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PROCESS INFORMATION TRANSFER AND ANALYSIS IN HOSPITALS USING HOSPITAL INFORMATION SYSTEMS, COMMUNICATION STANDARDS AND PROCESS MODELS

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ABSTRACT

The current interaction between medical devices and IT-systems in hospitals is characterized by inadequate interoperability and integration. One challenge is the monitoring of patient-related process lead times across the involved IT-systems. Therefore we propose a novel way of retrieval of quality and performance metrics along the clinical pathway of time-critical diseases in the context of various clinical standards and systems. For this reason, we investigated the hospital information systems and available clinical communication standards regarding the collection and communication of timing and process information. We found that the widely used clinical communication standard Health Level 7 (HL7) and the XML-based Clinical Document Architecture (CDA) can be extended to provide a valuable service for the acquisition and collection of process data including timestamps. Furthermore, based on the Event-Driven Architecture (EDA) we propose a clinical reference process model existing of process clusters and sub-clusters those we assign events to collect event timestamps.
In the following, we describe an integrated technical and process-oriented approach that provides the basis for an automated and standardized process monitoring, quality controlling and benchmarking and therefore represents a promising opportunity to recognize and eliminate workflow bottlenecks. In time-critical diseases, this typically directly translates into an improved quality of care.

KEYWORDS

Clinical process monitoring, clinical document architecture, clinical process modeling, events-driven architecture, process cycle times.

1. INTRODUCTION

Optimization of clinical pathways is one of the key elements of quality improvement initiatives in hospitals. The management of time-critical diseases such as heart attack and stroke – although highly standardized – can be more or less time-consuming depending on the workflow bottlenecks in a particular hospital. To identify bottlenecks in a process that overall can be accomplished within one or two hours, requires a thorough understanding of both workflow and durations each of the sub-processes take. During a hospital stay, a patient crosses several departments, which are based on various information system-catchment areas. This set of departments and IT-system boundaries represent process interfaces that must be bridged. On object-level (patient, blood sample etc.) the interfaces are connected temporarily by a local transformation of the objects. At the level of IT-systems, however, these interfaces very often do not exist. The lack of interoperability, i.e. the ability of an information system to participate in a complex information management process in a concerted fashion with a number of other information systems (Channin, 2009), is a major problem for any type of standardized and automated process monitoring because it complicates a digital information exchange, thus, hinders the full exploitation of the potential use of data.

The current interaction between medical devices and IT-systems in hospitals is characterized by inadequate interoperability and integration. One challenge is the IT-department and cross-system detection of patient-related process lead times. We propose a novel way of retrieval of quality and performance metrics along the clinical pathway of time-critical diseases in the context of various clinical standards and systems. In our approach the retrieval of KPIs is achieved using the example of a dedicated set of time-based process indicators. For this reason, we investigated the hospital information systems and available communication standards regarding the collection and communication of timing and process information. We found that the widely used clinical communication standard Health Level 7 (HL7) and the XML-based Clinical Document Architecture (CDA) can be extended to provide a valuable service for the acquisition and collection of process data including timestamps. Therefore, we propose an integrated technical and process-oriented approach which provides the basis for an automated and standardized process monitoring, quality controlling and benchmarking. This represents a promising opportunity to recognize quality lacks e.g. in form of bottlenecks over several clinical department and system borders and to further optimize processes by eliminating them. In time-critical diseases, this typically directly translates into an improved quality outcome for patients.

In our former research work, we developed a new generic inpatient reference process model to provide the possibility of standardized and comprehensive performance process monitoring in hospitals in the field of time-critical diseases. The first model development phase comprised the model construction with the purpose of process cycle time measurement. In the second phase, we focused on an event model to enhance the process model with event information and especially timestamps. In the following, we performed interviews with physicians, to derive relevant, valid, reliable and feasible clinical indicators for process

monitoring. Additionally we consulted relevant clinical guidelines in the field of time critical diseases (i.e. heart attack and stroke). We derived sets of time-based indicators, which we approved again with experienced clinicians. Afterwards we generalized the indicators to use them in our generic reference process model. Finally, we investigated the IT-infrastructures, which are nowadays commonly used in hospitals. We presented our research results partly in several contributions (e.g. Gattnar et al., 2011a; Gattnar et al., 2011b; Gattnar et al., 2011c; Gattnar et al., 2011d; Gattnar et al., 2011e; Gattnar et al., 2012).

This contribution is an extended version of our conference paper where we introduce an XML-based approach using the CDA to store process information during a patient's stay in hospital (Gattnar et al., 2011a). In the following, we extend the former version with a clinical process model and process events, which are highly important for monitoring process cycle times in our approach.

2. IT-BASED INFORMATION TRANSFER IN HOSPITALS

Healthcare processes are nowadays heavily dependent on Information Technology (IT). With the enormous impact and rapid evolvement of IT, there is a major demand for standardization in health care IT (Wirsz, 2000). DICOM (Digital Imaging and Communications in Medicine) as one of the clinical standards defines the format and mechanism for exchange and storage of information in radiological environment (DICOM, 2011). DICOM includes a large number of specific services and the producers are committed to their implementation because of so-called „Conformance Statements". By comparing the declarations of different systems, basically it is possible to determine, whether they can interact with each other (DICOM, 2009). Manufacturers have at least a minimum level of general conformance requirements to meet, in order to demonstrate general conformity to the DICOM Standard. Conformance Statements are an integral part of the DICOM standard.

So-called DICOM worklists are generated by the Radiology Information System (RIS). They contain patient data, details of the examination orders, the procedure parameters and appointments and can be accessed by image acquisition devices (modalities) for planning examinations. In return, a modality is able to generate so-called Modality Performed Procedure Steps (MPPS), a structured information (such as start time, end time, status, dose, material consumption etc.), which can be sent to the RIS at the beginning ("MPPS in progress") and the end ("MPPS completed") of an examination (Noumeir, 2005).

Outside the radiology department of a hospital the second important clinical standard, Health Level 7 (HL7), standardizes the transfer of patient information between IT systems (HL7, 2011). The communication in HL7 follows the message-based communication principle. Accordingly, the various systems interact with each other via messages. Data exchange is initiated between two or more systems through an event from the real world (called a trigger event), such as the admission of a patient. This event implies the exchange of data between the various systems, distinguishing between specific and general requests. The patient's master data request initiated by a laboratory information system (LIS) would correspond to a specific request. General requests are on the contrary usually caused by short-term events in the real world. If such a trigger event is registered in a system, a transaction is started, which in turn causes an event and respectively a transaction on the target system (Bärwolff et al, 2006). While DICOM is a standard for image transmission in

radiology, HL7 is a standard for electronic data exchange outside of radiology in the catchment area of the hospital information system (HIS). A HIS is an IT-based management system. It supports medical and clinical patient care and documentation, organization, administration and communication in a hospital (Haas and Kuhn, 2007; Huang, 2010). Another important task of the HIS is to evaluate the costs and the efficiency of hospital organization for a longer period of time (Huang, 2010).

A radiology information system (RIS) is one of the IT-systems in the field of radiology, which controls the daily tasks of one or more radiological departments. It is responsible for both the administrative and clinical support in the radiology to relieve the staff from administrative tasks. On the other hand, it improves the quality of radiological examinations (Huang, 2010). PACS (Picture Archiving and Communications Systems) as another component represent the technological core of a modern, digital radiology department (Ralston and Coleman. 2009). The main task of the PACS is to store, distribute and display medical images for interpretation and evaluation. Further IT-systems in radiology departments are so-called modalities. Modalities are known as imaging systems in the medical industry. Modalities represent combined with PACS the technological core of a modern, digital radiology department (Ralston and Coleman, 2009). Table 1 summarizes the interoperability issues between the described IT-systems including HIS, RIS, modalities and PACS.

Table 1. Interoperability of clinical systems (cf. (Wirsz, 2000))

Systems	HIS	RIS	PACS	Modality
HIS	HL7	HL7	___	___
RIS	HL7	HL7	HL7/ DICOM	DICOM
PACS	___	HL7/ DICOM	DICOM	DICOM
Modality	___	DICOM	DICOM	DICOM

3. PROCESS-BASED TIME ACQUISITION

Healthcare organizations such as hospitals are interested in measures about their quality of care. A common way to retrieve quality information is to examine the performance of organizational structure (structural performance) and processes (process performance) as well as outcomes (outcomes performance) by means of Key Performance Indicators (KPIs) (NHOP, 1997). The challenge is to develop measurable, significant, appropriate and quality relevant indicators. Such sets of indicators are being provided by healthcare organizations in many countries (e.g. Joint Commission on Accreditation of Healthcare Organizations (JCAHO, 2011), Agency for Healthcare Research and Quality (AHRQ, 2011), National Health Service (NHS, 2011) etc.).

Clinical IT-systems act in our approach as enabler for end-to-end process monitoring and therefore for clinical quality improvement as well as risk and cost reduction. The assignment of KPIs to the clinical IT-systems is presented in Figure 1 by means of dedicated KPIs using the example of a simplified inpatient care process including four basic sub-processes (admission, diagnostics, treatment and discharge). The affected IT-Systems are the hospital information system (HIS), in the field of radiology department: the RIS, Modalities and PACS and outside the radiology the laboratory information system (LIS).

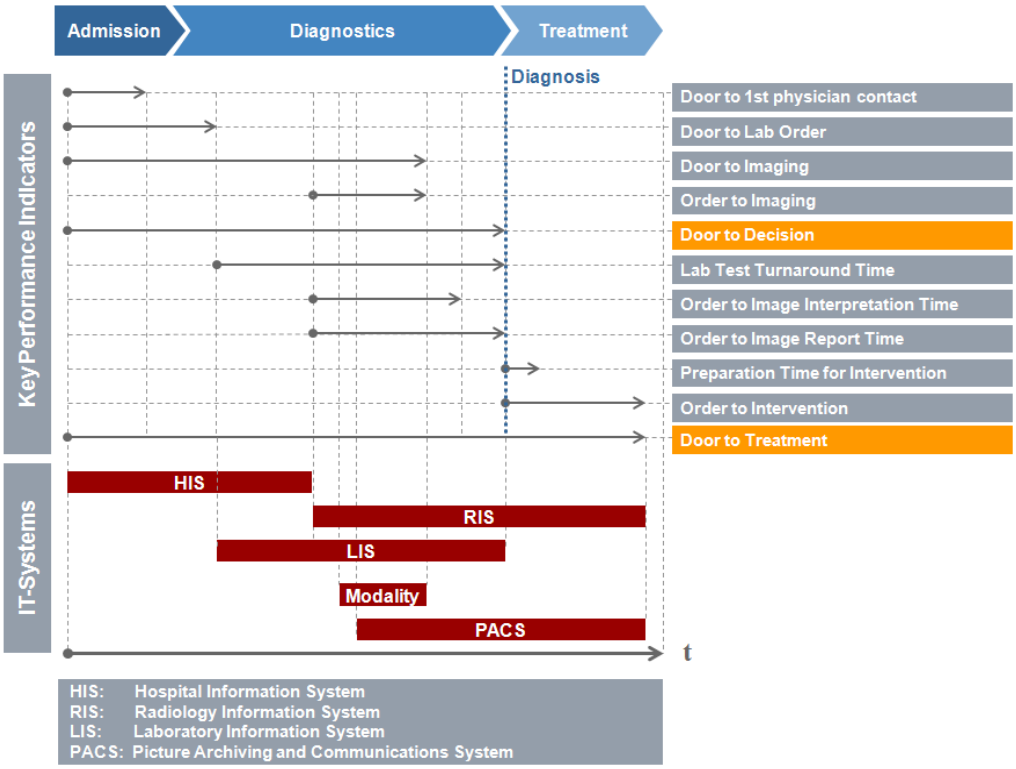

Figure 1. Clinical IT-systems in the context of clinical process

The information about the process metrics (i.e. KPIs resp. Key Performance Indicators) necessary for process monitoring is stored in our approach in so-called KPI-cards (see Table 2). These are structured and short descriptions of KPIs including further information about the start- and end-events, the IT-systems activating the events, the calculation of the KPIs, practical examples as well as related KPIs. In addition, the related process modules are referred to. For modeling purposes, Event-driven Process Chain (EPC) is used. EPC is a process modeling language that represents the temporal and logical dependencies between events and processes. Additionally, it allows the explicit notation of events, where process performance measurements can be performed.

Table 2. KPI-Card: "Order to Imaging" (cf. (Gattnar *et al.*, 2011f))

Order to Imaging		
Definition	Duration in minutes from imaging order entry (e_{start}) to completion of the imaging procedure (e_{end})	
Calculation	Event e_{end} - Event e_{start}	
IT-systems	e_{start}	Hospital Information System (HIS) (direct) Radiology Information System (RIS) (indirect: DICOM* Worklist**)
	e_{end}	Modality (direct), Radiology Information System (RIS) (indirect: DICOM "MPPS completed" ***)
EPC-module	e_{start}	Module Order
	e_{end}	Module PerformModality
Example	Order to CT (Computer Tomography); Order to MRT (Magnetic Resonance Tomography); ...	
Related KPIs	Door to Imaging (e_{end}); Order to Image Interpretation Time (e_{start}) ; Order to Image Report Time (e_{start}); ...	

* DICOM (Digital Imaging and Communications in Medicine) as one of the clinical standards which defines the format and mechanism for exchange and storage of information in a radiological environment.

** DICOM Worklists contain patient data, details of the examination orders, the procedure parameters and appointments . They are sent by a RIS-system and can be accessed by image acquisition devices (modalities) for planning examinations.

*** DICOM "MPPS" is a structured information (such as start time, end time, status, dose, material consumption etc.), which can be sent by a modality to the RIS at the beginning ("MPPS in progress") and the end ("MPPS completed") of an examination.

4. CLINICAL INFORMATION INTERCHANGE USING IT-STANDARDS

Healthcare organizations such as hospitals are interested in measures about their quality of care. A common way to retrieve quality information is to examine the performance of organizational structure (structural performance) and processes (process performance) as well as outcomes (outcomes performance) by means of Key Performance Indicators (KPIs) (NHOP, 1997). The challenge is to develop measurable, significant, appropriate and quality relevant indicators. Such sets of indicators are being provided by healthcare organizations in many countries (e.g. Joint Commission on Accreditation of Healthcare Organizations (JCAHO, 2011), Agency for Healthcare Research and Quality (AHRQ, 2011), National Health Service (NHS, 2011) etc.).

Due to involvement of several departmental IT-systems and related communication standards, the collection of clinical information in hospitals is still a challenging task. Figure 2 shows schematically the involved communication standards between the LIS ("Laboratory"), the RIS ("Radiology") and Modalities. All HL7-based paths should be connected to the HIS, the main hospital information system. Nevertheless, the DICOM-part is a separate communication area used especially in the radiology department to share images between the involved systems (i.e. RIS, PACS and modalities). Up to now, the possibilities to share extensive clinical information between both communication standard areas are due to the different information types (i.e. text-based information vs. images) the communication standards support rare, complicated and expensive. Based on these facts, focusing on HL7 as

the communication standard for end-to-end patient process monitoring is a beneficial way to retrieve a lot of process information, which is text-based. Subsequently, it can be automatically processed.

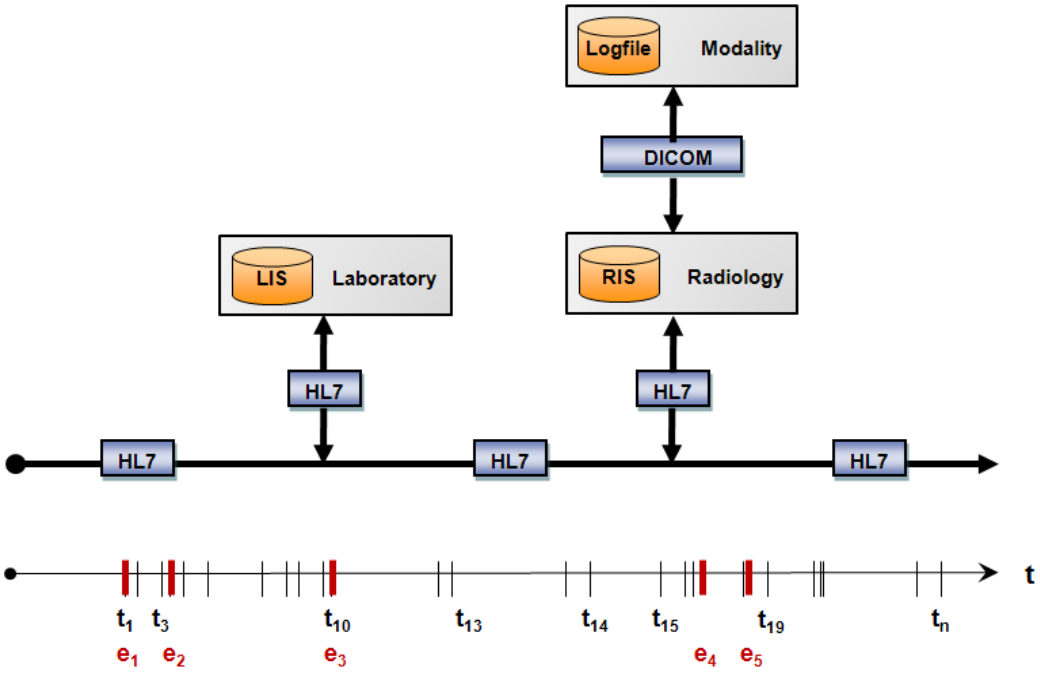

Figure 2. Timestamps and clinical IT-systems (cf. (Gattnar et al., 2011f))

Health Level 7 (HL7) is – as described above – a widely used and supported standard for the interchange of clinical, financial, and administrative information among heterogeneous information systems in the healthcare environment. (HL7, 2011; Chronaki, 2001; Campbell, Stetson 2003). Following the HL7 standard, it is possible to share clinical information between the hospital information system (HIS) and other departmental systems (e.g. radiology (RIS), laboratory (LIS) etc.) (see Figure 3). HL7 addresses the highest level (level 7) of the OSI model (Open Systems Interconnection model) and facilitates data communication in hospitals by providing rules to convert abstract messages associated with real-world events into strings of characters comprising an actual message. In December 2001, HL7 Version 3 was initially released. It uses an object-oriented methodology and a Reference Information Model (RIM) to create HL7 messages (Huang, 2010). RIM provides a coherent shared information model at the entire scope of health care IT that contains all data content relevant to HL7 messages (Paterson, 2002). It includes more than 100 classes and more than 800 attributes and defines the relationships of each class. RIM provides thus an explicit representation of the semantic and lexical connections between the information in the field of HL7 messages (HL7, 2011; Huang, 2010).

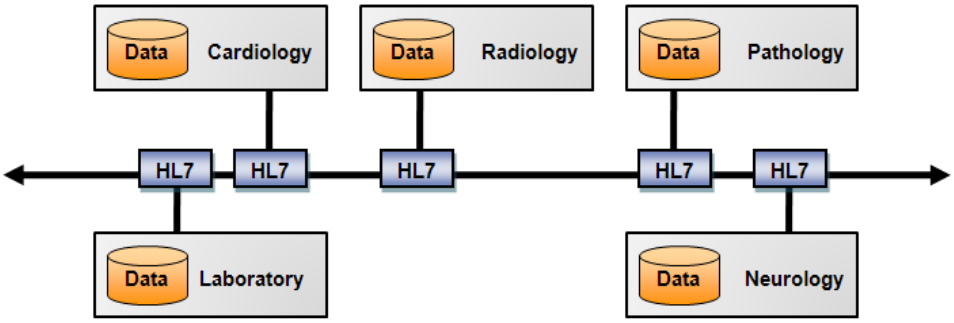

Figure 3. En example of a HL7-infrastructure at hospital

Considering intensive standardization efforts in the health care domain, the widely used extensible markup language (XML) is increasingly used, to exchange medical records (XML, 2011). XML is a system-independent language describing information data in a standard format and making data portable. Especially for clinical purposes, the XML-based Clinical Document Architecture (CDA) was developed. It is a document markup standard for the structure and semantics of exchanged clinical documents. CDA is envisioned as a hierarchically organized set of document schemas and document type definitions (DTD), which define the semantics and structural constraints necessary for the exchange of clinical documents (Paterson, 2002). A CDA-document is a defined and complete information object that can exist outside of a message and can include text, images, sounds, and other multimedia content. The CDA supports shared care between hospital-based and community-based physicians, knowledge integration by permitting external links to other documents, and outcomes research through the capture of discrete and coded clinical data (Chronaki, 2001).

CDA documents derive their meaning from the HL7 RIM. The elements and attributes and the relationships among these elements and attributes are drawn from the RIM and expressed in XML (Paterson, 2002). As XML-based documents, they must all have a header section that gives details of the patient, event, date of creation etc. The document body involves three levels and is defined by a DTD (Chronaki, 2001). CDA-Level 1 is thereby the root of the hierarchy and unconstrained. Each additional level adds further specificity and constraints to the architecture. CDA-Level 2 has structured sections and allows constraints to be imposed. Level 3 contains furthermore structured entries within the document body (Paterson, 2002).

5. IT-BASED CLINICAL PROCESS MONITORING

Most clinical departments in a hospital (e.g. cardiology, radiology, laboratory, pathology, neurology etc.) have their own specific operational requirements that differ from the general hospital operations. For this reason special information systems with different workflow environments may be needed in these departments (e.g. radiology information system, laboratory information system etc.) (Huang, 2010). Often the hospital information system (HIS) doesn't support their operations and must develop mechanisms to integrate data between these systems and the HIS. The integration of the information systems involved in a clinical process is extremely important for a hospital to monitor the process performance.

The HIS is in addition to business and administration processes also responsible for clinical processes. It should provide the access to patient clinical results generated by the various clinical departmental information systems and broadcasts patient data with the HL7-standard (see previous section). However, a standardized end-to-end clinical process monitoring is not supported.

An end-to-end process monitoring is based on timestamps collected at the start and the end of dedicated sub-processes resp. process steps. This timestamps are collected by several different information systems. For example, the start event (“Door”, i.e. the admission of the patient at hospital) of the KPI “Door to Imaging” is stored in the HIS, while the end event (“Imaging”, i.e. the finishing of imaging e.g. computer tomography) is stored in the radiology information system (RIS) (see Figure 1 and Table 2). Furthermore, several clinical workflow tasks are performed one after another which results are indeed stored in the HIS. However, the historical workflow timing information necessary for the end-to-end process monitoring is unrecoverable lost. Especially the monitoring of medication is not possible. But exactly this is a very important feature and relevant for quality management in hospitals. Medication (e.g. if aspirin is given after arrival at hospital in patients with acute heart attack) is a key parameter in clinical guidelines published by national and international health care organizations (e.g. European Society of Cardiology). Furthermore, the assurance of accurate medication diminishes risks in health care and improves the quality of care. Figure 4 shows the described problem in a demonstrative manner.

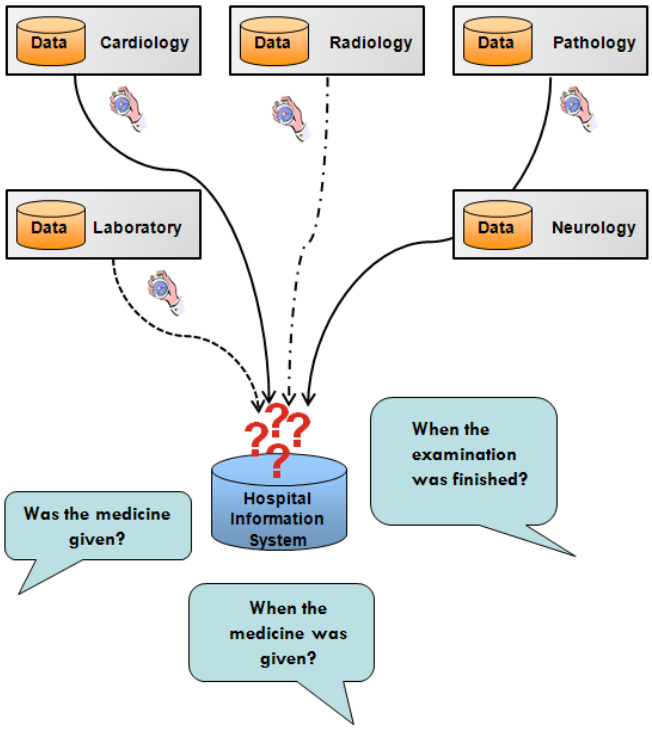

Figure 4. Heterogeneous hospital IT-systems

Therefore we present in the following a newly approach to enable the end-to-end process monitoring in a heterogeneous health care environment. Our approach provides a new possibility to concentrate information about the clinical process in a single complete clinical information object. For this purpose, the HL7 communication standard is used which ensures a standardized and efficient data exchange between different applications of different departments of a hospital (see previous sections). The Clinical Document Architecture (CDA), which was developed as part of the HL7 standard document architecture, offers the appropriate technological framework for the concentration of process and time data in a single information object. CDA is a document standard describing the structure and content of clinical documents in the field of health care for the purpose of electronic exchange (see previous section). However, CDA-documents contain only data such as treatment measures, the roles involved, examination results or information on diagnoses and treatments. They don't provide information about the clinical process.

In our approach, the XML syntax of CDA-documents is extended for the purpose of process monitoring. The CDA-documents are in our approach also used as a basis for a free and integrated access to relevant clinical process data. We expand the XML-based CDA-document structure therefore to store process information and timestamps within new introduced XML-tags (see Figure 5). Such new CDA-documents can be provided with a "start" timestamp indicating the beginning of the performed process step as well as the process step data describing the current process ID and type. After step completion, the "end" timestamp can be stored. Process data information stored in the CDA-document is derived from the HL7 messages sent by the departmental systems or the HIS itself. A special process database is used to collect all relevant clinical process steps. They can be assigned to the appropriate process entry within the CDA-document. The document itself can be referenced by the hospital information system (HIS). After the clinical step is finished, the document has to be updated with the process and timing data and used in the next step.

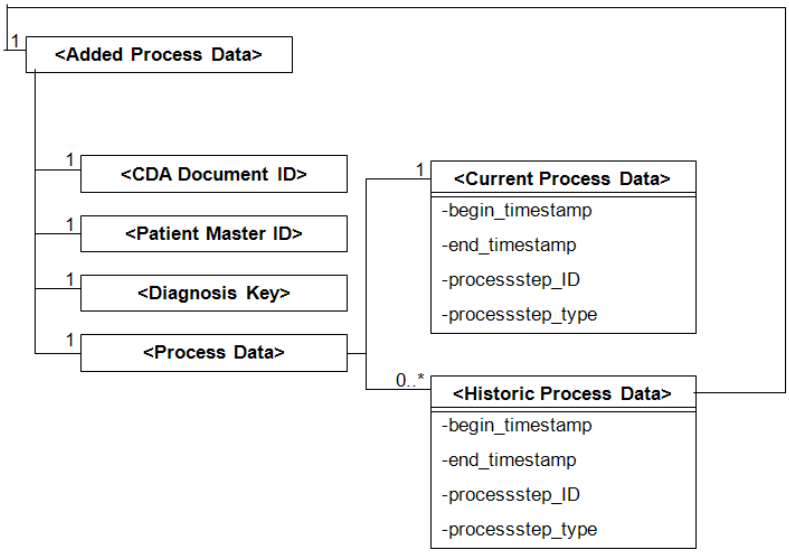

Figure 5. Introduction of new XML-tags for process monitoring within the CDA-document structure

Following this approach, the CDA-document will grow along the clinical pathway (i.e. the clinical end-to-end process) providing a continuous and accumulated process history involving all performed clinical steps involving data received from crossing departmental IT-systems. Since each CDA-document entry corresponds to a clinical process step-entity, any CDA-document contains the complete information about all previously performed examinations and interventions during a patient stay in hospital. Therefore each document entry is labeled by a unique and accumulated ID. In this manner, each document references all other entries generated in history and establishes an end-to-end process data chain. Such a solution allows an integrated and standardized end-to-end process monitoring.

6. TIME-BASED PROCESS CLUSTER MONITORING

In the former chapter, timestamps were described as the necessary part of the process monitoring concept. Using timestamps enables especially the monitoring of process cycle times. Therefore, for each process step - as it is already defined as a new XML-tag within the CDA-document structure - a timestamp for the process step start and the end has to be collected and stored in the CDA-document. Timestamps can be easily collected using the concept of events. As events have no time-duration and occur IT-based at a certain exactly determinable time, an event has usually a timestamp that can be stored for analysis or monitoring purposes (Bruns and Dunkel, 2010). So-called Event-Driven Architecture (EDA), an approach to manage IT-based events and to use them for triggering activities like process steps, describes timestamps as an event attribute that is integrated into the event structure itself (Luckham, 2007; Luckham, 2012).

As timestamps are closely related to events, we concentrate in the following on process events. Following the same idea as defined in the CDA-document structure in the former chapter, every process step is started by a start-event while an end-event shows the end of process step performing. Therefore, we enhance every process step with a start-event and an end-event to enable the possibility to measure the process step duration. Subsequently, to measure single process step duration the simple time difference calculation between the end-event and a start-event is sufficient. However, the interesting question is how to measure the process duration of a process that consists of several single process steps? Accordingly, for the process duration calculation the last process step end-event as well as the first process step start-event has to be used. At the same time, the precondition to calculate meaningful time measures is to define the relevant processes whose duration has to be investigated. In time critical area, these processes are time critical as well. For instance, the diagnostic and treatment procedures should be performed as soon as possible after patient’s admission in hospital to safe patient’s life and ensure a high treatment outcome quality.

For this purpose, we defined a clinical reference process model, which covers all relevant processes and helps to determine which of them should be monitored and therefore measured. Additionally, the model helps to identify the right process steps the process starts and ends with and thereby to determine the right events and timestamps to measure relevant process cycle times. We defined the reference process model in a generic manner and therefore we avoid using a specific modeling language to enable the possibility of switching between the most appropriate modeling languages and enable the process modeler to decide it himself based on the requirements in a specific hospital.

To distinct the processes, we propose an identification scheme for every process included in the model. Additionally, every process is assigned to a specific hierarchy process level and can be invoked from processes on a higher level. To emphasize the specific clinical purpose within one process area, we call the processes *cluster*. In the following, the cluster list including the processes on hierarchy level 1 till level 3 is shown:

- Cluster P: Patient process
- Cluster C: Patient's carriage
- Cluster A: Patient's admission
- Cluster B: Patient's treatment
- Cluster D: Diagnostic procedure
- Cluster T: Treatment procedure
- Cluster R: Reporting
- Cluster V: Result distribution, validation and archiving
- Cluster E: Patient discharge

If clusters are assigned to a hierarchy level higher then level 3, we call them *sub-cluster*. In the following, the sub-cluster at level 4 are shown as an excerpt:

- Cluster D:
  - Sub-Cluster L: Laboratory procedure
  - Sub-Cluster B: Imaging procedure
  - Sub-Cluster K: Clinical procedure
- Cluster T:
  - Sub-Cluster I: Invasive procedure
  - Sub-Cluster N: Non-invasive procedure
  - Sub-Cluster P: Care procedure

We define a cluster resp. a sub-cluster as a completely clinical process on a specific process hierarchy level. Thereby, every process step within a cluster resp. a sub-cluster can invoke another process chain (i.e. a cluster resp. sub-cluster) on a higher hierarchy level. We call all process steps, which can invoke other processes on a higher level *process interfaces* and add a start-event in front of the process interface as well as an end-event afterwards. As every process interface addresses another process on a deeper level, the time measurement can be performed using the process interface start-events and end-events. To simplify the identification of start-events and end-events the signs "minus" and "plus" are used. The event with the "minus": [e_-] is the start-event whereas the event with the "plus": [e_+] is the end-event of a process interface. Figure 6 shows schematically the hierarchical cluster order of the process interfaces B ("Patient's treatment") at level 2 and D ("Diagnostic procedure") at level 3. Additionally the related start-events and end-events are assigned to the process interfaces and shown in the figure as well.

Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Cluster	Start-event	End-event
Patient process							P	e_{P-}	e_{P+}
	Patient's carriage						C	e_{C-}	e_{C+}
	Patient's admission						A	e_{A-}	e_{A+}
	Patient's treatment						B	e_{B-}	e_{B+}
	Patient's discharge						E	e_{E-}	e_{E+}

Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Cluster	Start-event	End-event
	Patient's treatment						B	e_{B-}	e_{B+}
		Diagnostic procedure					D	e_{D-}	e_{D+}
		Treatment procedure					T	e_{T-}	e_{T+}
		Reporting					R	e_{R-}	e_{R+}
		Result distribution, validation and archiving					V	e_{V-}	e_{V+}

Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Cluster	Start-event	End-event
		Diagnostic procedure					D	e_{D-}	e_{D+}
			Laboratory procedure				DL	e_{DL-}	e_{DL+}
			Imaging procedure				DB	e_{DB-}	e_{DB+}
			Clinical procedure				DK	e_{DK-}	e_{DK+}

Figure 6. Hierarchical cluster order of the process interfaces B ("Patient's treatment") at level 2 and D ("Diagnostic procedure") at level 3 including assigned start-events and end-events

Figure 7 shows a further example using the EPC-syntax. Both elements in the middle (i.e. "Performing patient's admission" and "Performing patient's treatment") are process interfaces. The left one is the interface A and the right one the interface B (see Figure 6). The other redlined elements are events and connectors. As we see only an excerpt of the whole process in figure 7, only the "and"-connector is used to express the parallel admission and treatment process performing. The process interface B ("Performing patient's treatment") is initiated by the start-event [e_{B-}] ("Patient's treatment to be performed") and finalized with the end-event [e_{B+}] ("Patient's treatment performed"). Calculating the time difference between both events will lead to the process cycle time of the treatment process chain as it is referenced by the process interface B.

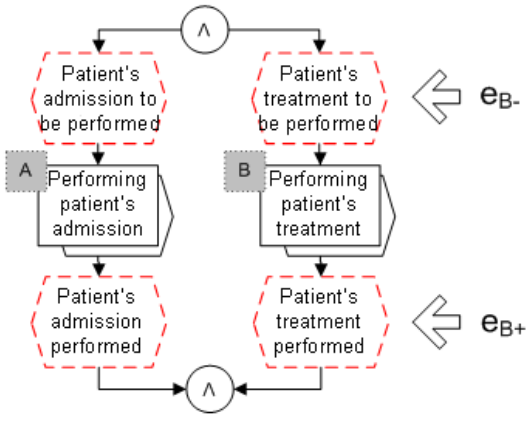

Figure 7. Example of process interfaces with the related start-events and end-events using EPC-syntax

Clusters are related to each other and can be performed in a specific order. To define the relationships we introduce cluster rules (i.e. process rules) and define the dependencies regarding the process order. As start-events and end-events as well as their timestamps are associated to every process interface, the process rules can be used for process cycle time measurement purposes. Table 3 shows the process rules for level 1 till level 4 using Boolean operators (i.e. or, and, not) as well as the so-called sequence operator, shown as a right-directed arrow. All process interfaces are marked with the color grey.

Table 3. Cluster and sub-cluster process rules - Excerpt

Cluster P:	$(C \text{ or } (\text{not } C)) \rightarrow (A \text{ and } B) \rightarrow E$
Cluster B:	$(D_1 \text{ or } T_1 \text{ or } (R_1 \rightarrow V_1)) \rightarrow \ldots \rightarrow (D_n \text{ or } T_n \text{ or } (R_n \rightarrow V_n))$
Sub-Cluster D:	$(DL_i \text{ or } DB_i \text{ or } DK_i)$
Sub-Cluster T:	$(TI_i \text{ or } TN_i \text{ or } TP_i)$
Sub-Cluster DL:	$DL1_i \rightarrow DL5_i$
Sub-Cluster DB:	$DB1_i \rightarrow DB2_i \rightarrow DB3_i \rightarrow DB4_i \rightarrow DB5_i \rightarrow DB6_i$
Sub-Cluster DK:	$DK1_i \rightarrow DK2_i \rightarrow DK3_i \rightarrow DK4_i \rightarrow DK5_i \rightarrow DK6_i$
Sub-Cluster TI:	$TI1_i \rightarrow TI2_i \rightarrow TI3_i \rightarrow TI4_i \rightarrow TI5_i \rightarrow TI6_i$
Sub-Cluster TN:	$TN1_i \rightarrow TN2_i \rightarrow TN3_i \rightarrow TN4_i \rightarrow TN5_i \rightarrow TN6_i$
Sub-Cluster TP:	$TP1_i \rightarrow TP5_i$

Using the process rules, those excerpt is shown in table 3, a completely patient process can be expressed as a sequence of process steps and assigned start-events as well as end-events. The sequence that is shown below can be stored using the proposed CDA-document structure. It demonstrates a patient process (P) that starts with the transport to hospital (C), patient's admission (A) and patient's treatment (B). The treatment itself references two diagnostic procedures (D), which is indicated by the index and finally one treatment procedure (T). As the patient process is initiated by patient's admission, it is analogous finalized with patient's discharge (E).

$$P \rightarrow C \rightarrow (A \text{ and } (B \rightarrow ((D_1 \rightarrow DB_1 \rightarrow DB1_1 \rightarrow DB2_1 \rightarrow DB3_1 \rightarrow DB4_1 \rightarrow DB5_1 \rightarrow DB52_1 \rightarrow DB521_1 \rightarrow DB521_2 \rightarrow DB521_3 \rightarrow DB6_1 \rightarrow R_1 \rightarrow V_1) \text{ or } (D_2 \rightarrow DB_2 \rightarrow DB1_2 \rightarrow DB2_2 \rightarrow DB3_2 \rightarrow DB4_2 \rightarrow DB5_2 \rightarrow DB51_2 \rightarrow DB6_2 \rightarrow R_2 \rightarrow V_2) \text{ or } (T_3 \rightarrow TN_3 \rightarrow TN1_3 \rightarrow TN2_3 \rightarrow TN3_3 \rightarrow TN4_3 \rightarrow TN5_3 \rightarrow TN51_3 \rightarrow TN6_3 \rightarrow R_3 \rightarrow V_3)))) \rightarrow E$$

7. CONCLUSION AND OUTLOOK

With the implementation of a CDA-based solution for acquisition and collection of process data including timestamps, the interoperability across the entire process (e.g. between the hospital information system (HIS) and the radiology information system (RIS)) will be ensured. The described method of process monitoring may be very helpful for identification of bottlenecks in clinical workflow. This requires, however, that all involved systems support first HL7 in the XML-based Version 3 and furthermore the CDA-standard.

As shown in Figure 2, both most important clinical communication standards DICOM and HL7 are used for communication within the clinical process. However, the CDA is only supported by the HL7 communication standard. In consequence, the introduced CDA-based approach is limited for process monitoring in the area of the hospital information system (HIS) where the HL7 standard is used. Nevertheless, the presented IT-based approach enables the usage of the model as a means of benchmarking and thus enables a more transparent standardized internally (over several departmental and system borders) and externally benchmarking (e.g. in form of public performance measures or quality reports). In addition, our newly developed clinical process model can be used as an instrument for clinical information monitoring and the development of evidence-based treatment processes (i.e. clinical pathways). The latter are important in the context of quality management and thus help towards the continuous quality improvement in patient care. Generally, we designed our clinical process model primarily to monitor the clinical process by means of process metrics. Secondly, it accelerates the modeling of disease-specific and hospital-specific clinical pathways and the measurement of KPIs in hospitals. In future, it could be used to support the clinical pathways construction.

In summary, it is established that a patient's process-oriented view represents a promising opportunity to accurately monitor the patient flow over several clinical departmental and system borders. The acquisition of KPIs based on established clinical standards like HL7 and CDA is a promising way to support quality improvement efforts in healthcare. Beyond the primary goal of improving quality, KPIs can by published e.g. as part of quality reports and can help as well to improve the reputation of a hospital. The retrieval of process cycle times and KPIs in the presented way enables standardized process monitoring and measurement of workflow bottlenecks, which can lead to more accurate analyses and workflow optimization by reduction of lead times and improving quality of care in the field of time critical diseases. Furthermore, the solution enables interoperability in means of supporting and completing clinical Electronic Health Records (EHR) with process information and providing an automatic retrieval of relevant clinical process data. In this way, not only the process monitoring will be facilitated but also reporting work may be reduced. However, to preserve the idea of the standard, extensions regarding CDA as part of the HL7 standard document architecture require in the long term the adoption of the HL7 standard itself.

REFERENCES

AHRQ, 2011. Agency for Healthcare Research and Quality. [online] Available at: <http://www.ahrq.gov> [Accessed 24 January 2011].

Bruns, R. and Dunkel, J. 2010. *Event-Driven Architecture: Softwarearchitektur für ereignisgesteuerte Geschäfts-prozesse*, Springer, Heidelberg, Germany.

Campbell, D.A. and Stetson, P.D., 2003. Medical Informatics. In: E.L. Siegler et al, ed. *An Introduction to Hospitals and Inpatient Care*. Springer, New York, USA.

Channin, D.S, 2009. Standards and Interoperability. In: B.F. Branstetter, ed. *Practical Imaging Informatics: Foundations and Applications for PACS Professionals*. Springer, New York, USA.

Chronaki, R. et al, 2001. An HL7/CDA framework for the design and deployment of telemedicine services. *Conference Proceedings of the International Conference of IEEE Engineering in Medicine and Biology Society*. New York, USA, pp. 3504-3507.

DICOM, 2010. *Digital Imaging and Communications in Medicine*. [online] Available at: <http://medical.nema.org> [Accessed 4 December 2010].

DICOM, 2009. *Part 2: Conformance*, National Electrical Manufacturers Association, Rosslyn, Virginia, USA.

Gattnar, E., Ekinci, O., Detschew, V., 2011a. Interoperable Process Monitoring using Clinical IT-Standards and Healthcare Information Systems. *Proceedings of the IADIS International Conferences Informatics 2011, Wireless Applications and Computing 2011, Telecommunications, Networks and Systems 2011*, Rom, Italy, pp. 59-66.

Gattnar, E., Ekinci, O., Detschew, V., 2011b. Event-based Workflow Analysis in Healthcare. *Proceedings of the 9th International Workshop on Modeling, Simulation, Verification and Validation of Enterprise Information Systems (MSVVEIS 2011). In conjunction with the 13th International Conference on Enterprise Information Systems (ICEIS 2011)*, Beijing, China, pp. 61-70.

Gattnar, E., Ekinci, O., Detschew, V., 2011c. An Integrated Approach to Standardized and Automated Extraction of Clinical Process Cycle Times. *Proceedings of the IADIS International Conferences eHealth 2011*. Rom, Italy, pp. 128-136.

Gattnar, E., Ekinci, O., Detschew, V. 2011d. A Novel Generic Clinical Reference Process Model for Event-based Process Times Measurement. *Proceedings of the 4rd International Conference on Business Process and Services Computing (BPSC 2011)*, Springer Lecture Notes in Business Information Processing (LNBIP), Poznan, Poland, pp. 66-77.

Gattnar, E., Ekinci, O., Detschew, V., 2011e. Clinical Process Modeling and Performance Measurement in Hospitals. *Proceedings of the 5th International Workshop on Advances in Quality of Service Management (AQuSerM 2011). In conjunction with 15th IEEE Enterprise Computing Conference (EDOC 2011)*, Helsinki, Finland, pp. 132-140.

Gattnar, E., Ekinci, O., Detschew, V. 2012. Health Care Performance Monitoring using an Inpatient Reference Process Model and Clinical KPIs. *Proceedings of the 4th ICST International Conference on eHealth (eHealth 2011)*. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering (LNICST), Malaga, Spain, pp. 34-42.

Haas, P. and Kuhn, K., 2007. Krankenhausinformationssysteme – Ziele, Nutzen, Topologie, Auswahl. In: R. Kramme, ed. *Medizintechnik: Verfahren, Systeme, Informationsverarbeitung*, 3 edition, Springer, Berlin, Germany.

HL7, 2011. *Health Level 7*. [online] Available at: <http://www.hl7.org> [Accessed 24 January 2011].

Huang, H.K., 2010. *PACS and imaging informatics*, 2 edition, Wiley-Blackwell, New Jersey, USA.

JCAHO, 2011. *Joint Commission on Accreditation of Healthcare Organisations*. [online] Available at: <www.jointcommission.org > [Accessed 24 January 2011].

Luckham, D., 2007. *The power of events: an introduction to complex event processing in distributed enterprise systems*, Addison-Wesley, Boston, USA.

Luckham, D. 2012. *Event processing for business: organizing the real time strategy enterprise*, N.J., Wiley, Hoboken.

NHOP, 1997. Quality and Outcome Indicators for Acute Health Care Services, National Hospital Outcomes Program, Australian Government Publishing Service, Canberra.

NHS, 2011. *National Health Service*. [online] Available at: <http://www.nhs.uk> [Accessed 24 January 2011].

Paterson, G. et al, 2002. Using the XML-Based Clinical Document Architecture for Exchange of Structured Discharge Summaries. *Conference Proceedings of the 35th Annual Hawaii International Conference on System Sciences.* Washington, USA, pp. 1200-1209.

Ralston, M.D. and Coleman, R.M., 2009. Introduction to PACS. In: B.F. Branstetter, ed. *Practical Imaging Informatics: Foundations and Applications for PACS Professionals*. Springer, New York, USA.

Wirsz, N., 2000. Overview of IT-Standards in Healthcare. *In Electromedica*, Vol. 68, No. 1, pp 21-24.

XML, 2011. Extensible Markup Language. [online] Word Wide Web Consortium (W3C). Available at: <http://www.w3c.org/XML>