Analytics Driven Application Development for Healthcare Organizations

Omar Badreddin, Aladdin Baarah, Austin Chamney, Craig Kuziemsky and Liam Peyton
University of Ottawa, 800 King Edward st, Ottawa, Ontario, Canada

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Abstract: In response to governmental and regulatory mandates, Healthcare organizations are increasingly interested in assessing the efficiency of their care processes and services. Traditional information systems for healthcare have focused on capturing administrative details related to services and resource usage on a departmental or healthcare provider basis. The resulting interoperability challenges make it difficult for analytics and performance management reporting to provide a detailed view of care processes. This paper presents a methodology and an analytics application framework that focuses on performance and efficiency. Starting from performance goals, the application framework development is driven by the identified key performance indicators. This methodology addresses interoperability challenges by defining the minimal dataset required for measuring outcomes of a care process. It enables an information system design that focuses on analytics and minimizes maintenance and integration issues. The application framework is developed in the context of a multi-year case study of a clinical information system for palliative care.

1 INTRODUCTION

Performance management is gaining increasing attention in healthcare. An aging population is putting more pressure on healthcare organizations that are already operating at full or near full capacity. Healthcare organizations need to better measure how care processes are achieving quality of care goals and objectives in order to allocate resources to processes that contribute most to their stated objectives.

A further challenge is that many current healthcare services are financially unsustainable. As diagnostics and treatment options (i.e. personalized medicine) extend people's life expectancy it puts further pressure on resource allocation. Moreover, governments want evidence-based healthcare delivery and demand health organizations measure operational efficiency. Hospitals struggle to balance the operational necessities while pursuing regulatory and governmental incentives that reward efficiency.

In an ideal situation, existing healthcare records could be reused to generate performance reports to justify financial expenditures. However, existing healthcare records are collected with one main objective, to support operations by providing records for patients and care providers. This results in health care records that are segmented with each setting responsible for its own patients. Sharing and integration of segmented data is expensive and technically challenging due to different providers and different resources from different organizations, each with their own information systems. Further, health records are subject to strict confidentiality measures making data integration difficult. This is particularly true when the care process involves.

Second, health records are often entered into information systems from paper or voice-dictated notes hours, days, or even weeks after the service has been provided. This results in records that are not available in real-time, and may reflect inaccurate time stamps. Much of healthcare data is still paper based which further adds to the integration challenges. While many healthcare organizations rely on data warehouses that use batch processes to integrate data from various data sources to support reporting requirements, it still often takes weeks for data to be migrated from operational databases in batch processes that populate the data warehouse for consolidated reporting (Bates, 2010).

Because healthcare information systems are mainly focused on capturing administrative details

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related to services and resource usage on a departmental or healthcare provider basis, it results in interoperability challenges that make it difficult for analytics and performance management reporting to provide a holistic view of care processes.

Our work with hospitals over the years to remedy this always focused on refactoring or extending existing systems to support the new performance management requirements. This approach, while feasible, faces key obstacles. First, this approach does not deal with data integration. The development team must integrate disparate data sources and address privacy. Second, the cost of refactoring existing healthcare systems is very high, at times beyond the reach of smaller healthcare institutions.

This paper presents a methodology and an analytics application framework to provide integrated information systems support for managing care processes in terms of their outcomes. The methodology identifies goals and key performance indicators (KPIs) to measure these goals, and then maps the KPIs to care processes. Forms are developed to provide values for the identified KPIs. This analytics application framework addresses interoperability challenges by defining a minimal dataset for reporting outcomes for a care process. It supports system design that focuses on analytics and minimizes integration issues. The framework was developed in the context of a multi-year case study of a clinical information system for palliative care.

This paper is organized as follows. We provide the necessary background in the next section. In section three, we give an overview of the methodology. A case study is presented in section four. We present the application model in section five. Section six presents the analytics application framework. We then present an evaluation of the analytics driven application development approach. A discussion of related work and conclusion follows.

2 BACKGROUND

Performance management is concerned with collecting data to quantify and measure outcomes obtained by organizational processes in order to determine how well they achieve organizational goals and objectives (Pourshahid et al., 2009). A significant challenge in implementing information systems support for performance management of care processes is to understand the relationship between care processes and measured outcomes (Sandra et al., 2011).

Electronic Health Records (EHR) have been advocated as a tool to facilitate patient management, provide performance measurement, and improve quality of care. However, results have been mixed (Bates, 2010), because of significant interoperability challenges that arise in healthcare delivery (Kaplan and Harris-Salamone, 2009), including technical, process and organizational issues (Ash et al., 2004). Research has also shown that EHR often improved administrative requirements, with little improvements to reporting and performance (Greenhalgh et al., 2009).

In previous work (Mouttham et al., 2012), we proposed a methodology for addressing interoperability issues (Kuziemsky et al., 2008) for managing community care of palliative patients in terms of outcomes (Ferris et al., 2002). Phase one (Peyton et al., 2012) made progess in addressing interoperability but adoption was impeded by complex data collection forms that. were not practical for care providers. In phase two of the case study, we used an application model for care process monitoring introduced in (Baarah and Peyton, 2012) to integrate it with a form-based application framework that collects a minimal dataset into an OLAP database (Inmon, 2005) for reporting outcomes. The result is an application framework that is agnostic about operational necessities, and is focused on developing sufficient analytics to provide performance management.

3 DEVELOPMENT METHODOLOGY

Traditionally, record keeping requirements for resource management and other operational activities drive application form development in healthcare organizations. This results in medical forms that are extensive; forms that focus mainly on operations, with little to no regard to performance management requirements. When the time comes for performance reporting, healthcare organizations must aggregate data from multiple sources, some of which may reside outside their healthcare organization and are subject to privacy policies. This process takes days and weeks before such performance reports can be made available (Bates, 2010). For example, to report the number of days patients wait for a procedure, the organization will need information about the original referral, which in many cases occurred outside the boundaries of the concerned healthcare organization.

Our development methodology is driven by performance management requirements. Rather than focus on solving operational requirements, we drive our form development activities by analyzing the objectives of the health care institution for a particular care process, and analyze how such goals are to be measured. The overview of the methodology is illustrated in Figure 1.

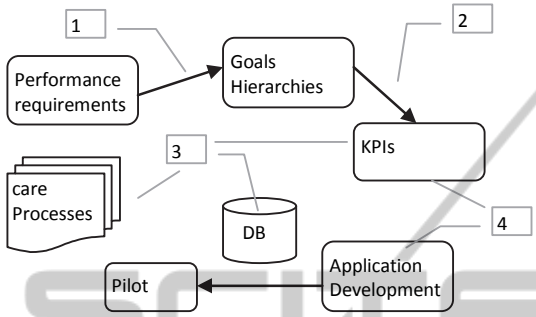

Figure 1: Overview of the methodology.

3.1 Goal Hierarchy

Government and regulatory mandates are a source of performance management requirements. These requirements overlap and are frequently in conflict of each other. Increasing the patient intake will inevitably affect patient wait time negatively. These requirements are modeled and conflicting objectives are explicitly defined in goal models.

The first step in the methodology is to construct goal models (Pourshahid et al., 2009); (Kuziemsky et al., 2010); (Barone et al., 2011) that represent the structure of objectives that the healthcare organization tries to achieve. Examples of such goals include reduce cost, reduce wait time of patients, reduce patient readmission, maximize resources utilization, etc.

Conflicting objectives are not a concern for our methodology. This is because our application will support measuring performance of the care process against all objectives. The healthcare organization can then review the relevant performance reports to determine what actions, if any, they want to take to resolve any conflicts between goals.

3.2 Identifying Key Performance Indicators

The second step in the methodology is to identify how each goal is measured. For example, maximizing resources utilization can be measured by counting the number of nights a bed or a room is empty, or by counting the number of patients a physician has seen over a specified period of time. In the first case, the target might be to achieve zero nights in which a room is empty, and in the second case, the target might be an average of seven patients per working day per physician.

Some regulatory requirements mandate how such performance requirements to be reported upon. For example, a regulatory requirement may mandate that a patient who suffers from symptoms of a heart attack must be seen within 60 minutes, or the average wait time for patients at Emergency department must not exceed 24 hours. In such cases, the care institution has little freedom in deciding which KPIs to collect. In other cases, which is not uncommon, care institution can chose how to measure and report on some performance requirements.

KPIs can be course grained or fine grained. The number of patients the healthcare organization treated in a single day is an example of a coarse grained KPI. The number of minutes a nurse was idle is a fine grained measure. Clearly, find grained KPIs may require additional records collection which will typically result in complex and possibly time consuming forms.

In this step, we work with the hospital teams to decide on the minimal set of required KPIs and use these KPIs to drive the application development. The minimal data set is iteratively refined in close collaboration with domain experts.

3.3 Mapping KPIs to Care Processes

Once the KPIs have been identified, we need to determine what states of the care process they correspond to and what data needs to be collected to compute them. In this step, we perform mappings (usually one to one mappings) between the KPIs, the Database system, and the care process involved.

These mappings are relatively simple. Each KPI corresponds to one database field. These simple mappings ensure that the developed application is agile. This is particularly important since reporting and performance requirements are subject to change.

3.4 Application Development

At this step, forms are designed and integrated into the flow of the care process. The form and a list of look up values for each field in the form need to be accessible by the care practitioner filling in the form. The lookup tables for the form are defined by considering both the needs of clinicians to document what the process they are doing and the design of a

OLAP data model which will store the data and support reporting of the measures. We effectively determine which form, and which role will be responsible for providing values for these KPIs.

Each form field corresponds to one or more KPIs that have been identified in the previous steps. The result is an application that has forms which fields are directly linked to a data base model optimized for reporting. In fact, during the review sessions, form fields that do not contribute to performance reports are removed from the application.

As with typical software development projects, change requests are constant. This methodology enhances change management in two ways. First, tnstitution objectives and goals are less susceptible to change as compared to operations and activities. Second, change in how organizational goals are measured and assessed are easier to handle. This is because our application development maintains tight integration with the identified KPIs.

The developed application is piloted for a period of about 6 months, during which, functional and usability concerns are identified. The piloting makes available some realistic operational data, against which sample performance reports can be generated. Once the pilot project is completed, the application is put on production servers, and ownership is transferred to the hosting institution.

Before we introduce the application model in section five, we present the case study next. The case study illustrates the proposed methodology using concrete goals, KPIs, and forms. This aids in the presentation of the application model.

4 CASE STUDY

We have applied this methodology in the development of a form-based analytics application for a palliative care organization in Ontario. The Palliative Information System (PAL-IS) is intended to support a palliative care program that provides consultations by an expert team of specialists for a registry of palliative care patients. The system was developed in two phases.

In phase 1, a web application was developed, accessible by laptops over the Internet to capture consultation data. The application was found to be impractical to use in the field because of the huge data entry burden. On average, 50 fields were required per form. Many of them were complex and most involved duplicate data entry into other systems. A data entry clerk was hired to fill in forms based on transcripts of dictated notes. Nonetheless, the application was considered a success because it provided reports that measured quality of care to justify program funding and meet accreditation and regulatory requirements.

The outcome of phase 1 motivated us to rethink our development methodology. We observed that healthcare favored solutions that brought little to no change to their day to day activities. Later in the development lifecycle, adoption was increased and training needs were minimized, partly because care providers did not need to adapt their activities. We were also motivated by the fact that, despite the forms being overly complex, healthcare organization staff was determined to adopt the system. Their motivation stemmed from their desire to see the performance reports that the system generated periodically and on demand.

In phase 2, PAL-IS was reinvented as a form-based analytics application that focuses on maximizing the value of the performance management provided while minimizing the data entry burden. This was particularly attractive for those physicians who have started using smartphones or tablets. The first step in designing the application was to document and analyze the goals of the program and define how outcomes would be measured. Domain experts from the healthcare organization were the main source for soliciting and specifying the goal model. We have used their existing documentation and review sessions to validate our models. The final goal model was verified with healthcare organization staff and with the palliative care program managers. Listing 1 illustrates a sample goal model for wait times.

Goal: Wait Time
Description: "This goal ensures that the average wait times from referral to schedule an appointment and average time to respond to alerts triggered by the palliative patients are minimized"
Metrics: Average Wait_Triage Time, Average Wait_FollowUp Time

Listing 1: Sample Goal model.

The listing shows a goal for Wait Times. The goal ensures that the palliative care program is responsive in a timely manner to referrals and alerts.

The second step is to identify the KPIs to measure each goal. The main source of the KPIs was reporting requirements and accreditation specifications of the palliative care program. The program director and team managers contributed to the identification of the KPIs. The two KPIs for the goal from listing 1 is presented in Listing 2.

Consider for example the metric

Average_Wait_Time, which is the amount of time the patient was waiting for Triage. This is calculated to be the time from referral to an appointment (see Figure 3). The target for this measure is a value less than 7 days. The KPIs also specifies which alerts to fire when the target is not achieved.

Metric: Average Wait_Triage Time
Description: "This metric measure the average time the palliative patients wait once they are referred to the palliative care program until a scheduled appointment is booked"
Computation: AVERAGE STATE: WAIT_TRIAGE. duration Over Period of Time
State: WAIT_TRIAGE
Events: Referral
Target: <7 days
Alert: WAIT_TRIAGE_WARNING, WAIT_TRIAGE_UNACCEPTABLE
Metric: Average Wait_FollowUp Time
Description: "This metric measure the average time the palliative patients wait when abnormal condition occurred until a consult occurs"
Computation: AVERAGE STATE: WAIT_FOLLOWUP. duration Over Period of Time
State: WAIT_FOLLOWUP
Events:
Status:
Target: <=4hours
Alert: WAIT_FOLLOWUP_WARNING, WAIT_FOLLOWUP_UNACCEPTABLE

Listing 2: Sample KPIs.

Next, we identify at which step of the care process these measures are to be collected. We refer to the application model of the process to indicate where in the process to collect measures for these KPIs. The model is explained in detail, in the next section. In this step, we effectively identify the minimal dataset to be collected to provide operational measures for the identified KPIs.

The final step is to implement a forms-based application for care process analytics that links a simple user interface for forms with a data base model optimized for reporting outcomes. The palliative team has collaborated closely with us to design the forms and perform user testing of the system.

The forms were designed so that they can be completed on a mobile device, or a laptop computer. In fact, one of the guidelines we followed was to make sure that all fields to be viewable on a single screen. This is to minimize the need for forward and backward navigation. We achieved this by using multiple drop-down menus whose values are dependent on other fields in the form. For example, if the patient under examination is at home, the rest of the form fields eliminate questions or fields that are related to patients that are in the healthcare organization.

Each report had links to where the data is originating from. One or more form fields contribute to each data point in the report. Form fields that had no report contribution were removed.

5 APPLICATION MODEL

The application model defines goals in terms of the metrics which are reported to measure outcomes. Those metrics are mapped to a simple state transition diagram which identifies the key patient states and events in the care process for which the data that must be collected. Forms are defined for each event to collect this required data.

Figure 2 maps goals to metrics to forms. For each metric, the form(s) that collect data for the metric is shown in parentheses (e.g. "Referral" is the form used to count "# of Patients Cancer").

The first set of goals ("Care") is related to understanding the quality and coverage of care provided. To ensure coverage of the patient population ("Demographics"), a "Referral" form captures the data for "# of Patients Cancer" and "Non Cancer" (with drill down into diagnosis, gender, and age). To ensure "Wait Time" is minimized, the "Average Wait_Triage" time (from "Referral" to "Appointment") is measured as well as "Average Wait_Followup Time" taken to respond to alerts (from "Alert" to "Consult"). Finally, "Outcomes" are measured to ensure "# of Alerts" is minimized (patients should be stabilized) and to track the number of unnecessary interventions during a patient's last days ("Decease" form).

The second set of goals is used to measure how effective the program is in promoting palliative care to facilities and physicians so the number of referrals by physician and facility is captured. As well, the "# of Consults With Resident Present" is tracked ("Consult" form).

Figure 3 illustrates the state transition diagram that identifies the key patient states for the palliative care process and identifies when forms are used to collect data. The process begins with a "Referral" form from a physician or facility. Then, an "Appointment" form schedules a consult. If the patient's condition is stable, then repeated a "Consult" form is followed by an "Appointment" form for the next regularly scheduled consult until

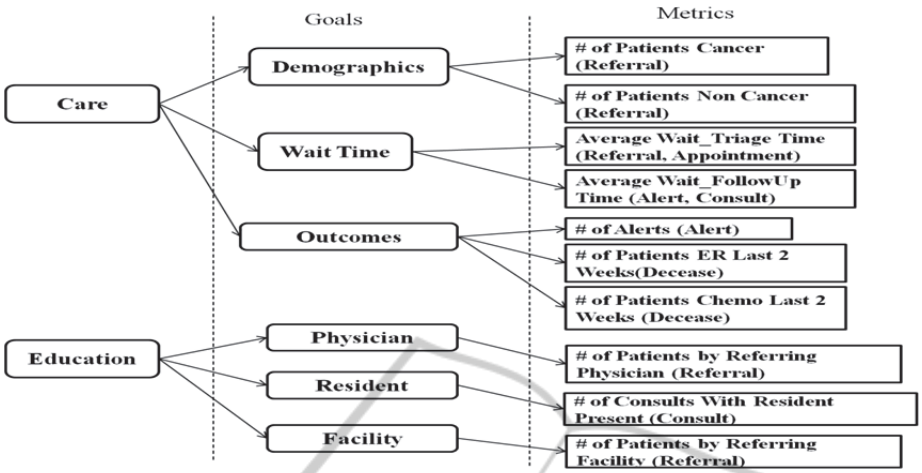

Figure 2: Performance management of palliative care goals based on outcomes.

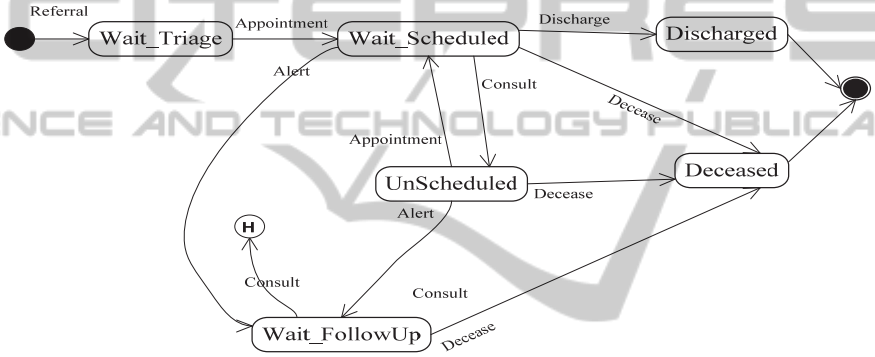

Figure 3: Palliative care process state.

there is either a "Decease" form or a "Discharge" form (if no longer considered terminally ill). But if something goes wrong, an "Alert" form captures the issue and the patient waits for a follow up consultation (recorded by a "Consult" form). After the follow up, the patient returns to whatever state they were in when the alert occurred (Wait_Scheduled or Unscheduled).

6 EVALUATION

Table 1 below summarizes the advantages of an information system design based on our analytics driven application development over the customized web application based on a complete Electronic Health Record (EHR) that was created in Phase 1. First, the methodology used has greatly reduced the complexity of PAL-IS. In Phase 1, any change to the system required deep knowledge of the entire application logic and the particular way forms and data were combined. Now, an HTML designer can optimize the look of a form for usability based on user feedback and then make a simple call to one of the API calls to link it to lookup tables and queries defined in the database. The core middleware logic is application independent and off the shelf. The application is available on any device and shows only the reports or forms specific to the user.

Finally, the application model enabled us to identify the minimal data set needed to measure performance. This greatly reduced the number of fields and thus reduced the data entry effort. It also ensured that goals were directly linked to reports and data collection forms. Building the application model also brought us in contact with all stakeholders of the organization ensuring full information support for all roles, not just the front line care providers that were addressed in Phase 1.

7 RELATED WORK

The use of goal models to support Health Care

Table 1: Evaluation of phase 2 analytics application framework.

Criteria	Phase 1 (Complete EHR)	Phase 2 (Analytics Application)
System Maintenance Effort	Forms, data mixed. Customized system. Significant custom support	Separate but linked forms & data. Off the shelf system. Low maintenance support.
Data Entry Effort	~ 50 fields per form. Many complex fields.	~ 10 simple fields per form.
Ease of deployment	Desktop or laptop.	Any device (phone, tablet, laptop, PC…).
Usability	One complex interface for all users. Reporting disconnected from forms.	Individualized interfaces shows only relevant forms and reports (Linked).
Organizational Goals	Information system disconnected from goals.	Application model links goals to reports to forms.
Organizational Roles	Focused on front line care providers.	All roles by forms / reports linked to goals.

analytics has been investigated in a number of studies (Ferrand, 2010); (Ghanavati et al., 2010); (Barone et al., 2010); (Barone et al., 2011). These approaches typically utilize a goal modeling notations, such as GRL and i*, and reports compliance and performance against those models. Kuziemsky et al., (2010) proposes a five step methodology to help identify the impact of health care informatics on the organization goals, such as quality of care. Ferrad (2010) applied an analytics framework to reduce the number of adverse events in healthcare. Their approach quantifies the source of adverse events using goal models and metrics. Goal models are also used to assess the effectiveness of business strategies while ensuring that medical regulations and guidelines are respected (Ghanavati et al., 2010).

The gap between operational details and high level organizational objectives have been identified and discussed in a number of industries (Barone et al., 2011) as well as in healthcare (Behnam and Badreddin, 2013). A number of approaches have been suggested to bridge this gap, including the use of Business Intelligence Models (Barone et al., 2010) to represent the business view, and Conceptual Integration Model to represent the data collection and reporting view.

8 DISCUSSION

Performance management and compliance are increasingly playing a significant role in many industries. In our previous work, we have developed a methodology that enables organization translate their regulatory documents into performance models to support business analytics reports (Badreddin et al., 2013). This work expanded earlier work by looking at the issue that regulations are drafted with little regard to how the compliance of regulations will be measured. Medical forms are designed and implemented without sufficient understanding of analytics and compliance requirements. This can be attributed to the fact that software development is by and large driven by functional requirements for operational necessities.

The key contribution of this paper is a new paradigm for application development for healthcare institutions. This paradigm is based on performance driven application development where each field in the medical form is driven by a performance management requirement, rather than operational requirements. This results in significantly simpler forms that can be completed on smartphones or tablets as part of the care giving activity. It reduces the need for integrating disparate data sources for performance management, and is significantly more agile in the face of change. More importantly, this approach ensures that the required data for analytics reports are readily available and accessible.

Our experiences indicate that operations staff is a key source in requirement specifications, but it is the management team that is more concerned with performance management. That results in patient records that do not support business analytics. Our work also showed that focusing primarily on the analytics and compliance requirements can result in simple systems that are easy to use, and satisfy enough functional requirements to ensure adoption.

While the trend in software engineering is towards big data; symbolized in massive data collection, storage, and analysis, this approach can result in excessive overhead and costs. involved. Healthcare is a domain where small data can at least as successful. Less data means fewer patients' privacy concerns. In this paper, we have demonstrated that small data should also be considered when applicable.

9 CONCLUSIONS

We have presented a novel methodology and application model. In this approach, the development of applications are driven by performance reporting requirements. The approach starts by identifying the healthcare organization goals and the key performance indicators to measure those goals. Fields in the application forms are directly related to these KPIs. This results in forms that satisfy the analytics requirements, while keeping the form as simple as possible. Out work has resulted in two major contributions for the palliative care team. First, it provides information system support that delivers clear insight for all roles in the organization through reports on palliative care process delivery. Second, it has reduced the data entry burden to the point where care providers can use their phones for dictation and then tap on a few fields to provide essential data for performance management.

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