemed lost, but generating too many alarms can lead to alarm fatigue.

Actors in Details: The *Actors in Details* (Figure 1.c) summarizes the performance of each actor involved in a step, showing one PCD per actor, sorted by the total number of completions. Managers use the radio menu to highlight in light blue the actor with most in time, late, or not-completed. If there are a large number of actors managers have to scroll to see all the actors, but sorting by performance e.g. percentage of late completion can be useful as well. In this view the timescale in the X-axis matches the timescale of the step PCD while the Y-axis is adjusted to the highest number of completions performed by an actor of this step. The same principles as in the other two views apply for the minimum and maximum value of the late completions. A gap between the green and orange rectangle is possible (see Figure 1.a), whenever the maximum in-time performance and minimum late performance do not match the step's threshold of lateness (marked as a small circle in the Y-axes).

EVALUATION

We conducted pilot studies with two physicians and with five students using a de-identified medical dataset of 1606 records, extracted from a four step medical process in a hospital, and added some additional synthetic data when it was not available for a step in order to test the entire design. The purpose of the studies was to investigate if users were able to efficiently use MSProVis and compare delays in the process rapidly. In addition, these studies served to identify usability problems and provide suggestions for improvement.

Study with Physicians

Two medical doctors from the Copenhagen region used MSProVis. They were not currently managers of medical clinics but had 25 to 30 years of experience so were very knowledgeable of how lab-test results are handled, or mishandled. After explaining the PCD, physicians were able to interpret the information presented in MSProVis rapidly. They located problem steps, and identified actors performing poorly. The physicians appreciated the fact that MSProVis showed data on different levels using the PCD. Further, they found the interactive thresholds very useful. Adjusting the threshold of the most problematic step showed to them how it would decrease the number of overall late performances. One of them discussed how several hospitals use a tool, known as the Controlled Chart, that monitors events and triggers alarms but did no know of tools that provided retrospective analysis. He thought that it would be very useful to integrate MSProVis in these environments.

User Study

A second study used five graduate students that were not familiar with process analysis and did not have a medical background. They were introduced for the first time to MSProVis during the usability test. After explaining the PCD, participants explored MSProVis for 10 minutes. Then, they used 10 minutes to carry out nine tasks in a think-aloud manner, and evaluate MsProVis and its interactive features using a 10-point scale.

Exploring data using MSProVis: Participants explored the data presented in the *Process Overview* by interacting with the time slider. They were able to compare the performance between months. Participants were told that by making a double-click on the *Process Overview*, the *Steps in Details* would open. All participants found the *Steps in Details* view intuitive and easy to understand. They could recognize the steps in the process and compare the number of tests that were completed and not-completed. However, the different timescales in the steps caused some confusion when participants compared the duration time. They appreciated the fact that they could adjust the threshold of lateness, and were able to understand what happened. However, threshold of lateness bars were not often thought to be interactive. Finally, the participants explored the *Actors in Details*, by double-clicking in one of the steps. They were able to rapidly gain insight on actors' performances. Participants were able to more easily compare actors' performances than steps' performances, due to the consistent scales used in X-axis and Y-axis between actors. Initially, participants found it strange to see the gap

between the green and orange rectangle. However, they were able to figure out what it meant on their own.

Executing tasks: Participants used the data from April 2011 for the first seven tasks, where participants were asked to gain insights on process, step and actors' performances. In the next two tasks, participants were asked to compare the performance for March, April, and May 2011. All participants answered all tasks correctly. The first seven tasks were performed easily and quickly. Average execution time for all seven tasks was five minutes. The last two tasks were more complex, and took approximately two minutes for both. Users had to switch from one month to another, and memorize the late and not-performed percentages for three months. On average, they rated MSProVis 8.5 out of 10 for being comprehensible, and interactive features in the visualization were rated 7 out of 10. Introducing mouse-hover tooltip and having a thicker adjustable threshold should improve interactivity.

CONCLUSION AND FUTURE WORK
This paper presents a visual approach to expose delays in multi-step processes by retrospective analysis. MSProVis is a multi-view presentation that allows managers to analyze and compare several scenarios interactively using thresholds of lateness at different points in time. Although this approach was evaluated using a scenario from the medical domain, it can be applied for multi-step processes in other domains as well. The feedback from our usability studies will be used to improve MSProVis. Challenging improvements such as comparing more than one month in a single screen, space limitations for large numbers of steps and actors, and using MSProVis in parallel processes will be addressed in the future work.

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