

EHR BUSINESS PROCESS MANAGEMENT: FROM PROCESS MINING TO PROCESS IMPROVEMENT TO PROCESS USABILITY

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Abstract

Process mining of event log data from electronic health records (EHRs) promises new methods to systematically improve EHR-mediated patient care processes and workflow usability. Process mining is part of a larger front of process-aware business process management (BPM) technology diffusing into the healthcare information technology (HIT) industry. Process mining can discover evidence-based process models, or maps, from time-stamped user and patient behavior; detect deviations from intended process models relevant to minimizing medical error and maximizing patient safety; and suggest ways to enhance healthcare process effectiveness, efficiency, and user and patient satisfaction. Process mining provides an “X-ray” of processes that can explain clinical business intelligence report and dashboard key performance indicators (KPI). Demand for better evidence-based process maps will drive demand for better EHR event logs, which in turn will drive demand for more process-aware BPM-based EHRs and HIT. Many complaints about EHR usability are about EHR workflow. Process mining techniques and process-aware EHR and HIT systems will increase EHR usability and increase EHR adoption. They are relevant to the central issues of healthcare reform: identification of best practices, coordination of care among clinical staff, consistency across patient care processes, and efficient use of healthcare resources.

Keywords: Electronic health records, process mining, business process management, usability

Introduction

“There’s gold in them thar EHR processes!” (a paraphrase of “There’s gold in them thar hills!” popularly associated with the 1848 California gold rush, but origin debated). EHRs increasingly mediate patient care effectiveness, resource efficiency, and user happiness. EHR process mining is a new medical “imaging” technique, one which allows process diagnosticians to view workflow blockages, errant workflows, and unused resources. Process mining promises to do for healthcare workflow what Röntgen’s invention of X-rays and radiography in 1895 did for medicine proper.

Authors should avoid quoting themselves, but I cannot help but note that in 2005 I wrote about EHR workflow systems:

“Process Mining[:] Workflow management systems generate tremendous amounts of time-stamped sequential data as a byproduct of execution of process definitions by workflow engines. By analogy to data mining, analysis of such data (typically collected in log files) is called workflow or process mining [1]. Process mining can discover new and useful process definitions, compare process definitions to what users are really doing, and optimize existing process definitions—all of which can be used to improve ambulatory workflow.” [2]

Today, EHR process mining can discover, monitor and improve evidence-based processes (not assumed processes) by extracting knowledge from event logs available in (or “generatable” from) today’s EHRs. Process mining can answer three types of questions [3] for an EHR-using hospital or clinic: What is happening inside processes (Discovery)? It can compare what is happening with what should be happening (Conformance: especially relevant to medical error and patient safety). It can suggest ways to improve healthcare process effectiveness, efficiency, and user and patient satisfaction (Enhancement).

Process mining is part of a larger front advancing into healthcare of business process management systems technology. BPM systems use workflow engines to execute process definitions representing process models. Nonprogrammers can edit and systematically improve these models using BPM techniques, including process mining. BPM systems carry out workflow by interpreting explicit process models. Most EHRs rely on process models implicit in their non-process-aware software. Their workflow is more difficult to change. However some EHRs are adding workflow engines that execute process definitions and this trend is growing.

Of particular note to anyone interested in applying process mining techniques in healthcare is the Process Mining Manifesto [3]. It is not specifically about healthcare, though it does mention “paper-based medical records” as examples of poor event logs. The Manifesto is authoritative (co-authored by more than 75 process mining experts), timely (recent and relevant to problems facing EHR adoption), and accessible to health IT and process improvement professionals.

The credited “godfather” of process mining is Professor Wil van der Aalst, a Dutch computer scientist

and mathematician. Professor van der Aalst writes “Healthcare is notorious” for dismayingly complex “spaghetti processes.” [4] Nonetheless, process mining research can learn a lot from tackling the healthcare domain. On one hand there is great opportunity to learn from intuitively creative medical experts. On the other hand spaghetti processes often are the greatest process improvement opportunities.

Process Mining and Clinical Intelligence

Process mining EHR event log data is a form of clinical business intelligence. What van der Aalst notes [5] generally about business intelligence also applies to clinical business intelligence:

“Business intelligence tools tend to be data-centric while providing only reporting and dashboard functionality.”

This describes many clinical (business) intelligence tools.

“They can be used to monitor and analyze basic performance indicators (flow time, costs, utilization).”

These are the KPIs, or Key Performance Indicators, in clinical intelligence reports and dashboards.

“However, they do not allow users to look into the end-to-end process.”

If you cannot look “into the end-to-end process” you cannot, in an evidence-based way, determine what is wrong—and therefore what is to be done—for ineffective, inefficient workflows and their unhappy users.

“Moreover, despite the “I” in BI, most of the mainstream BI tools do not provide any intelligent analysis functionality.”

Again, most current clinical business intelligence, or clinical intelligence, tools are reports or dashboards. Without access to detailed evidence-based representations of end-to-end processes, clinical intelligence reporting and dashboard systems can flag process problems, cannot diagnose and solve them.

EHR Event Logs

An EHR event log is a record of named activities (“Check Medications”, “Patient Examination”) created as a byproduct of EHR use. Encounter, or case, ids, tie together collections of events. Events occur in an order relative to

each other, usually represented by time stamps. Intervals between time stamps can be years, in long-running chronic conditions; to hours and minutes, in patient encounters; to seconds or less between user clicks on a single EHR screen.

The first three columns in the following EHR event log extract—CaseID, Activity, and TimeStamp—are required for process mining to create a process map, or model, from event data. The column of “...”s to the right represent additional data not shown: UserRole (a user such as Dr. Smith or Dr. Jones, or Physician vs Nurse), EncounterType (such as Sick vs. Well Checkup vs. Vaccination), and Facility (such as Facility 5, 7 or 9, see upcoming illustrations).

CaseID	Activity	TimeStamp	...
7859,	"Get Patient",	9/19/2011 15:44:27	...
7859,	"View Chart",	9/19/2011 15:53:58	...
7859,	"Current Meds",	9/19/2011 15:59:52	...
7859,	"Allergies",	9/19/2011 15:59:59	...
7859,	"Labs",	9/19/2011 16:00:27	...
7859,	"New Note",	9/19/2011 16:05:46	...
7859,	"Examination",	9/19/2011 16:17:01	...
...

Optional additional columns, over and above case id, activity name, and time stamp, depend on what you want to compare, explain, understand, or predict about your processes. Do you want to understand processes of a poorly performing clinic or hospital relative to a better performing clinic or hospital? You need a facility column. Do you want to do the same for users? You need a user column. Or do you want to understand workflows for sick visits compared to well checkups? Add a column for that. This additional information allows you to filter an event log and ask different questions about logged processes.

The bottom row of “...”s represent the many other rows, with different CaseID’s for separate process instances, usually required to generate useful process models. Healthcare processes generate a lot of time stamped data which can result in large event logs. Process mining will be required to understand and leverage this “Big Data.”

Evidence-Based Process Maps

Figure 1 is a relatively unannotated (for example, no frequency or performance statistics) process model, or process map, generated by ProM, a free and open source process mining tool. Even a simple example, with only six possible EHR activities, begins to look like the aforementioned pile of spaghetti.

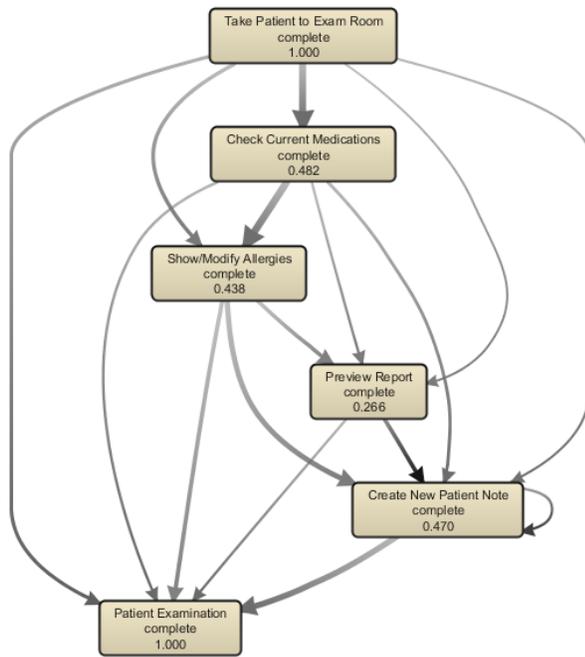


Figure 1: “Spaghetti” Process Map Generated By ProM Fuzzy Miner Plugin

The process model can be simplified using event log filtering techniques and by asking specific questions to narrow investigations. Figure 2 Shows process mined process maps compare just the most common workflows from three similar medical practices.

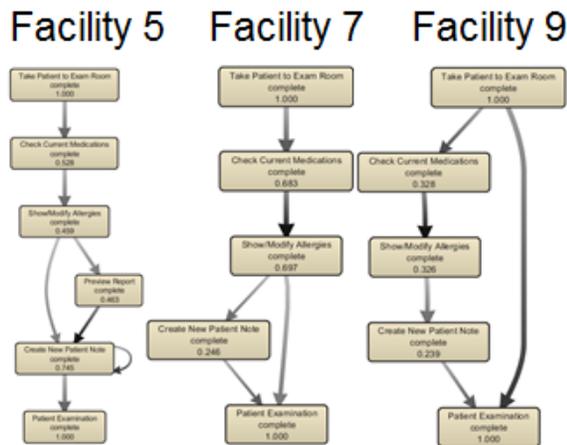


Figure 2: Process Maps Generated By ProM Fuzzy Miner Plugin Filtering on Facility and Suppressing Some Path Detail

Suppose you know some Key Performance Indicators (KPIs) for these facilities, such as patient throughput and cycle time, cost per encounter or encounter type, or perhaps even measures of user or patient satisfaction.

Process mining can generate process models that you can compare to explain differences between KPIs [6]. Traditional clinical business intelligence report and dashboard software may tell you what the KPIs are and help benchmark them. However, to understand the likely causes of flagged KPIs, you’ll need evidence-based process models such as process mining can provide.

EHR Event Log Maturity

Process Mining Manifesto’s [3] Table 1 describes five levels of event log maturity. For each level I’ll provide an EHR-relevant description here.

A highly mature event log contains event data that is complete (there are no missing events of interest), reliable (if it says an event took place at a particular time, you can trust that it did), and semantically useful. You can think of semantics here in the same sense as medical informatics professionals use when they speak of semantic interoperability of patient data. Do we know what a drug or diagnosis code means and does it mean the same in different EHRs? Similarly, do we know what an EHR event in an EHR event log means and does it mean the same in different systems. This last will be important for comparing process models, as EHRs are so user-customizable. “Check Meds” in one EHR might be called “Medications” in another. What exactly does “Check Meds” mean? Where, exactly, does it fit in a hierarchy of tasks, such as “checking” other things besides medications or involvement of medications in other activities besides “checking”? Is asking a patient about medications (or retrieving the medication list from online) an example of “Check Meds”?

At the bottom of the maturity hierarchy, one-star event logs are incomplete and untrustworthy, let alone have clearly understandable semantics. The Process Mining Manifesto ironically uses a healthcare example of a poor quality event log: the traditional “paper-based medical record.”

Moving up the event log maturity hierarchy we get to two-star maturity, the level of many EHR event logs. These event logs, whether flat files, tables in an EHR database proper, or generated by running SQL queries, likely exist for such purposes as debugging EHR code or auditing EHR user behavior.

At the three-star level, the most trustworthy event logs likely are EHR-certification mandated security and privacy user access audit logs. Though guaranteed to have certain properties, they were not intended to be used for process mining. Most EHRs likely have two- or three-star event log maturity.

Moving up the hierarchy to four-star event log maturity we get to a few EHRs that rely on workflow management system components, such as workflow engines, process definitions, and graphical workflow editors to change workflows. They do exist, but are so far

flying under marketing radar. Touting these capabilities hasn't achieved much mindshare yet, but it will.

Finally we climb back up to the top of the event log quality hierarchy to five-star event log maturity. BPM systems with semantically annotated logs are still mostly academic exercises. No such production EHR systems likely exist.

EHR Process Usability

The last two words in the title of this presentation are "Process Usability." We've seen the process improvement part, what about usability?

Much is made about lack of EHR usability impeding EHR adoption in the face of considerable compensatory or compulsory financial incentive. These usability problems are more than skin (or screen) deep. Structured document-based EHRs have fundamental workflow usability problems compared to structured workflow-based EHRs.

In fact, if you look at lack of EHR usability as a set of problems and business process management as a set of solutions, you'll find a startling alignment. For each EHR usability weakness there is a corresponding BPM strength. Figure 3 compares a definition of usability [7] and a definition of business process management [8].

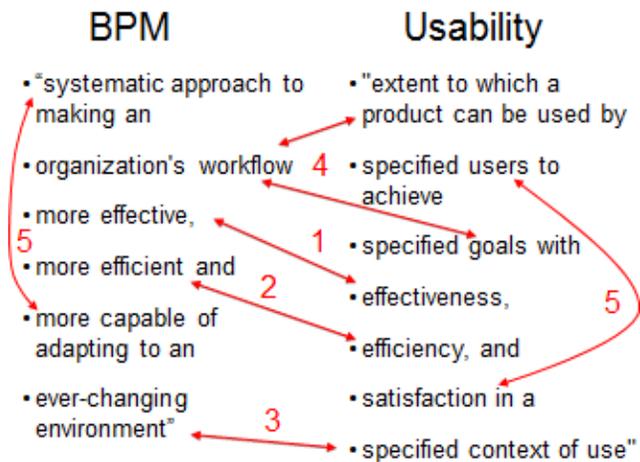


Figure 3: Similar BPM and Usability Definitions

On the left is a typical definition for business process management. On the right is a popular definition of usability. The most obvious parallels regard (1) effectiveness and (2) efficiency. The (3) context of use is an ever-changing environment. Using a product involves pushing it (or being pulled by it) through a (4) workflow and this workflow has a goal. The goal may be an organizational goal, but it becomes a user's goal when adopting a workflow role. Users tend to be (5) more satisfied with products whose workflow can be more easily (systematically) adapted to their needs.

Parallels are even evident between the previously outlined EHR event log extract and the usability definition. "Specified users" corresponds to UserRole in the event log. "Specified goals" would be the goal of the patient visit, such as Sick (treat a sickness) or Well Checkup (keep from getting sick). "Specified context of use" is harder because defining "context" is always hard, from philosophy of language to collecting user requirements. However, one obvious candidate is the environment in which a user pursues a goal. In this case, the environment corresponds to a location or facility.

The structural analogy between a definition of BPM and a definition of usability rings true. Many complaints about EHR usability are complaints about EHR workflow. Improve EHR workflow and you'll improve EHR usability.

Ultimately, EHR workflow management systems [9] and EHR BPM systems will be more usable than EHRs that are not process-aware. Consider these usability principles: naturalness, consistency, relevance, supportiveness, and flexibility. EHR BPM systems more naturally match the task structure of a physician's office through execution of process definitions. They more consistently reinforce user expectations. Over time this leads to highly automated and interleaved team behavior. On a screen-by-screen basis, users encounter more relevant data and order entry options. An EHR BPM system tracks pending tasks—which patients are waiting where, how long, for what, and who is responsible—and this data can be used to support a continually updated shared mental model among users. Finally, to the degree to which an EHR BPM system is not natural, consistent, relevant, and supportive, the underlying flexibility of a workflow engine executing process definitions can be used to mold workflow system behavior until it becomes natural, consistent, relevant, and supportive [10].

Process-Aware EHRs

Information systems evolve. EHRs are information systems. Therefore EHRs will evolve. This is obvious. Less obvious, but also true, is that evolution of EHRs will parallel evolution of information system in general.

Once upon a time, software applications lived alone. Within each application, data mixed with business logic, user interface (UI), and (implicit) workflow code. Over time, data, UI, and workflow increasingly separated within each application and were increasingly shared among applications [11]. Databases came first; then much UI infrastructure; and, finally, workflow too.

Workflow management/BPM systems are furthest along in separate explicit representation of workflow and process, with workflow engines to execute and editors (usually graphical) to edit. Other kinds of information systems, such as email and databases, also facilitate process and workflow, but are not themselves "aware" of

the processes they mediate. They cannot reason or easily be used to reason about the workflows they make possible.

More and more applications in more and more industries are following the trend toward the process-aware. EHRs, too, are gradually becoming process-aware information systems. As process mining tools improve and successful case studies emerge, demand for better EHR event logs will occur. This will create demand for more process-aware EHRs able to generate higher quality event logs.

Current EHR “process-awareness” is already a continuum between less and more process-aware EHRs. Newer EHRs are entering the market with workflow system and groupware features, such as workflow engines, process definitions, and graphical editors, as well as adaptive case management (ACM) functionality for dealing with non-routine processes. Long-established EHRs are adding and retrofitting the same, with varying degrees of success.

Compared to process-aware EHR workflow management, or business process, management systems, many EHRs (1) do not track tasks at a sufficiently high degree of resolution, (2) do not distinguish among the large number of possibly useful time-stamped events, and (3) have no means for process model insights to drive improvement at the point-of-care through automated workflow.

Non-process-aware EHRs do not distinguish between unitary tasks at the same fine degree of granularity as process-aware EHRs. Many EHRs have high resolution screens with a multitude of simultaneous data review and entry and order entry options. Multiple user events, spanning multiple tasks, are often committed together to the underlying database, conflating together logically separate workflow steps. In contrast, a process definition-driven EHR can present just the data review and entry and order entry options on each screen that are relevant to a single step in a task workflow sequence. For example, a nurse checking allergies and then current medications are two different tasks that at highly granular resolution should be distinct and acquire different time stamps.

Non-process-aware EHRs do not capture all the potential meaningful timestamps for those events that they do log. They may log when data and orders are committed to a database but they do not typically log when tasks are first available to be accomplished, when they begin, when they complete, and other relevant timed-stamped events such as cancellation, postponement, or forwarding. Much of this missing time stamp information is invaluable for understanding why bottlenecks occur, why certain tasks are subject to rework, and what slack resources are available elsewhere in the system.

Non-process-aware EHRs, even if their event logs result in useful process models and actionable insights, lack means to actively influence changes to workflow. There are no process definitions or workflow engines to

execute them; so there are no process definitions to change and influence and improve effectiveness and efficiency. A clinical intelligence reporting system without ability to trigger automated workflow is a passive reporting system (in which reports must be handed to staff for disposition, “Please put a note in each patient’s chart so that the next time they have an appointment...”). A more active clinical intelligence reporting system feeds directly back to a workflow engine and process definitions to automatically perform useful tasks. Even if a process model has an obvious flaw, there is no way to consistently and automatically deflect behavior at critical point-of-care workflow junctures.

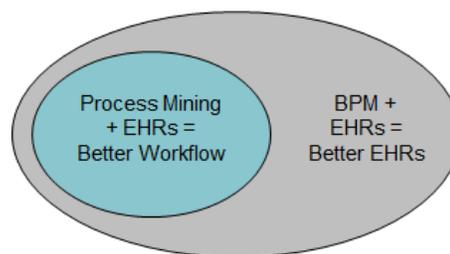


Figure 4: Process Mining, BPM and EHRs

That said—extolling EHRs with workflow engines executing process definitions editable by non-programmers—EHR workflow is still malleable compared to many other desktop applications. Process mining can improve that workflow, while it also increases awareness process-aware EHRs and health information technology (Figure 4).

Conclusion

This paper, as you can tell, is not just about process mining applied to EHR event log data. It is also about diffusion of process-aware ideas and technology into healthcare. Process mining is just one of many BPM technologies finding application in healthcare [12]. What makes process mining different is that it is also new to the BPM industry. Other more conventional BPM components and capabilities include [13]:

1. Process execution and state management engine
2. Model-driven development environment
3. Document and content management
4. User and group collaboration
5. System connectivity
6. Business events, business intelligence (BI) and business activity monitoring (BAM)
7. Inline and offline simulation and optimization
8. Business rule management
9. System management and administration
10. Process component registry/repository.

Many EHRs have built-in document management systems or use third-party software. Many EHRs manage clinical rules as part of their clinical decision support functionality (some mandated). Interoperability among EHRs and HIT systems is generally recognized and increasingly achieved. Business intelligence, clinical groupware, and componentized architectures are increasingly popular. However, BPM's core technology innovation, "process execution and statement management engine" (that is, workflow engines executing process definitions") and "end-to-end" business intelligence made possible by process mining, have not yet had impact, let alone achieved significant mindshare.

Confluence between EHR and HIT problems-to-solve and workflow automation and BPM solutions-to-offer is inevitable. Process mining will facilitate spread of related process-aware information systems ideas throughout healthcare. Confluence is beneficial to both industries. Healthcare processes are like "spaghetti" because EHR users are smart and creative problem solvers. They deserve to be studied, not just to improve healthcare but to improve ability to create highly usable information systems for smart and creative people. And, by the way, BPM researchers and professionals also receive care from physicians using EHRs.

Process mining and process-aware EHR and HIT systems are natural bridges between traditional Industrial Engineering topics such as mathematical programming, discrete-event simulation, process improvement, workplace safety and human factors on one hand and Medical Informatics topics such as clinical decision support, EHR usability, and patient safety on the other. In short, business process management and process-aware information systems, including offshoots such as process mining, are relevant to central issues of healthcare reform: identification of best practices, coordination of care, consistency across processes, and efficient use of resources.

Addendum

For free process mining tools, most roads lead to ProM at processmining.org, where you can download free process mining software for Windows, OS X, and Linux. Commercial process mining vendors are appearing (Table 1 lists some and provides a short link to each, or the Google Translate version of the page). Also appearing are process mining consultants and companies that license and incorporate process mining technology into software and services they sell.

Of note, there are two direct spinoffs listed on the ProM website: Fluxicon (I used Fluxicon's Nitro to convert from the illustrated comma delimited flat file to XML formats compatible with the ProM process mining tool) and Futura Process Intelligence (licensed by Pallas

Athena, I've created some impressive Flash animations of workflow using their process mining software).

Process Mining Vendors	
Fluxicon	http://ehr.bz/flux
Fourspark	http://ehr.bz/fsp
Fujitsu	http://ehr.bz/fuj
Futura Process Intelligence	http://ehr.bz/fpi
OpenConnect	http://ehr.bz/oct
QPR	http://ehr.bz/qpr
SoftwareAG	http://ehr.bz/sag
StereoLOGIC	http://ehr.bz/slg
Verint/Iontas	http://ehr.bz/vrt

Table 1: Commercial Process Mining Vendors

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