A Business Process Management Methodology for Care Process Monitoring

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Thesis

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Abstract

Reporting patient states is considered an important part of care process monitoring in the hospital to efficiently monitor how well the health care system is performing. Monitoring care processes with enough fine-grained detail to precisely track wait states and service states in order to reduce wait times and improve their quality of care are challenging. Business Process Management (BPM) technology is used to bring care processes online, but there is no clear methodology on how to integrate performance management into BPM tools in a systematic matter that is effective, and minimizes complications and development costs.

This thesis proposes a BPM methodology for care process monitoring that structures how to integrate performance monitoring into BPM. The major contribution of this thesis includes a generic methodology for care processes monitoring that describes how to structure and instrument a business process model for systematic care process monitoring which includes support for handoff points between organizations where many wait-time bottlenecks occur. It also includes a prototype implementation based on an existing case study based on a real cardiology care process from an Ontario hospital. Our results are evaluated using three different prototypes based on this same care process. The research methodology for the thesis is based on Design-Science research.

Acknowledgements

First and foremost I would like to thank the Almighty God for His guidance and protection throughout my studies.

I also would like to express my sincere gratitude to my dear supervisor, Prof. Liam Peyton, for allowing me to pursue this tremendous opportunity, for the continuous support, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing this thesis.

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List of Acronyms

Acronym	Definition
ACS	Acute Coronary Syndrome
BAM	Business Activity Monitoring
BI	Business Intelligence
BP	Business Process
BPD	Business Process Definition
BPM	Business Process Management
BPEL	Business Process Execution Language
BPML	Business Process Modeling Language
BPMN	Business Process Model and Notations
CCL	Cardiac Catheterization Lab
CEP	Complex Event Processing
CPM	Care Process Management
CPMA	Care Process Monitoring Application
CW	Cardiology Ward
DAO	Data Access Object
DB	Database
ECG	Electrocardiogram
ED	Emergency Department
EHR	Electronic Health Records
ETL	Extract Transform and Load
FM	Framework Manager

IS	Information System
KPI	Key Performance Indicators
MIE	Message Intermediate Event
OLAP	Online Analytical Processing
PCI	Percutaneous Coronary Intervention
PDW	Performance Data Warehouse
RTLS	Real Time Location System
SME	State Monitoring Engine
SOA	Service Oriented Architecture
SQL	Structured Query Language
TP	Tracking Point
UCA	Under Cover Agent
XML	eXtensible Mark-up Language

Chapter 1. Introduction

1.1. Problem Statement

In recent years, there has been pressure on health organizations in Canada, and other countries, to effectively and efficiently improve care process monitoring capabilities to support operational decisions, improve delivery of care and reduce wait times in emergency rooms to ensure timely delivery of service. Since the health care processes are complex, we focused only on improving the software technology used for care process monitoring.

The ministry of health and long-term care for Ontario announced that reducing wait times in emergency rooms is its top health care priority. As a result, reporting patient wait times in ER departments is considered as an important part to be able to monitor how well the health care system is improving emergency room performance (Ontario Wait Times, 2015). Wait times negatively affect patient safety and the quality of health care delivery (Pizer & Prentice, 2011) .

The traditional approach to performance monitoring in many hospitals depends on using data warehouses to integrate data from different operational systems from different departments in the hospital. The data from operational systems are loaded into the data warehouse in batch through an Extract Transform and Load (ETL) process. Due to the batch processing, only historical reports on performance measures are obtained from these data warehouses. However, these do not have enough detail and cannot be delivered in real-time. The batch processing of data can take days or even weeks to generate the required health care analytics and evaluation performance (Chieu & Zeng, 2008).

Hospitals have started to use BPM technology, but it is still relatively new to adapt to clinical care, never mind integrating care performance monitoring.

Recent work has started to look at how to integrate BPM with Real-Time Location System (RTLS) and Complex Event Processing (CEP) (Baffoe, 2013) (Tchemeube, 2013) (Baarah A. H., 2013), but this is preliminary research. They build a care performance monitoring application and dashboard external to the BPM system that integrates data from different sources in real-time.

1.2. Thesis Motivation and Contributions

The main motivation behind this study is that BPM was designed as an integration technology between the business architecture layer of an organization and its Service Oriented Architecture (SOA). Besides, it should be possible to define an approach, and develop techniques to integrate and manage data for care performance monitoring within a single BPM framework.

Moreover, there should be a development methodology for care process monitoring applications that are integrated into executable business process models in a structured and layered manner to provide a reporting framework that spans health care organizational boundaries.

The main contributions of this thesis are:

1) A generic methodology for creating online care processes monitoring that describes how to structure and instrument a BP model for systematic care process monitoring.

    a. A layered model that integrates horizontal and vertical swim lanes with tracking points for identifying where to monitor care process states.
    b. A technique of integrating event messages with a flexible triggering mechanism to address processes that span health care organizational boundaries.

2) A case study of care process monitoring for cardiac care that was used to evaluate our thesis against related work.

1.3. Thesis Methodology and Organization

Design science research methodology has been used quite regularly in Computer Science, Software Engineering, and Information Systems research (Iivari, 2007). We have followed this methodology by focusing on the three research cycles as shown in Figure 1below.

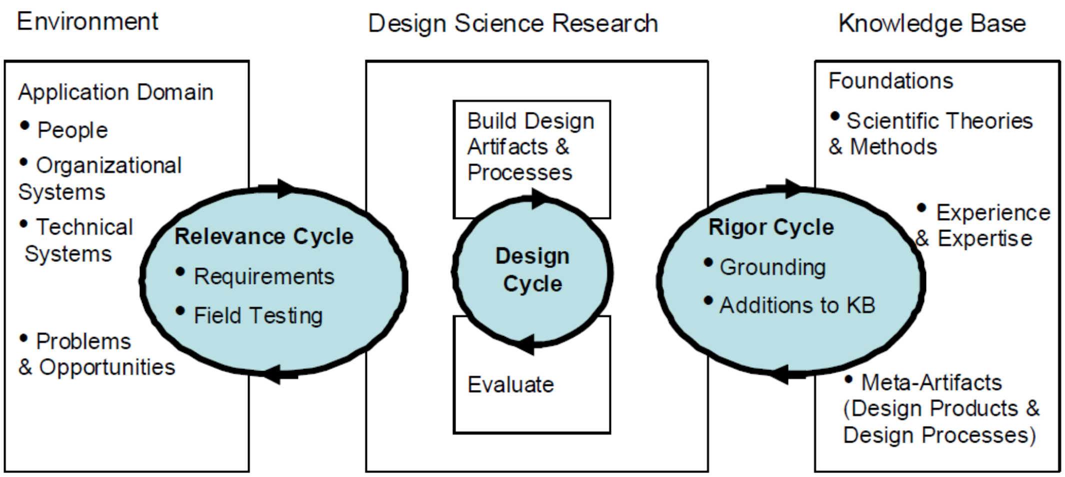


Figure 1 Design Science Research Cycles (Hevner, 2007)

Below are the steps we followed in the thesis methodology:

1. Business process identification based on existing literature and talking with health experts (Relevance Cycle):
    a. Comparative study of actual real-time care process monitoring.
    b. Identify the problems and opportunities in the care process.
    c. Identify the most important evaluation criteria to analyze and measure care process.
    d. Perform gap analysis between existing and proposed solutions to address the problem and evaluation criteria.
2. Redesign process model and prototypes based on existing technologies in the lab.
3. Application of prototype to ACS care process case study.
4. Evaluation of prototype based on criteria drawn from the gap analysis based on the literature survey and discussion with experts (Design Cycle).

5. A comparative study with related work in care process management. (Rigor Cycle).
6. Conclusions and future work.

This thesis document is organized as follows:

- Chapter 1 presents an introduction, together with the context and the scope of the research.
- Chapter 2 provides relevant background information to our research and a review of existing related works. The technologies and tools used in these related works are analyzed and compared.
- Chapter 3 is the core of this thesis. It elaborates the research problem, our research model, and evaluation criteria.
- Chapter 4 presents our case studies.
- Chapter 5 uses our case studies and evaluation criteria to evaluate our research and identify the strengths and limitations.
- Chapter 6 summarizes conclusions drawn from our research and discusses future work.

Chapter 2. Background

In this chapter, we first introduce and define the key concepts that are relevant to the development of this thesis. Then, a more detailed background is given on the most important areas related to care process monitoring. Finally, in the related works section, we identify and explain other approaches in the literature similar to our thesis. These are used for comparison in the evaluation of our thesis in Chapter 5.

2.1. Concepts

2.1.1 Business Intelligence

Business intelligence systems gather historical and business data with advanced analytical tools to present valuable and competitive data to support decision makers. Moss and Atre clearly stated that:" BI is neither a product nor a system" (Moss & Atre, 2003). BI defined as an umbrella that combines architecture, applications, and databases that "enables the real-time, interactive access, analysis, and manipulation of information, which provides the business community with easy access to business data" (Olson & Kesharwani, 2010).

The main goal for BI is to answer questions, solve a business problem and predict customer behavior using advanced analytical information system techniques (Trkman, McCormack, Valadares de Oliveira, & Ladeira, 2010).

2.1.1 Complex Event Processing (CEP)

Complex event processing is defined as "an approach that identifies data and application traffic as events of importance, correlates these events to reveal predefined patterns, and reacts to them by generating actions to systems, people and devices" by (Adi, 2006) and stated that CEP is about getting operational data in real time (Adi, 2006). (Baffoe, 2013) built a component architecture called State Monitoring Engine (SME) that is an example of the use of CEP for care process monitoring.

The main goal of CEP is to process complex series of events from different distributed information systems and correlate these events to produce other meaningful complex events (Kang & Han, 2008) (Luckham, 2002), it can be used spot real-time threats (Adi, 2006). For example, CEP is used in fraud detection by reporting when two credit card transactions are performed within an hour at a distance greater than 300 km (Adi, 2006).

2.1.2 Message Broker

A Message broker is a hub architectural approach responsible for routing events from different system sources in a variety of formats into a single stream of events in a homogeneous format (Baarah, Mouttham, & Peyton, 2011). IBM developed a powerful Websphere Message Broker (Davies, Cowen, Giddings, & Parker, 2005).

2.1.3 Web Services

Web services are defined as a "new web-based standards to create communication platform allowing older applications to communicate with newer applications" (Laudon & Laudon, 2006). The W3C is Web Services Architecture Working Group defines web services as "a software system designed to support interoperable machine-to-machine interaction over a network" (Booth, et al., 2004).

The main benefit of web services is allowing applications to communicate and share information with one another without rewriting applications or distributing older legacy systems (Laudon & Laudon, 2006) (Curbera, Duftler, Khalaf, Nagy, Mukhi, & Weerawarana, 2002). Moreover, web services are an important implementation for service-oriented architecture because it provides a "distributed computing approach integrating extremely heterogeneous applications over the internet" (Endrei, et al., 2004).

2.1.4 Service Oriented Architecture

Service-oriented architecture clearly described as an "approach for building distributed systems that deliver application functionality as services to either end-user application or other services" (Endrei, et al., 2004) to achieve business goals. Also, SOA refers to the "use of Web services in a firm to achieve integration among disparate applications and platforms" (Laudon & Laudon, 2006).

The main goal of using SOA is for cost reduction and leveraging existing assets, since redeveloping all the previous application and adopting a new application systems is not necessary (Laudon & Laudon, 2006).In other words, an organization can continue to benefit from existing systems instead of having to redevelop from scratch (Endrei, et al., 2004). Moreover, SOA reduces the implementation complexity by "providing a service specification in front of existing resources and assets built on disparate systems, integration becomes more manageable since complexities are isolated" (Endrei, et al., 2004).

2.2. Business Process Management

The terms process, business process, business process modeling, and business process management are seemingly self-explanatory enough that they are used most of the time without an explicit definition.

A business process is defined as "a set of linked activities that take an input and transform it to create an output, and it should add value to the input and create an output that is more useful and effective to the recipient" (Johansson , McHugh, Pendlebury , & Wheeler , 1994).

BPM is defined as "the art and science of overseeing how work is performed in an organization to ensure consistent outcomes and to take advantage of improvement opportunities" (Dumas, La Rosa, Mendling, & Reijers, 2013). The concepts, methods and techniques established in BPM used to support the design, execution, management and analysis of business processes by using specific tools and methods (Weske, 2012) (Pourshahid, et al., 2009).

Typically, BPM lifecycle is shown in Figure 2 consists of phases that are related to each other and helps to understand the role of technology and concepts in BPM (Dumas, La Rosa, Mendling, & Reijers, 2013) .

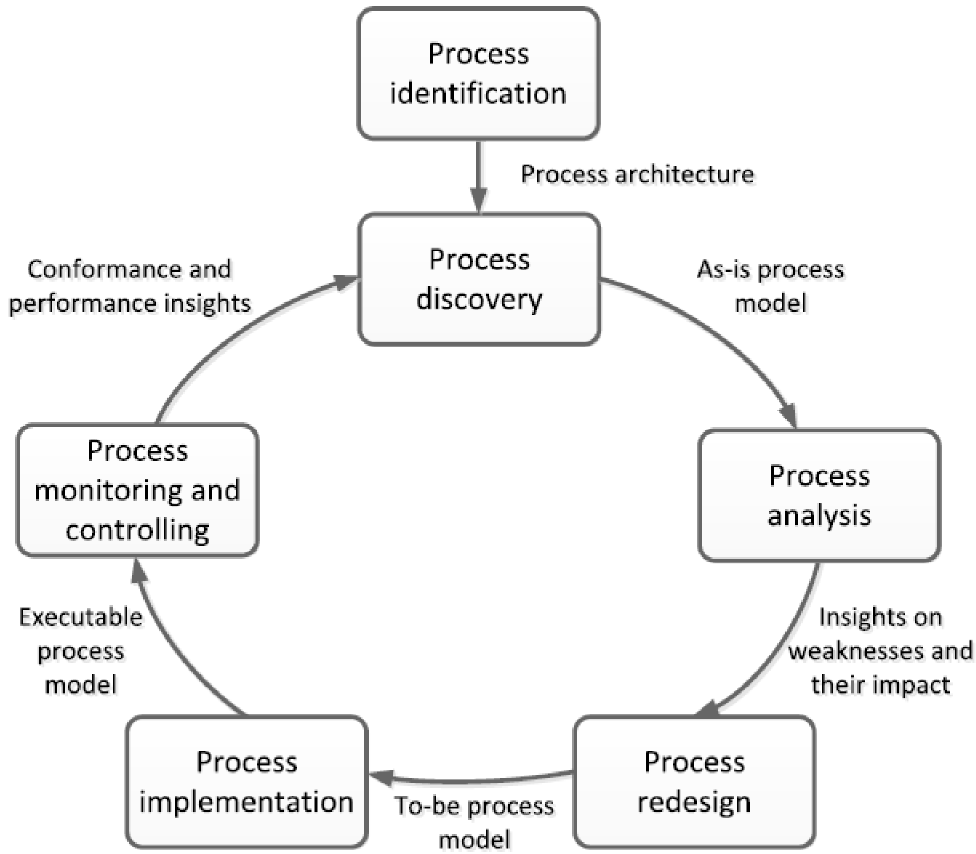


Figure 2 BPM Lifecycle (Dumas, La Rosa, Mendling, & Reijers, 2013)

The BPM life cycle organized over 6 major phases: starting by process identification the goal of this phase is identifying the business problem and creating a new or updated process architecture that provide an overview of the overall business process.

In process discovery also called as-is process modeling documentation for the business process is defined. Then, in process analysis identify and document the limitation of the as-is process model and provide insights on the weakness and their impacts.

In process redesign, the main goal is to identify the critical changes that can improve the process and cope with the business requirements and goals then apply these changes to a new process model called to-be process model. Then, in the process implementation, an executable process model is created by performing and organizing the critical changes from the as-is process model to to-be process model. Finally, in process monitoring and controlling focus on monitoring the redesigned process and determine how well is the process performing in terms of performance objectives and measures.

In our research will be focusing on how to implement care process monitoring within BPM following our generic methodology specifically at the process monitoring and controlling phase.

2.2.1 Business Activity Monitoring (BAM)

From a business perspective, monitoring process instances can be done passively using pull technology or actively by using push technology (Muehlen & Rosemann, 2000).

Active monitoring is done using Business activity monitoring which is used to align the process with its overall business objectives and ensure the quality of currently running process instances, where the performance metrics like their processing time and calculating the Key Performance Indicators (KPIs) on the execution of processes is provided online using charts and dashboards dynamically (Dumas, La Rosa, Mendling, &

Reijers, 2013) (Koster, May 2009).In passive monitoring, a request for information about running process an instance is required (Koster, May 2009) in another word you can request data to monitor this instance.

According to Gartner group BAM "describes the processes and technologies that enhance situation awareness and enable analysis of critical business performance indicators based on real time data" (Gartner, 2016).

2.2.2 BPM Technology

The technologies of BPM we categorize under 3 different aspects as the following:

- **Business process modeling and design language -** such as Business Process Model and Notations (BPMN) which is designed to allow process models to be understandable and readable by business people with a well-known graphical modeling notations (OWen & Raj, 2003).

- **Integration technologies -** such as adapters and data transformation for example such as Business Process Execution Language (BPEL) is an XML-based language designed to enable task-sharing for distributed computing or grid computing environment even across multiple organization using a combination of web services (Alves, et al., 2007) . Another language used for integration is Business Process Modeling Language (BPML) which is a meta-language for the modeling of business processes such as an Executable Markup Language (XML) that is a meta-language for the modeling of business data developed by the Business Process Management Initiatives (BPMI) (Barry, 2016).

- **Business activity monitoring -** describe above in Section 2.2.1.

Several vendors have sold BPM Suites/Systems (BPMs) for many years. TABLE 1 briefly presents three different vendors of BPM and show how they differ in terms of the technologies in BPM system.

For instance, in terms of the process modeling, the three vendors used the same process modeling language BPMN. On the other hand, in terms of the integration technologies with other systems, they were different. IBM BPM used BPEL and Cordys BPM used BPML while Oracle BPM did not expose it and kept it proprietary. In terms of supporting BAM both IBM and Cordys BPM system support active and passive BAM while Oracle supports only passive BAM according to (Koster, May 2009).

TABLE 1: BPM VENDORS TECHNOLOGIES

Technologies	IBM BPM	Cordys BPM	Oracle BPM
Process modeling language	BPMN	BPMN	BPMN
Integration technology	BPEL	BPML	Proprietary
Business activity monitoring	Active & Passive	Active & Passive	Only Passive

2.2.3 IBM BPM Monitoring Support

IBM BPM supports the concept of Tracking Intermediate Events or Tracking Points (TP) that can be added to a business process model to generate a data point used in performance reporting on process instances. All such data points are logged to IBM BPM PDW when reached during a process instance.

Tracking groups are used to explicitly control TP (®IBM Knowledge Center). The main advantage of tracking groups is to group data for analysis. For example, you can track patient status information in independent tracking groups for the desired report. Another advantage is the ability to track process variables across multiple business processes. For example, if an organization includes several locations and handoffs between departments, creating a tracking group gives the ability to capture the business data for all these processes.

PDW databases track process instances performance data and contain historical data about the outcomes of completed process instances and can be used for reporting through the IBM BPM Process Portal or other third party tools to examine how processes performed in the past. (Kolban, Kolban's Book on IBM Business Process Management, 2014).

IBM BPM Process Portal is a browser-based environment can be referred as an active BAM tool. The main benefit is to visualize process performance in near real time on built-in dashboards and to work on an assigned business processes and collaborate with others to complete the work. (Kolban, Kolban's Book on IBM Business Process Management, 2014)

2.3. Care Process Monitoring

According to (Baarah A. H., 2013) the main goal of care process monitoring is to provide performance reports to measure if the care process metrics are achieved or not. For example, monitoring the patient care process wait times and service times in the emergency department is important. As well, the ability to display the monitoring results in reports is important in order to reduce wait and service times to increase quality of care. In this case, care process monitoring is capturing the care process metrics in terms of patient states to measure the process performance and display the monitoring results including service and wait times of the care process through reports to be able to identify where the bottlenecks are and increase the quality of care and support decision makers.

2.3.1 Electronic Health Records

EHR system is official digitalized patient health information shared among multiple healthcare providers at a hospital for patient health care status monitoring. The main goal of an EHR is to increase the quality of care and reduce wait times and cost (eHealth Ontario, 2014).

A survey conducted by (L. Edsall & G. Adler,, 2009), acquire an insight on how physicians rate many of the best-known EHRs. The survey final question asked 2,012 family physicians if they agreed or disagreed with the following statement "*I am highly satisfied with this EHR system.*" Remarkably, nearly 50% of all respondents said that they would not agree.

In addition, the lack of usability has been a major cause of dissatisfaction with EHR systems. “It has been estimated that one in every three EHR adoptions fail, with poor usability likely a major contributing factor” (BERTMAN & SKOLNIK, 2010).

2.3.2 Real Time Location Systems (RTLS)

RTLS is a tracking application used to support timely operational decision making (Zang & Wu, 2010). RTLS has been defined as “local systems for the identification and tracking of the location of assets and/or persons in real or near-real-time” by (Boulos & Berry, 2012).

RTLS applications are used in the healthcare system to track personnel, patients, and assets during a medical emergency. The way most of RTLS technology implemented is by using unique wireless tags that transmit data to the reader and holds data including an identification number attached to each patient. It can enable personnel to monitor the handoffs between different departments. For example, when transferring a patient from ED to CW department the reader will sense the tag and wake up and decodes the data then transmits the data to a host system which process the data from the tag that has been transmitted by the reader over wireless connections. Thus, the hospital management staff can determine how many patients are located where in order to allocate staff and determine where the bottlenecks are in the hospital (Stahl, Drew, Leone, & Crowley, 2011) (Boulos & Berry, 2012).

An extensive evaluation study of RTLS in 23 hospitals completed by (Fisher & Monahanb, 2012) discovered that the material environment of hospitals can impede the effective deployment of RTLS due to the non-standardized design of buildings and the complex flow of people and equipment which can present problems for accurately triangulating tags when signal strength is affected.

According to (Gaffney, 2012) the number of RTLS tags per network cell is an important factor. Depending on the application (asset tracking in a warehouse or patient tracking in a hospital) the number of tags per network cell will vary. The larger number of tags needed the more will be challenging to the RTLS systems.

Moreover, according to (Gaffney, 2012) the most significant challenge to any RTLS device is the channel environment. For instance, concrete walls and metallic structures reduce the degree of accuracy and functionality in the estimate of the location.

2.4. Related Works

2.4.1 Integrated Approach

An integrated care process monitoring framework defined by (Baarah A. H., 2013) as shown in Figure 3 and developed by (Tchemeube, 2013), and (Baffoe, 2013) collects location data through RTLS combined with process data from BPM system and integrated with SME for inferring and managing key patient states. They do care process monitoring using integrated approach to BPM, RTLS, and SME which just treats BPM as a source of events.

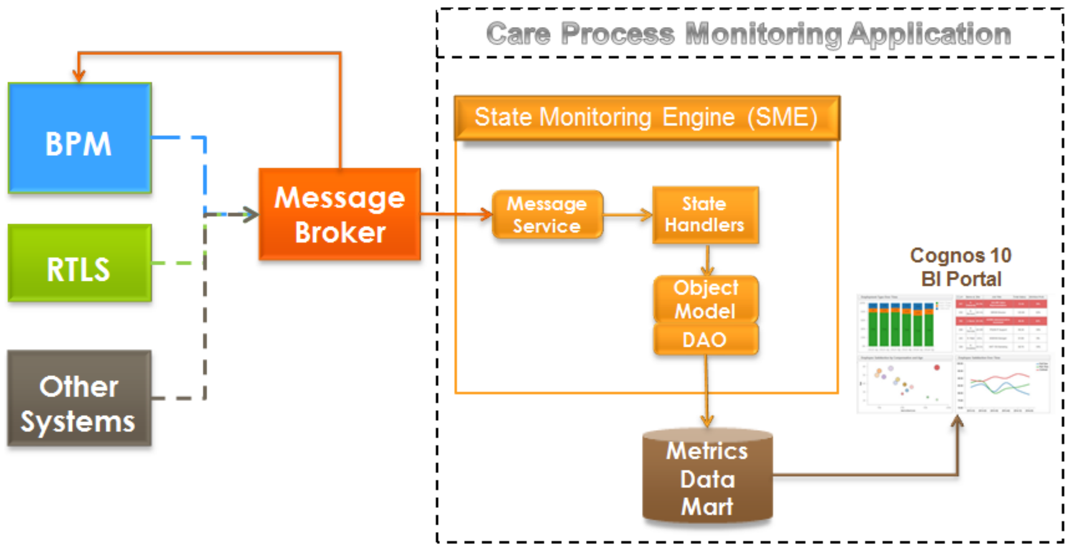


Figure 3 Integrated Care Process Monitoring Architecture (Baarah A. H., 2013)

The key point of the integrated methodology is to separate performance monitoring from the BPM and have the performance monitoring application built outside the BPM. In (Baarah A. H., 2013) their methodology has a separate performance monitoring application model built completely unrelated to the business process model that defines the events that are coming from everywhere and depends on the business process delivering special events to it.

Since the performance monitoring is external and integrates data from anywhere it enables very sophisticated and fine-tuned monitoring. However, there is complexity in the sheer amount of technology, and by separating care performance model from business process model you lose all the benefit that were provided by explicitly modeling and supporting the care process in the business process model environment.

2.4.2 Standalone BPM

IBM BPM is a rich set of tools for BPM and has a general methodology for developing business processes. A care process management project developed by (Dickman, Gilmore, & Schume, 2012) implemented care process management that uses best practices for business process management to improve clinical quality without changing care process or displacing the role of health providers via a standard BPM methodology shown in Figure 4 defined by (Dyer, et al., Scaling BPM Adoption From Project to Program with IBM Business Process Manager, March 2012)

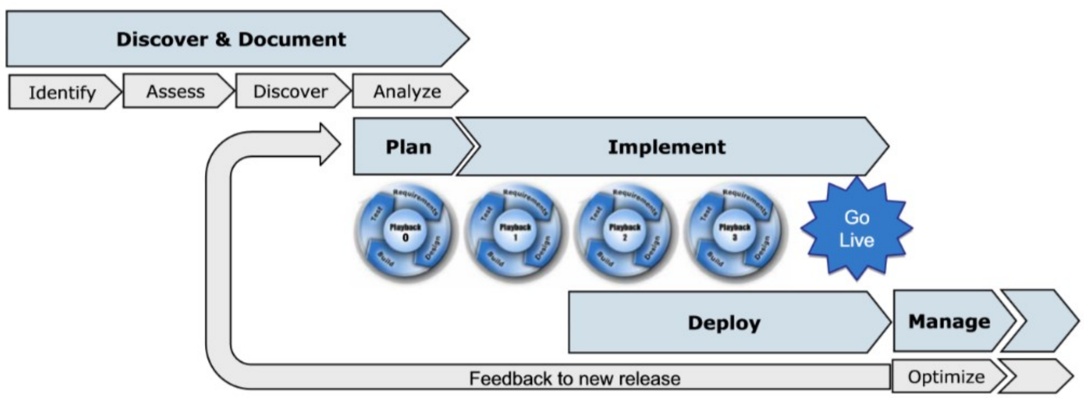


Figure 4 Standalone BPM Methodology (Dyer, et al.,2012)

This does provide feedback in real-time, and it spans departments, but it does not provide guidance on how to integrate performance monitoring with operational systems and get the level of detail you need for service times and wait times.There are no methodologies for developing BPM applications that give clear guidance on performance monitoring.

Chapter 3. Generic Methodology for Care Process Monitoring

In this chapter, we present our generic methodology for care process monitoring which serves as a template that can be followed to create, implement and monitor any care process application. In Section 3.1, we provide a detailed description of the problem and a gap analysis. In Section 3.2 we define the criteria that will be used to evaluate our solution. In Section 3.3 we provide an overview of our methodology. From Section 3.4 to Section 3.8 we describe each phase of our methodology.

3.1. Problem Description

Monitoring care processes with enough fine-grained detail to precisely track wait and service states to reduce wait times and improve the quality of care are challenging, especially if one wants to minimize the extra burden of human input to provide the data. Since health care processes are complex and skipping any care process step may compromise care, we focus only on improving the software technology used for care process monitoring. In particular, we focus on simplifying the complexity of the software implementation. Figure 5, illustrates the problem and the relevant technologies.

Typically, the EHR does not have enough data and is lacking precise timestamps for such a monitoring. Often, there is additional low-level data from other systems that are not captured in the EHR. This can be captured and integrated with EHR data in conjunction with data warehouse reporting in order to do performance monitoring. However, the data warehouse does not allow you to process and correlate the data quickly enough to track wait and service states in real-time as the data is often integrated days after the fact.

As BPM technology is used to bring care processes online, there is the potential that a business process management system can measure operational care processes while they are taking place. It can integrate data from different departments and different systems in real-time as care processes are taking place.

However, there is no clear methodology on how to integrate performance management into BPM tools in a systematic matter. BPM tools have built-in support for process performance monitoring, but traditionally performance monitoring has been defined on the data in a data warehouse.

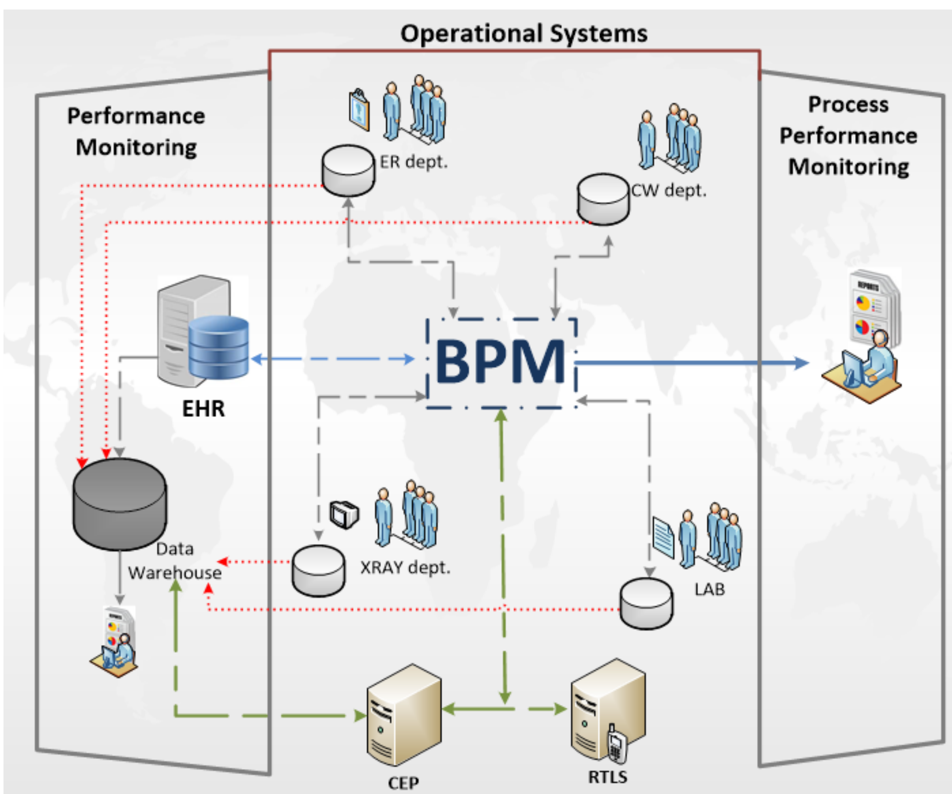


Figure 5 Problem Description

As shown in Figure 5 there is personnel, system, and data in different departments like ER, cardiac ward, lab, XRAY etc. BPM can integrate these systems and provide process performance monitoring. On the other side, there is an EHR and even a data warehouse but the information you can get in EHR has not enough details and not real time. The BPM system can, however, integrate EHR data as well.

The problem is you have peoples, data, and systems which are operational systems. In theory, they are connected with the EHR and you even integrate data sources from the data warehouse for reporting. However, there is usually not enough detail and it is not delivered in real time. It would be efficient if we have a BPM system that coordinates these operational to give a view of what is happening for performance monitoring.

The old way of performance monitoring is to do reports off the data warehouse but the reports you get do not have enough detail and they are not delivered in real time. EHR was never designed for performance monitoring but unfortunately, that is what hospitals are using since they have no other mechanism. It would be efficient to have more performance monitoring interface off of the BPM that is coordinating among these operational systems.

Newer technologies like RTLS and CEP have also been considered by hospitals as a mechanism for tracking wait and service times using location data. However, this complicates the pictures as yet more technology need to be introduced, and there are no clear guidelines on how to integrate with process management data.

The problem we are addressing in this research is:

Can we define a methodology for care process monitoring technology that is effective, less complicated and less costly?

3.1.1 Gap Analysis

In this section we summarize and analyze the following gaps which exist in current approaches for care process monitoring:

- Operational processes are not captured in real time.
- Not enough details for reporting wait and service states
- Difficulties monitoring processes across departments.
- Lack of a clear development methodology for care process monitoring.

TABLE 2 below summarizes the gaps in four different approaches to the problem. The last two rows summarize EHR and RTLS approaches which lack explicit business processes models and on their own are largely ineffective for monitoring care processes.

The first two rows summarize the gaps in the two related works that were identified in Section 2.4 The integrated approach is successful for precise care process monitoring for wait and service states with a clearly defined methodology, but it is complicated and costly. The Standalone BPM approach has been used for care process management but there is no clearly defined methodology for how to develop and integrate performance monitoring into care process management.

TABLE 2: CPM MODEL APPROACHES AND LIMITATIONS

Approach	Limitations
Integrated Approach (Baarah A. H., 2013), (Tchemeube, 2013), (Baffoe, 2013)	❖Performance Monitoring Model is disconnected from Business Process Model ❖Complex methodology. ❖ Difficult to maintain across multiple platforms. ❖ High implementation cost. ❖ High developer effort.
Standalone Approach (Dickman, Gilmore, & Schume, 2012), (Dyer, et al.,2012)	❖Not clear how to integrate performance monitoring with operational systems and get the level of detail you need for service times and wait times.
Real Time Location Systems /RTLS/ (Fisher & Monahan, 2012), (Gaffney, 2012)	❖The degree of accuracy and functionality of RTLS device affected devices and network. ❖The number of tags per network cell.
Electronic Health Records /EHR/ (BERTMAN & SKOLNIK, 2010), (L. Edsall & G. Adler,, 2009)	❖Not enough report details ❖Not in real time ❖Not a cross departments ❖Lack of usability

3.2. Evaluation Criteria

Based on our gap analysis, literature survey and discussions with experts we identified five criteria by which we evaluate our generic methodology. The criteria are based on the features of our optimized care process, developer skills, technology costs, and the implementation complexity.

3.2.1 Features

We identified five features that we would like to have for any implementation of business process performance monitoring for health care as the following:

1) **Fine grain granularity for wait states and service states** - this is important in order to have improved the visibility of process execution by gathering, as processes execute, accurate and granular process information including wait time measurements according to (Tchemeube, 2013).
2) **Detailed performance reporting of metrics eg.wait times -** the ability to drill through, filter, drill up and drill down is essential to enable care providers the fine-grained analytics in discovering and solving patient flow bottlenecks according to (Baffoe, 2013).
3) **Minimize human inputs -** this is important to avoid information overflow by only providing the information relevant to task to be completed and minimize required interaction and intrusiveness according to (Tchemeube, 2013).
4) **Integrated 3rd party reporting** - this is significant to integrate process performance data with overall enterprise reporting according to (Baffoe, 2013) since IBM BPM only store the process performance data in PDW according to (Kolban, Kolban's Book on IBM Business Process Management, 2014).
5) **Cross-organizational transitions** - it became clear to us in analyzing our case study that the transition between organizations was most problematic and also one of the most likely sources of bottlenecks. Therefore, any approach should address this issue.

3.2.2 Developer Skills

Obviously, an online business process management tool is required for building business processes and performance monitoring online business processes.

TABLE 3 presents the list of skills that was needed from the integrated approach described in Section 2.4.1 separating out the different BPM skills needed. BPM standalone is the most basic set of skills needed based on the related works described in Section 2.4.2. BPM tracking points and BPM performance database were also added to the list, as these are part of our thesis motivation to leverage built-in BPM capabilities of performance reporting. The BPM skills are based on (Kolban, Kolban's Book on IBM Business Process Management, 2014) (®IBM Knowledge Center) while the extra skills (CEP, Enterprise Reporting, RTLS, IBM Message Broker) come from (Baarah A. H., 2013).

TABLE 3: DEVELOPER SKILLS CRITERIA

Skills Required	Level of Skills
BPM Standalone	Simple developer BPM skills
BPM Message Events	Medium developer BPM skills
BPM Integration Services	Sophisticated developer BPM skills
CEP (Complex Event Processing)	Sophisticated developer skills
Enterprise Reporting	Sophisticated developer skills
RTLS (Real Time Location System)	Sophisticated developer skills
IBM Message Broker	Sophisticated developer skills
BPM Tracking Points	Medium developer BPM skills
BPM Performance database	Medium developer skills

3.2.3 Technology Costs

TABLE 4 lists all the technologies associated with the integrated approach (Baarah A. H., 2013). Each separate technology implies a significant cost in terms of the cost of purchasing the software, the cost of training developers and the cost of hiring developers with those skills. The standalone and our approach will be a subset. TABLE 4 is extracted from (Baarah A. H., 2013) except the performance database which we added form (Kolban, Kolban's Book on IBM Business Process Management, 2014).

TABLE 4: TECHNOLOGIES USED IN INTEGRATED APPROACH

TECHNOLOGIES USED IN INTEGRATED APPROACH
IBM Business Process Manager (BPM)
Ekahau RTLS (RTLS)
IBM WebSphere Business Events
Generic BI Application
IBM Message Broker
Complex Event Processing Event (CEP)
Report DB
RTLS DB
CEP DB
Process Performance DB

Baarah defined framework to make it simpler to develop Care Process Monitoring Applications model for healthcare organizations whether they have minimal infrastructure and require less monitoring data, or they have a complex infrastructure and requires measuring and high monitoring data for every aspect of the process and the major challenge is how to engineer a CPMA so that the engineering process requires less developing time, less developer effort and less complexity (Baarah A. H., 2013).

3.2.4 Implementation Complexity

We evaluate the implementation complexity by following a rough order magnitude estimate called ROM established by (Dyer, et al., Using the rough order magnitude estimate, 2012) we can estimate a business process project as low, medium, or high complexity.

The ROM estimation method works by comparing measurable characteristics of the process to typical low, medium, and high complexity processes. The ROM estimates requires a high-level process model of the As-Is process such as our initial care process model described below in Section 3.4 to calculate the key elements required in the estimation.

TABLE 5 is based on data from hundreds of process projects aggregated by IBM over a period of nearly six years (Dyer, et al., Using the rough order magnitude estimate, 2012) and the factors that influencing the business process model complexity and developer efforts.

TABLE 5: IMPLEMENTATION COMPLEXITY CRITERIA

Business Process Model Complexity factors:	Low	Medium	High
Process Activities	15	30	60+
Coaches (user interfaces)	10	15	20+
Decisions / Events	1	5	6+
Reports	4	6	8+
Integration Services	2	3	4+
Developer Efforts:			
Implementation Duration	10 weeks	14 weeks	20 weeks
Developer Hours	900-1500	1500-2500	2500-5000
Number of Developers	2-3	3-4	4-5

3.3. Methodology Overview

In this section, we present an overview of our development methodology for building an executable care process model that integrates process monitoring. The resulting care process model is layered and integrates process, state, events and key performance indicators in a reporting framework that spans organizational boundaries and handoffs.

As shown in Figure 6, the first step is creating an initial care process model with horizontal swimlanes based on reviewing the existing process document to identify the actors, forms and activities involved in the process.

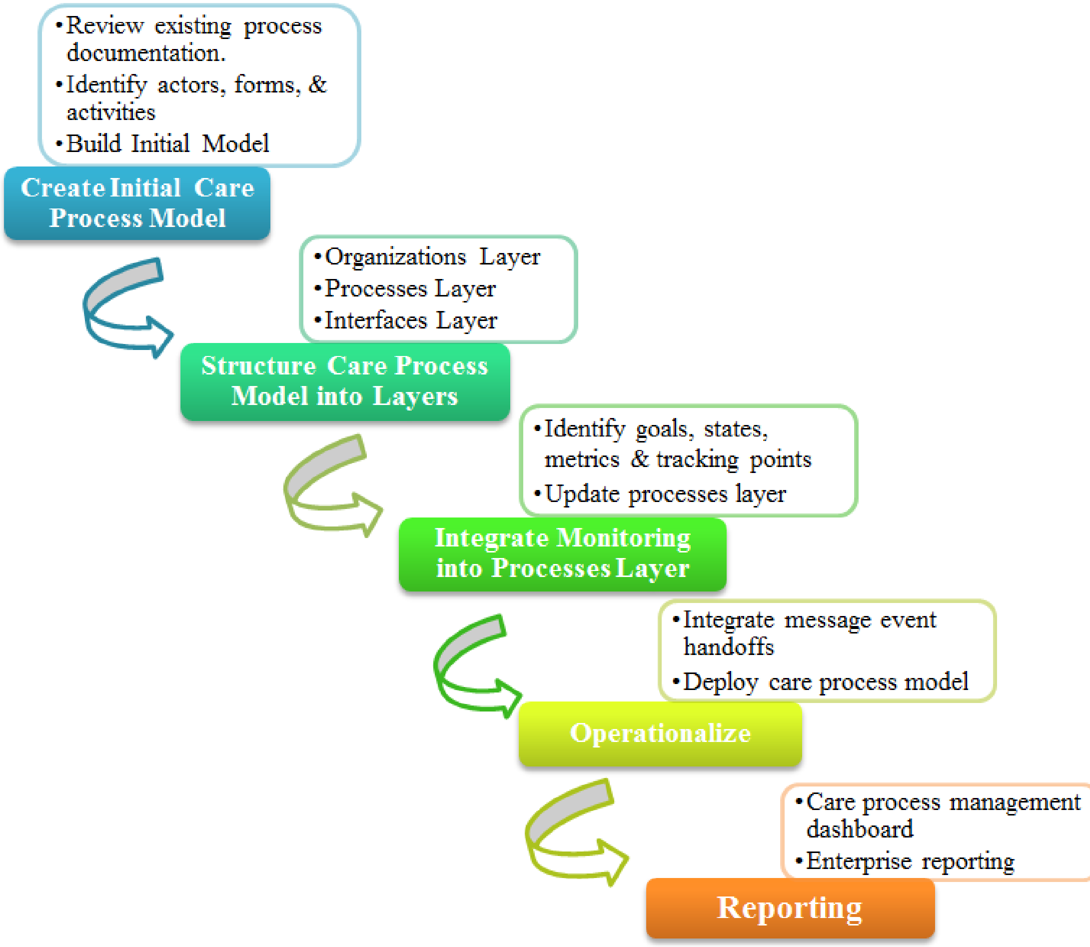


Figure 6 Generic Care Process Monitoring Methodology

The second step is structuring the care process models into 3 layers. At the top layer (organizations layer) the activities of the initial process model are grouped according to organizational divisions and handoffs. The middle layer (processes layer) contains the basic activities and swim lanes from the initial process model. While in the bottom final layer (interfaces layer), the activities from the middle layer are detailed in terms of the human interfaces (forms) and systems interfaces (web services) by which interactions with humans and systems are orchestrated to implement the business process online.

Once these three levels are established, the third step is to interact with stakeholders to figure out what to monitor in the care process by identifying the goals, states, tracking points and metrics. Performance monitoring is integrated and modeled in the processes layer with tracking points for capturing monitoring data and vertical swim lanes for grouping and identifying wait and service states.

The fourth step is to operationalize the care process model by filling in the details in the interfaces layer and deploying in the typical fashion for executable process models. However, special mechanisms are needed in the interfaces layer to implement the handoffs and feedback needed across organizational and transitional processes identified in the organizational layer message event handoffs.

Once the business process model with integrated care process monitoring is fully implemented, the final step is defining the reports displayed in a care process monitoring dashboard, as well as integrating performance monitoring data into enterprise reporting as needed.

3.4. Create Initial Care Process Model

As shown in Figure 7, the first step is to capture the process at a high level by reviewing the existing documentation of the process in order to;

- Identify who are the actors?
- Identify the existing forms used by the actors to capture and communicate the essential information in the process?
- Based on the forms, determine what activities are performed by the actors.

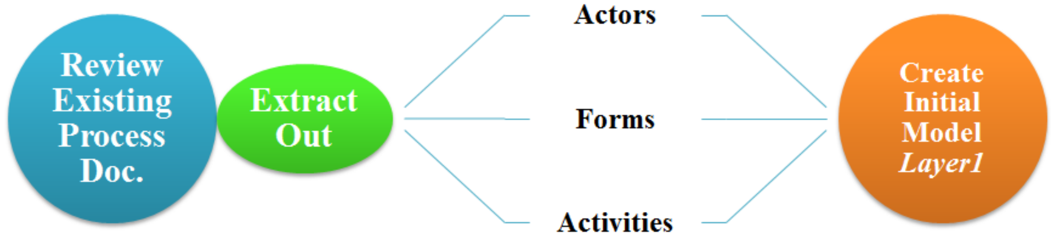


Figure 7 Initial Care Process Model Steps

This information is used to build an initial care process model that captures at a high level the basic flow of the process. Figure 8, shows an example care process model (from our case studies in chapter 4).

There are five actors in the process for admitting and treating cardiac patients, each of which is mapped to a swim lane. There is an ED nurse that triages patients, takes blood samples and performs ECG test. There is a Cardiologist who does initial, follow up and post procedure consultations with the patient, as well as eventually performing an Angiogram and PCI procedure There is a CW nurse who admits patients, schedules procedures and discharges patients and there is an operating room CCL nurse who prepares the room and the patient for the procedure and does post procedure monitoring. And finally, there is Housekeeping staff who cleans the room after the patient is discharged before a new patient is admitted.

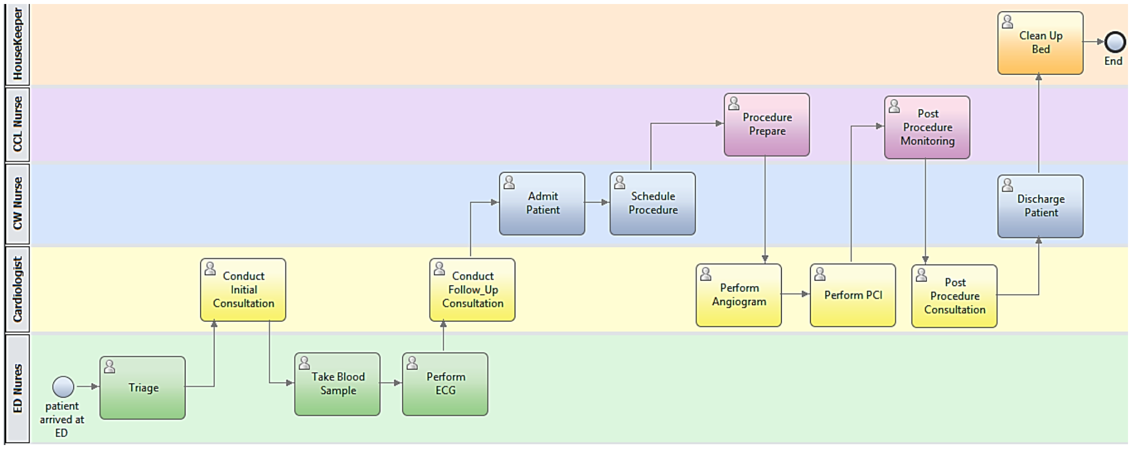


Figure 8 Initial Care Process Model

Figure 8 is drawn using the IBM BPM tool, but the initial process model can be draw in any tool that supports BPM modeling (including the cloud hosted IBM Blueworks Live ® (IBM Blueworks Live), IBM BPM ®, any BPMN compliant drawing tool or any Unified Modeling Language (UML) Activity Diagram tool (UML - Tools & Utilities).

3.5. Structure Care Process Model into Layers

Typically, if you speak about a care process model one need to understand that care processes span organizational boundaries and have many interfaces. As a result, a separation of the organizations and interfaces is necessary. In this step, well-defined care process model layers should be created.

3.5.1 Organizations layer

Typically, in a care process there are departmental activities in which care is managed by a single department, and then transitional activities where care is handed off from one department to another or the patient is admitted to/discharged from the hospital. In the organization layer, the different activities in the initial care process model are grouped into high-level activities or sub-processes corresponding to the departments that manage them, or they are grouped into transitional activities or sub-processes between departments.

Figure 9, shows the organization layer corresponding to our initial care process model. There are organizational sub-processes (ED Process; CW Process) corresponding to the Emergency Department and the Cardiac Ward, and there is a transitional sub-process (Admission) for the handoff from ED to CW and a transitional sub-process for discharging patients from CW.

ED Process contains all the activities that the ED is responsible for, and CW process contains all the activities that CW is responsible for. The Admission transitional process is responsible for checking bed availability for cardiac patients. If the bed is available on the CW, then the patient will be admitted and transferred from ED to CW. If not, the patient will wait to be admitted. The discharge transitional process is responsible for freeing up beds for admission after patient discharged by the physician and a housekeeper cleans up the room.

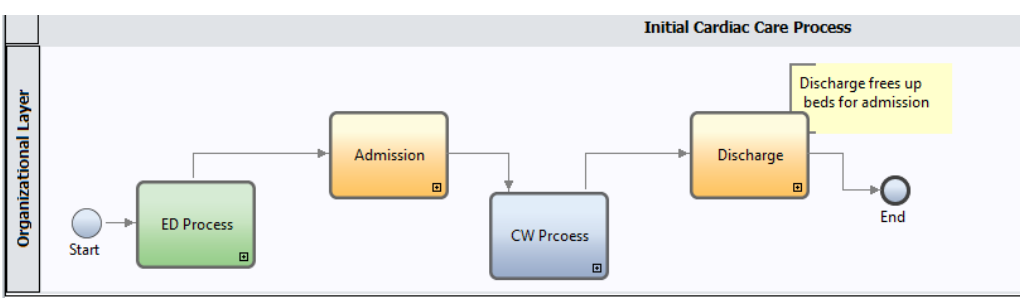


Figure 9 Organizational Care Process Layer

3.5.2 Processes Layer

In the processes layer, focus on having more details for actors, swim lanes and activities as shown in Figure 10. The main difference between this layer and the initial care process model is that each activity is categorized by phases (patient state) using vertical swim lanes. This allows us to identify precisely service states and wait states. We want to make sure that the organizational boundaries are very well known and we have the actors in terms of activities. However, any implementation required goes to the lowest level (interfaces layer) described in Section 3.5.3.

Figure 10 illustrates this using the first six activities from our initial care process model. Vertical swim lanes are used to define six states. Triaged is a service state that starts and ends with Triaged. Wait_for_PHY_INIT_ASSESS is a wait state that starts when Triaged ends and Ends once the physician confirms entering the ED room for initial consultation. IN_PHY_INIT_ASSESS is a service state that starts once the physician starts conducting initial consultation for the patient and ends once the initial consultation is done. Wait_for_Tests is a service state starts after conducting the initial consultation and requesting test orders and Ends once the test order request done and request a physician to follow-up consultation. Wait_For_PHY_Re_ASSESS is a wait state that starts when the process order requests activity is done and Ends when the physician confirms entering the ED room for a follow-up consultation. IN_PHY_RE_ASSESS starts when the physician starts conducting follow-up consultation and ends once the follow-up consultation is done.

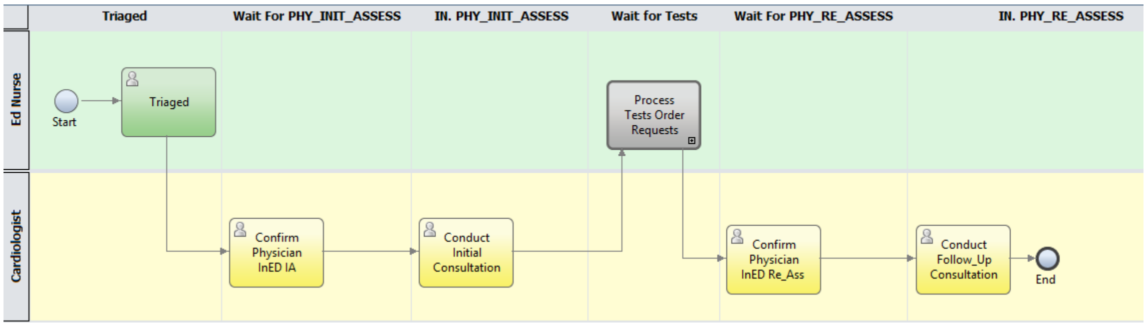


Figure 10 Processes Layer

3.5.3 Interfaces Layer

This is where the interfaces to actors and services are elaborated. At the interfaces layer, the focus is on implementing services to support the care process such as fetching data from databases and getting results. For example, in Figure 11 below, the Admit Patient activity is marked in red on the initial care process model.

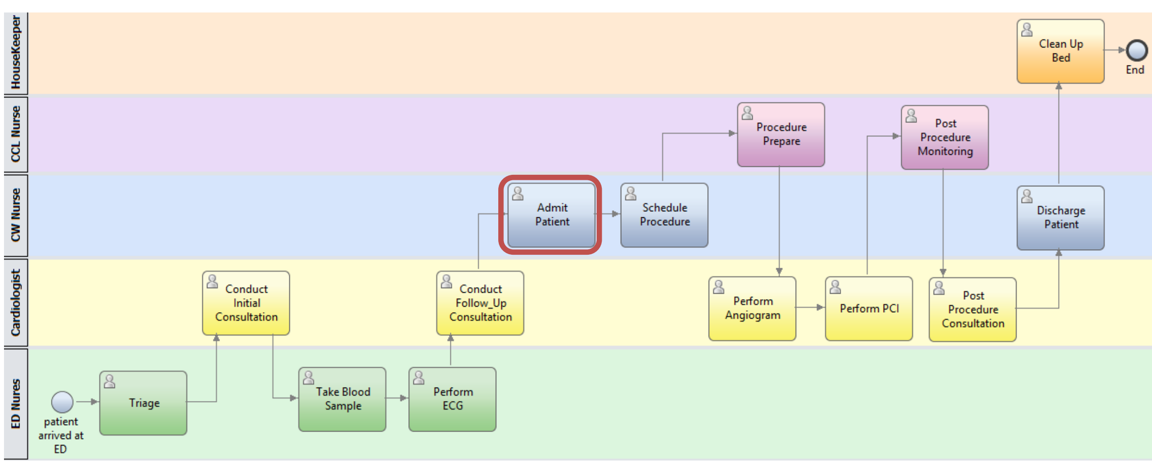


Figure 11 Processes needs human and system interface

The interfaces layer contains the elaboration sub-process shown in Figure 12 that provides the implementation for the Admit Patient activity. The blue boxes are the system interfaces that query the database (DB) for available beds and update the database when a bed is selected, while the yellow boxes are human interfaces that provide the forms used by the CW Nurse to admit the patient (select and assign a bed).

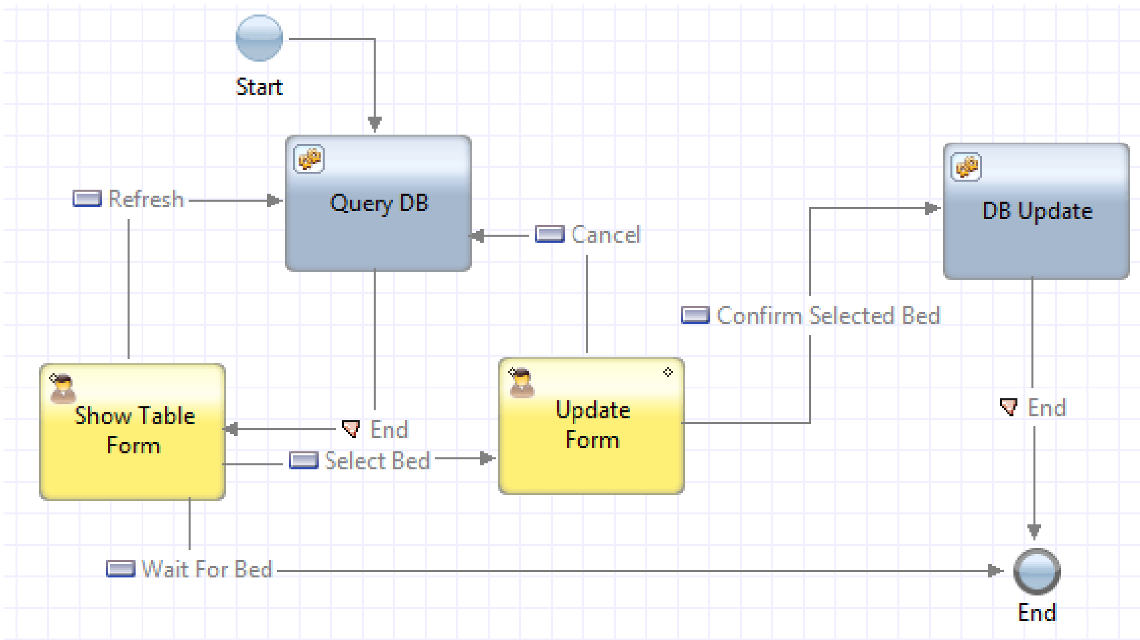


Figure 12 Interfaces Layer: Services

Figure 13 illustrates the property definition of the interface that includes server script to fetch the data such as the room unit, number, and the status of the room (available or not available) from the OSLER database, then flow to a nested service (SQL Call) that is responsible for executing the SQL statement defined in the server script to the database.

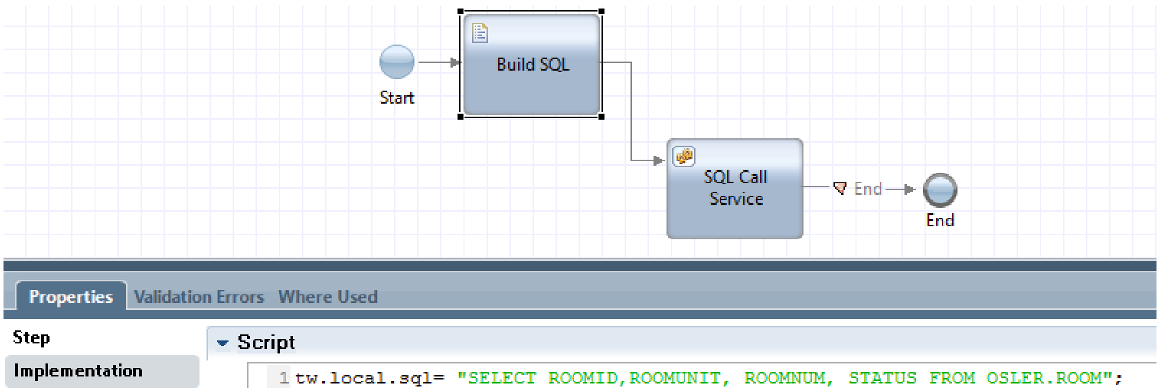


Figure 13 Interface Layer: Query DB Nested Service

Figure 14 show the coach (form) that corresponds to the service shown in Figure 12. Show Table form includes the patient information and the admission request received by the cardiologist and table that presents the CW units availability.

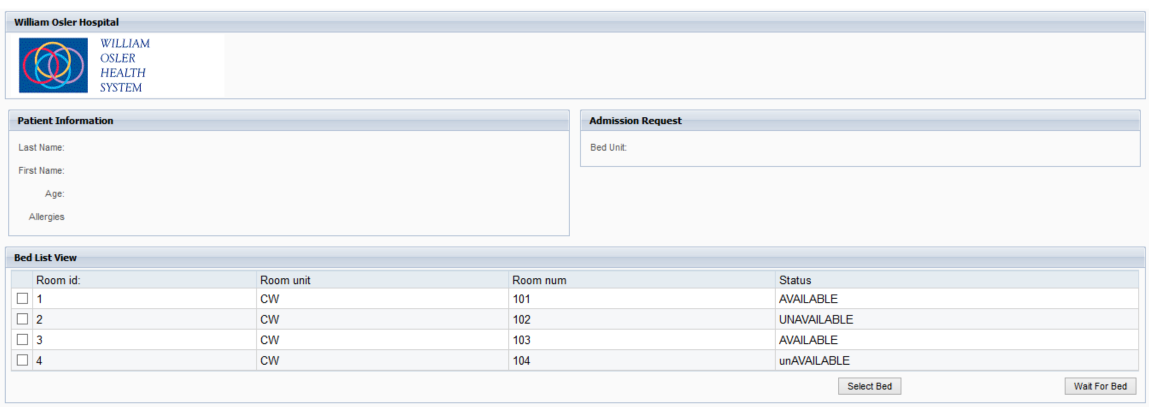


Figure 14 Interface Layer: Show Table Form

3.6. Integrate Monitoring into Processes Layer

Once the organizations layer and interfaces layer has been cleanly separated out from the processes layer, performance monitoring can be integrated into the processes layer. The main benefit of integrating monitoring into processes layer is the ability to explicitly represent and organize the relationship between process activities, process states, tracking points and the metrics used to measure the quality of care goals.

3.6.1 Identify goals, states, metrics & tracking points

At this phase, quality of care goals and metrics used to measure them are mapped to states in the process model. Wait states and service states are measured with tracking points. As shown in Figure 15, quality of care goals is achieved by processes that proceed in steps through a series of intermediate states. Wait times and Service times data can be collected from those states with which to collect metrics that communicate performance in reports which are used to monitor the step by step progress of processes through intermediate states to achieve the quality of care goals.

On the one hand, one can figure out the metrics to determine whether the goals have been met or not, on the other hand, one can figure out the state that is needed in the process in order to achieve quality of care goals and you must have some instrumentation of the states in the process in order to collect the data that is measured.

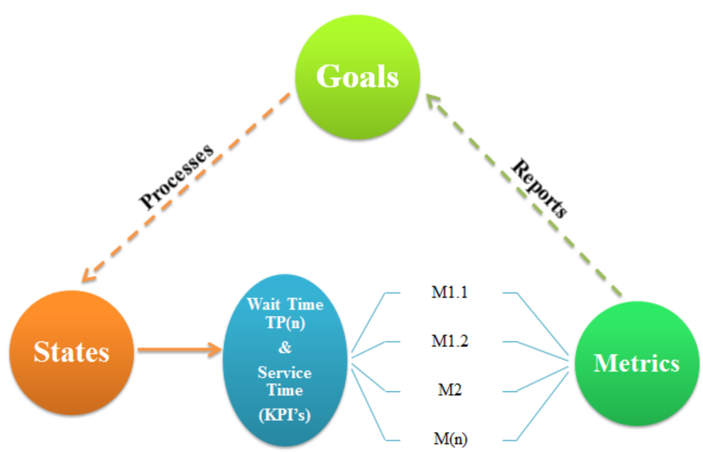


Figure 15 Performance Monitoring

3.6.2 Update Processes Layer

After the performance monitoring requirements have been determined, one can update the care process model with vertical states lanes, tracking points (TP) and metrics. As shown in Figure 16 we use vertical lanes for grouping process activities to identify states and drive dashboard and enterprise reports in a systematic fashion. The vertical swim lanes group together activities and their associated forms and services. Tracking points represented as flags are inserted between the activities to provide data for metrics. For example, TP1 can count the number of arrivals to the ED. While an average wait-time can be computed by the difference between the time captured at TP2 and at TP1 and an average service time can be computed from the difference between TP3 and TP2.

In the next section, the forms, services and the event message handoff between Activity4 and Activity5 shown in Figure 16 will be explained.

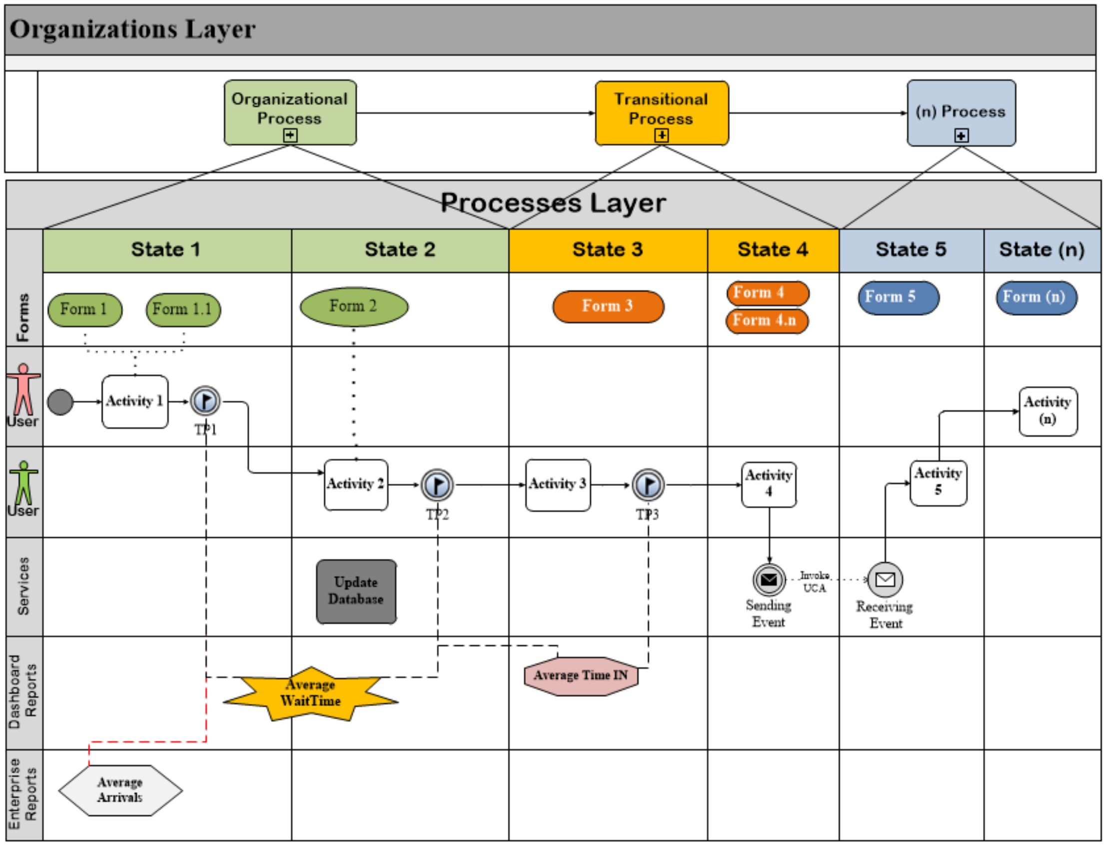


Figure 16 Integrate Monitoring into Processes Layer

3.7. Operationalize

At this point, both the care process model and its associated performance monitoring have been defined, but we need to operationalize and deploy the care process model by defining the form interfaces used by human actors and the service interfaces used to integrate the care process with the service oriented architecture for the hospital.

3.7.1 Deploy Care Process Model

To deploy the care process model, one must ensure that all process forms are implemented where necessary to interact with human actors in each activity. One must also step through the process and ensure all data interactions with system interfaces to the services in the service oriented architecture of the organization are implemented. Additional data items may need to be added to forms interfaces to ensure the data needed for tracking points is available. In some cases, additional forms or additional service interfaces may be needed to provide the data.

3.7.2 Integrate Message event handoffs

As we described above in Section 3.5.1 Organizations Layer, often you may also need to implement message intermediate events handles in order to coordinate between departments, because typically you have to wait for a response from the department to which you send the request.

For example, in Figure 9, the admission of patients must wait for the discharge of another patient to free up a bed, and the bed will not be ready until housekeeping has cleaned the room. The implementation of this using Message Event handoffs is shown in Figure 17. When a patient is discharged this triggers a clean-up request event message to be sent to housekeeping. Housekeeping receives this message in their in-box and which triggers a clean-up activity. When that activity is completed and the bed availability list is updated, that triggers another event message to say that the room is ready, so that the admission activity can start.

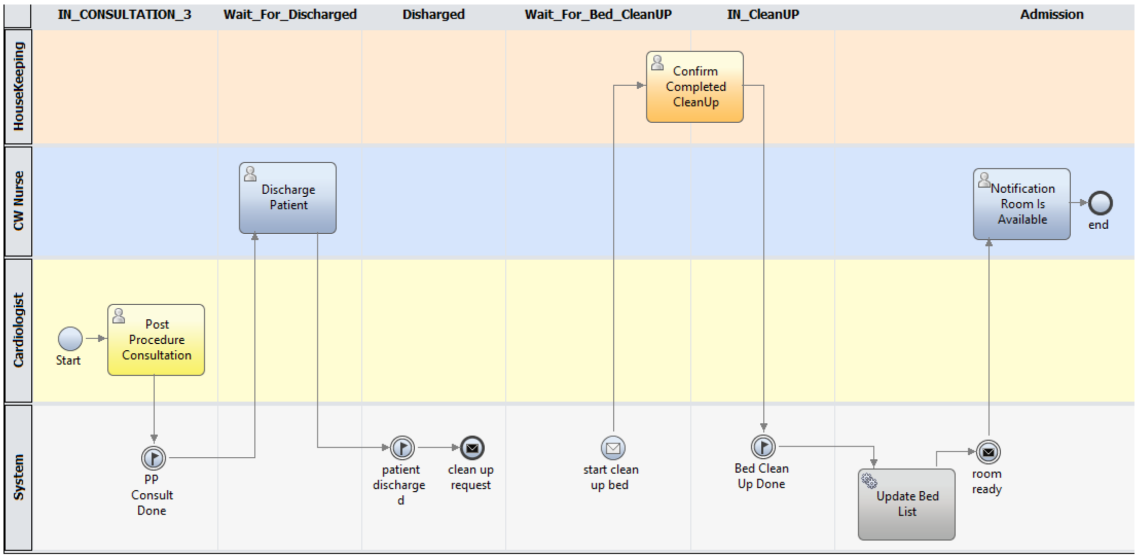


Figure 17 Integrate Inbound Message Event Hands-off – Discharge Process

Therefore, part of modeling a care process is that often you have a normal process and when you wait there is a secondary process using an event message handling service.

3.8. Reporting

Basically, for reporting in our generic methodology for care process monitoring, it is important to have detailed reporting of what is happening in the process while the process is being used. It is also important to provide data about process performance to enterprise data warehouse to integrate with enterprise reporting. For the first we will have a Care Process Management (CPM) dashboard. For the second we will specify the mechanism for integration with enterprise reporting.

3.8.1 Performance Monitoring Architecture

The performance monitoring architecture is shown in Figure 18. The process server that reads business process definitions and keeps track of process instances and executes and provides the human interfaces also saves monitoring data to the performance data warehouse. It also supports ETL to an enterprise data warehouse for enterprise reporting. It also communicates with the process portal which displays human interfaces and CPM dashboards.

Typically, monitoring care processes require two types of reporting. In the first type, reporting takes place in a care process management dashboard where the users involved in the care process are able to monitor quickly what is happening as the process is taking place. It is very focused and oriented toward the care process.

The second type is enterprise reporting where the organization has the quality of care goals and strategic KPIs that is related to care processes and care process data needs to feed into the enterprise reporting system.

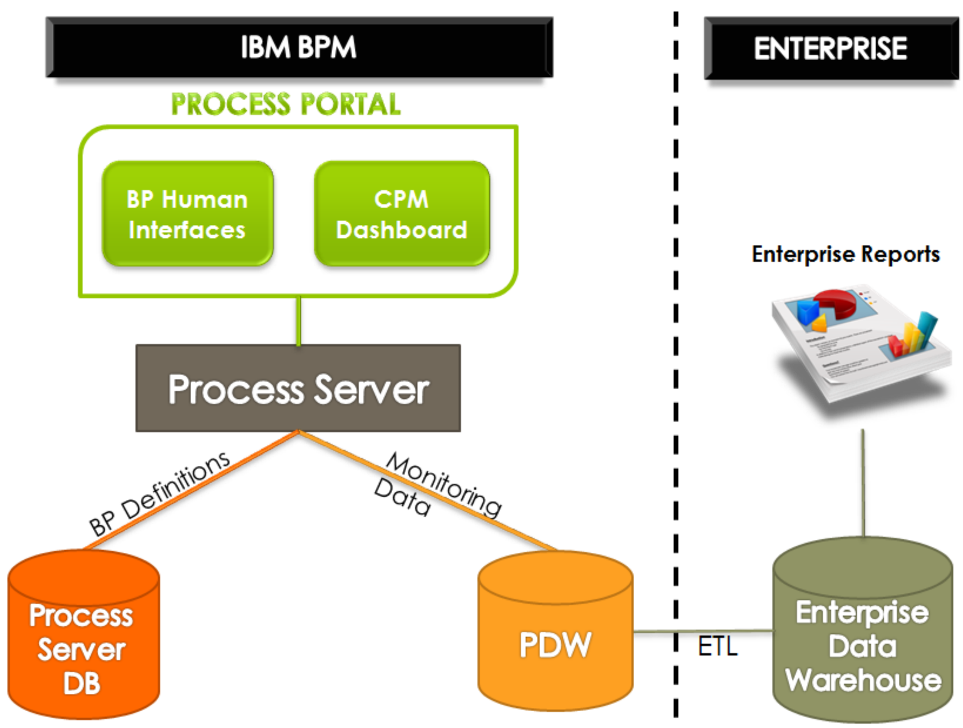


Figure 18 IBM BPM Performance Monitoring Architecture

Once everything is implemented and fully instrumented, the last step is creating the reports.

According to (Kolban, System of Record data vs Business Intelligence data, 2014) in IBM BPM data can be divided into two categories System of Record data (SOR) maintained by systems outside BPM and Business Intelligence data (BI) which can be recorded through PDW.

3.8.2 Care Process Management Dashboard (CPM)

The CPM is shown in Figure 18. It displays reports to show the state of care processes while they are taking place using data from PDW. As the system is running, the business process engine or process server that is running the processes stores performance data into PDW and reports strictly on the data that available in the care process based on what is captured by tracking points. However, it is also possible to access other databases from your CPM Dashboard. These can be accessed the same way that third-party reporting accesses them (as described below in Enterprise Reporting).

3.8.3 Enterprise Reporting

The enterprise reporting system is shown in the right section of Figure 18. The Process Server is the source of all the critical variable and tracking data that is logged in PDW. This data is fed into the enterprise data warehouse through ETL. 3rd Party reporting tools can then be used for enterprise reporting that combines data from other sources as well as the Process Server.

Chapter 4. The Case Study

In this chapter, we have conducted an extensive case study and set up three prototypes in the lab. Prototype 1 (Integrated Approach) is a pure integrated prototype defined by (Baarah A. H., 2013). We took the Osler care process model for cardiac patient care that was deployed at Osler hospital and brought it to the lab and set it up as a demonstration of a pure integrated approach. Then, in the second prototype (Standalone Approach) we rebuilt the Osler care process model following a pure standalone approach. The intent was to see how much functionality would be lost if we simply removed all the non-BPM technology from the Integrated Approach for reducing the cost and complications involved in the approach. Lastly, in the third prototype (Optimized Approach) we rebuilt the Osler care process model following our generic methodology for integrating care process monitoring to create a purely optimized approach and see how much functionality could be regained while still minimizing cost and complication.

In section 4.1, we provide an overview of our experiment. In section 4.2 we briefly describe the ACS Clinical Pathway monitored in our case study. In section 4.3, we describe the integrated approach and its challenges. In section 4.4 we describe the standalone approach and its weakness. In section 4.5 we describe the optimized approach and its advantages and disadvantages.

4.1. Overview

We took an existing care process model called The Acute Coronary Syndrome (ACS) clinical pathway from the literature that has been deployed at William Osler Hospital where we actually had access to the process model and the full architecture. Then, we experiment how people currently implement the integrated care process model and analyzed it and we noticed that there could be an improvement in the use of BPM that might avoid the need for extra technology. Then, we experimented first with a simplified standalone BPM and an optimized BPM based on our generic methodology. We clearly define our contrived experiment steps as the following:

1. Evaluate and quantify the integrated approach (Baarah A. H., 2013) (Baffoe, 2013) (Tchemeube, 2013).
2. Eliminate external dependencies and re-design using standalone BPM following IBM's methodology (Dickman, Gilmore, & Schume, 2012).
3. Redesign using our generic methodology and technique.
4. Compare the three prototypes.

Our design science experiment is to see:

- Is it necessary to be complicated "What are the pros and cons / gain versus lose/"?
- Do we have a good methodology for getting the best possible care process model for monitoring?

4.2. The Process - ACS Clinical Pathway

Monitoring and reducing the wait times for these patients is particularly important because the patient may require an urgent cardiac re-vascularization which must be completed within 90 minutes of the event to be effective.

The Process is the Acute Coronary Syndrome (ACS) clinical pathway as defined by the Ontario government (Quality-Based Procedures Clinical Handbook for Coronary Artery Disease, 2014). The integrated approach was developed by (Baarah A. H., 2013) (Tchemeube, 2013) (Baffoe, 2013) as described in Section 2.4.1. Figure 19 illustrates a high-level initial process model for the ACS clinical pathway in IBM Process Designer.

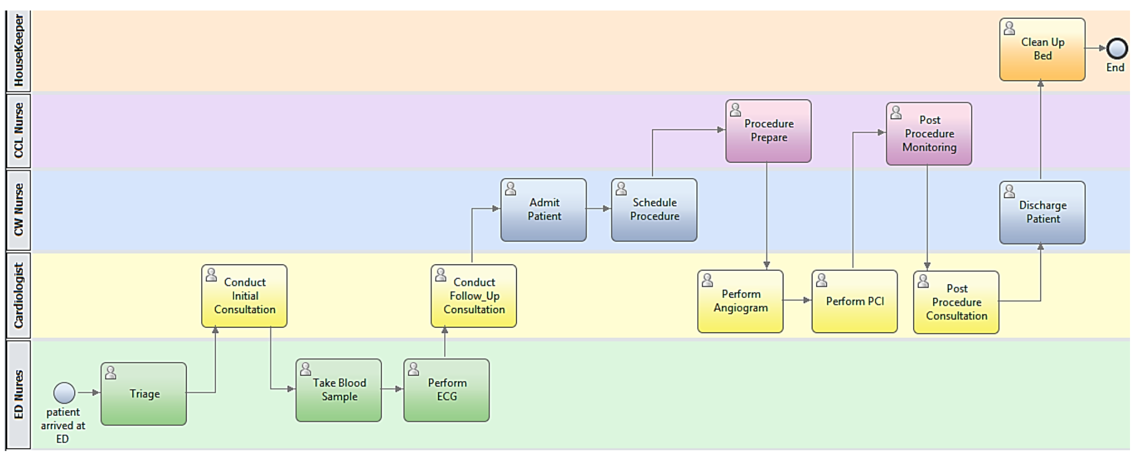


Figure 19 Process Overview

The ACS process takes place between five stakeholders ED Nurse, Cardiologist, CW Nurse, CCL Nurse and Housekeeper with the purpose of giving care to the cardiac patient and discharge him/her. Each stakeholder is responsible for multiple tasks to proceed listed below:

- **ED Nurse** is responsible for triage patient after arriving at ED, take a blood sample and send it to the lab and perform Electrocardiogram (ECG) test.
- **Cardiologist** is responsible for conducting an initial consultation with the patient after they have been triaged. The cardialogist can request blood and ECG tests, then conduct a follow-up consultation wehre they diagnose the patient, review the test results, and admit patient to a bed in the CW department. They perform the cardiac procedure including performing Angiogram and PCI, the final task is to the post procedure consultation to check the patient after the procedure and request discharge if the patient is ready.
- **CW Nurse** is responsible for admitting patient in CW department, schedule procedure, and discharge patient.
- **CCL Nurse:** is responsible for preparing the patient for the procedure and for monitoring the patient after the procedure.
- **Housekeeper** is responsible for cleaning up the room after the patient being discharged.

4.3. Integrated Approach

In the first phase of the case study, a location-aware business process management system for real-time care process monitoring integrated with a generic Care Process Monitoring BI application was developed for monitoring the ACS clinical pathway.

4.3.1 Performance Monitoring Architecture

Figure 20 illustrates the performance monitoring architecture of the integrated approach. The Source systems include the design of an integrated BPM and RTLS solution architecture developed by (Tchemeube, 2013) for accurate, granular, flexible, and real-time visibility over care process.

The application meta-model (*Message Broker)* provides a linkage between the key care process states and the source events used to infer those states, on the one hand, and a linkage between the key care process states and the metrics used to measure the performance of the care process (Baarah, Mouttham, & Peyton, 2011).

Accompanied with SME developed by (Baffoe, 2013), to integrate events from various care process sources in real-time to maintain an up to date care process model and populate an OLAP database to support performance reporting.

Integrated with a BI portal used to present the performance measures in real-time with a Cognos BI Portal which is driven off an FM OLAP data mart accessing a star schema MS SQL database.

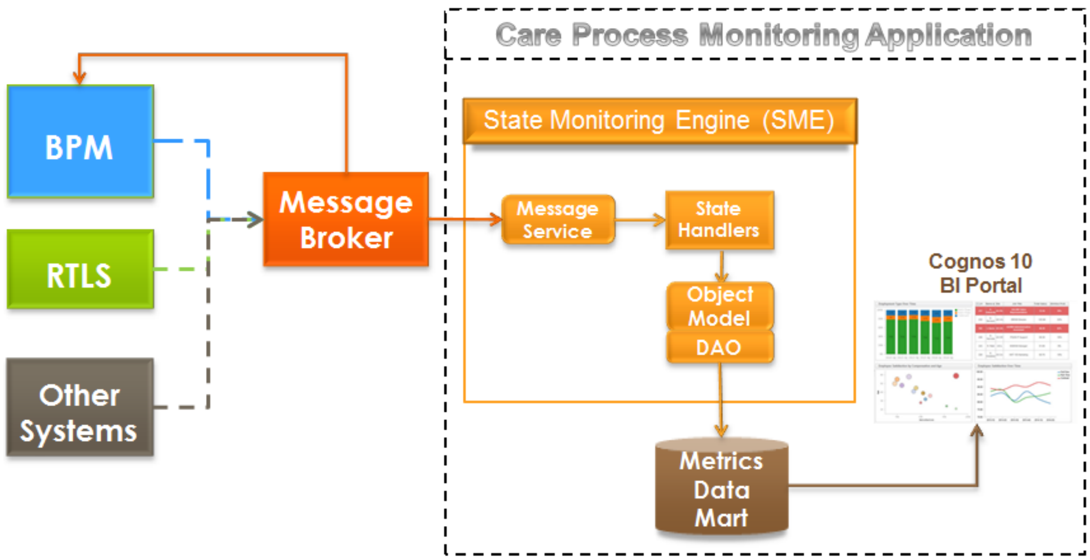


Figure 20: CPMA Performance Architecture (Baarah A. H., 2013)

4.3.2 Business Process Model

Figure 21 shows the steps involved in the emergency department process for a patient after being registered in the hospital. The process model is divided into 4 swim lanes as Transport, ED Nurse, Cardiologist, and system. Each team assigned to a particular swim lane and has their own activity colored in blue for cardiologists, green for ED nurses, purple for transport and gray for the system.

The process starts by triage patient activity including check vitals and request for a physician. Then conduct initial consultation activity includes a physical examination and test order. Then test order execution and results activity include performing ECG and blood samples for testing. Then conduct follow-up consultation for diagnosis and decide whether the patient will be admitted to treatment or not. Lastly, the ED process will end once the patient transport out of ED.

The key feature of this model is using intermediate messages events added in the system lane for receiving external events in order to capture patient states. For example, after performing the welcome activity the patient will wait for an initial consultation by the physician in the ED room. Once the physician enters the room an RTLS device attached to the physician will send an event to the BPM through the Message Broker intermediate message events created in the system lane of ED process model that is responsible for receiving external events such as RTLS in order to continue the process.

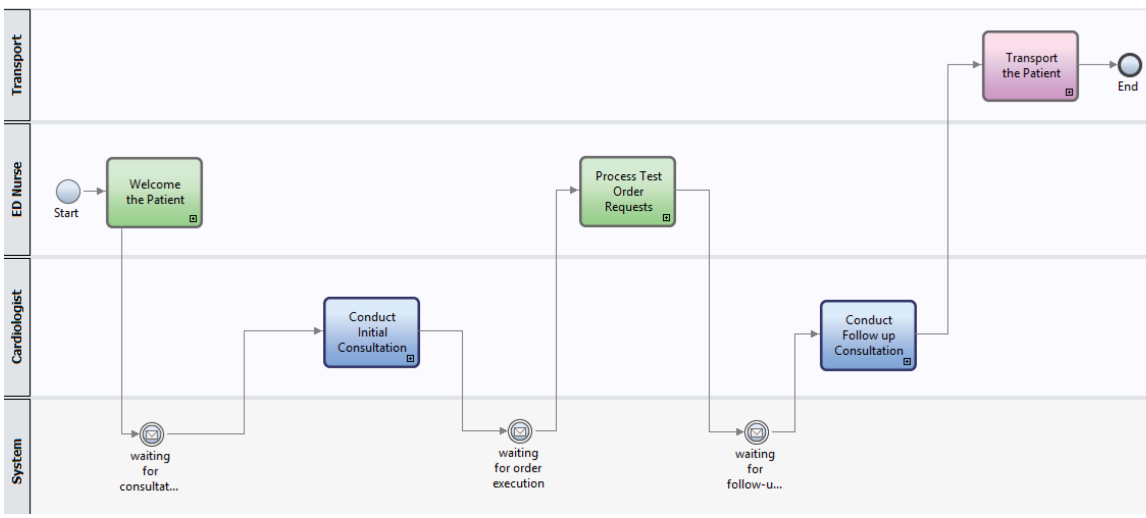


Figure 21 Integrated ED Process

Figure 22 shows the steps involved in the process test order requests activity for a patient. As shown below the process model divided into three swim lanes as the following Cardiologist, Ed Nurse and System.

The key feature of this model below is capturing the patient states (waiting and service times) through receiving events from RTLS and sending events to BI application for monitoring and reporting the patient states. For example, after performing take blood sample activity by Ed nurse the process will flow to the Notify-Blood sample is taken system task colored in gray which is responsible for sending an event from BPM to BI application through web service defined in the system tasks. Then the process will flow to an intermediate message event and hold at this point till receiving blood test result from other sources then the process will flow to Notify-Blood analysis done system task and send an event to BI application from BPM and so on and so forth.

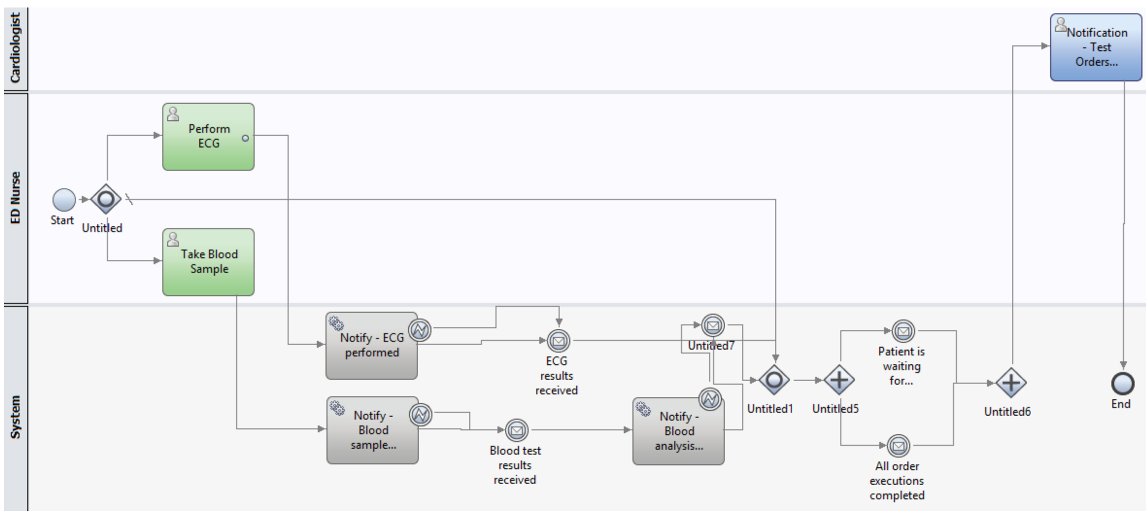


Figure 22 Integrated Test Order Request

Figure 23 shows the steps involved in the follow-up consultations process which includes diagnosis the patient and admits patient to bed etc. The key feature of this model is sending events from BPM to BI application in gray boxes and receiving events from RTLS to BPM in messages symbol. However, the process model becomes more complicated and not clears in terms of patient states and overall process view. To summarize, in this process model only we have 5 events from RTLS and 6 events send to BI application is not that too complicated to capture the patient states.

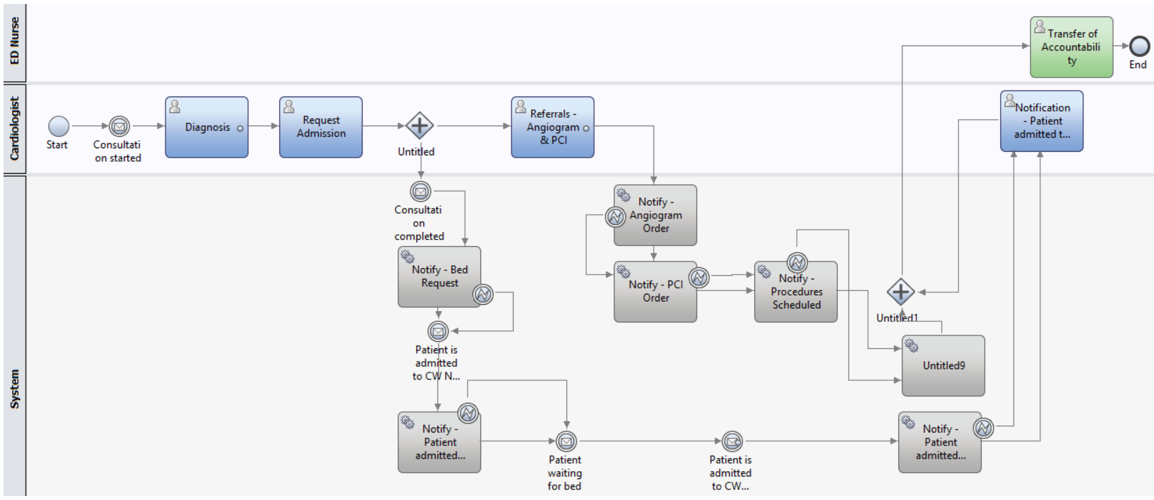


Figure 23 Integrated Follow-up Consultations

Figure 24 shows the steps elaborated in the cardiac care process for a patient after being admitted to CW process. On the day of the procedure, the patient will be transported to CCL room for performing the procedures and transported back to his bed when done. Then a post-procedure consultation is later conducted to assess the condition of the patient during recovery. Lastly, at the end of CW process, a discharge is then requested for the next day if patient condition is approved by the cardiologist.

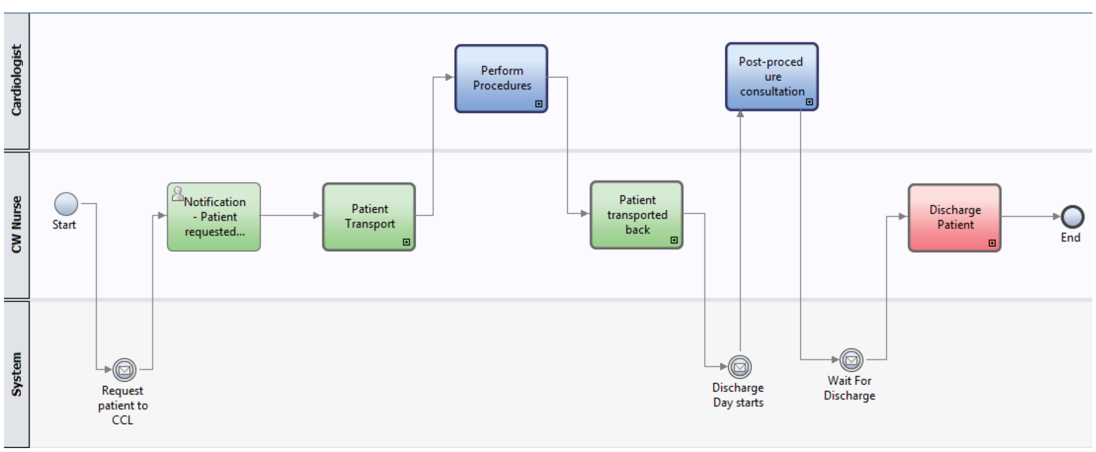


Figure 24 Integrated CW Process

Figure 25 show the steps involved in performing the procedure at the CW process described above. The key feature of this process model is using and external systems for sending and receiving events.

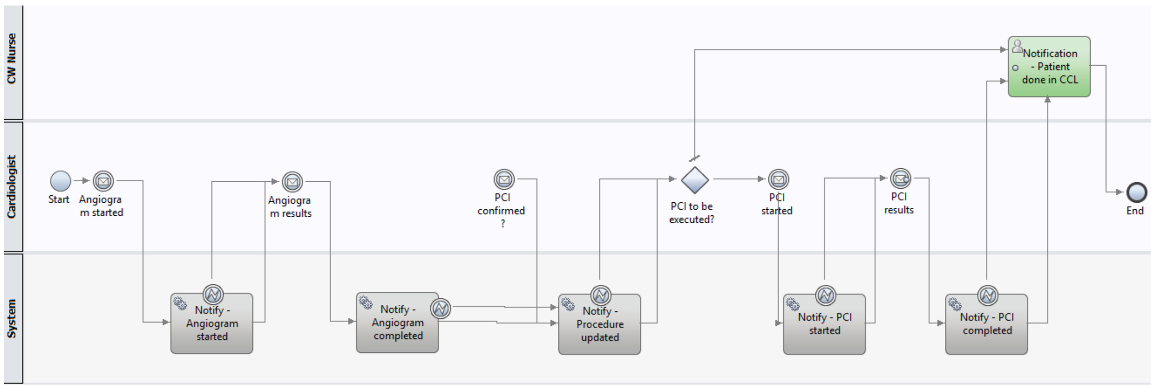


Figure 25 Integrated Perform Procedure

To conclude, there is very sophisticated fine grain monitoring of events using RTLS and computation of states using SME, but the solution is expensive and complicated. Was it really necessary? As well, the integrated business process models were unnecessarily complicated (extra information and events from the outside) and it is not possible to understand the overall view of the whole process in terms of monitoring.

Moreover, in case any modification required in the process you have to recode and modify your process where you send events to CEP and you should have to change the code and rules that calculate the states in CEP.

4.3.3 Performance Reports

The integrated approach focused on the enterprise reporting integrating events received from BPM and creating a care process monitoring portal using Cognos Report Studio to visualize the reports and monitor the current patient states in real time.

Figure 26 illustrates an online report of how many patients arrive in the hospital per hour from the integrated care process dashboard.

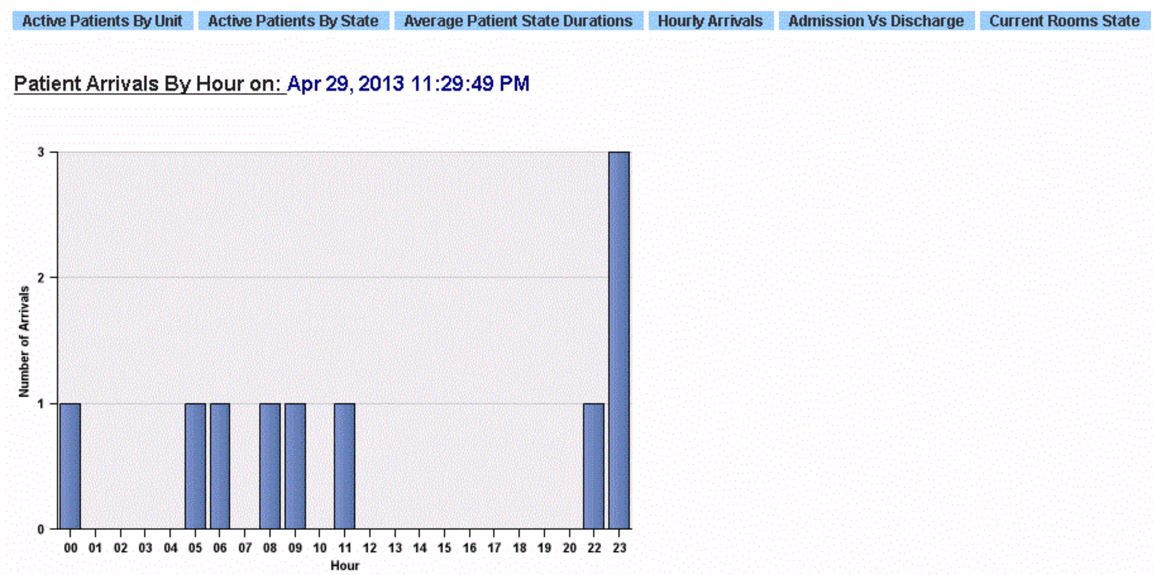


Figure 26 Patient Arrivals by Hour

Figure 27 show an online report of the number patients in each state grouped by the duration.

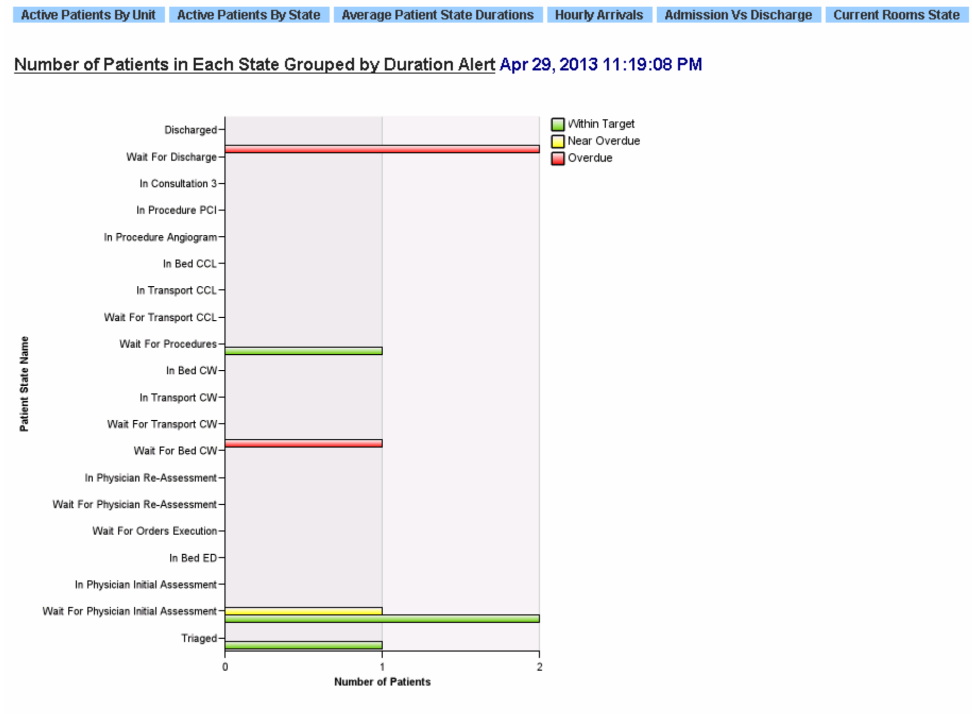
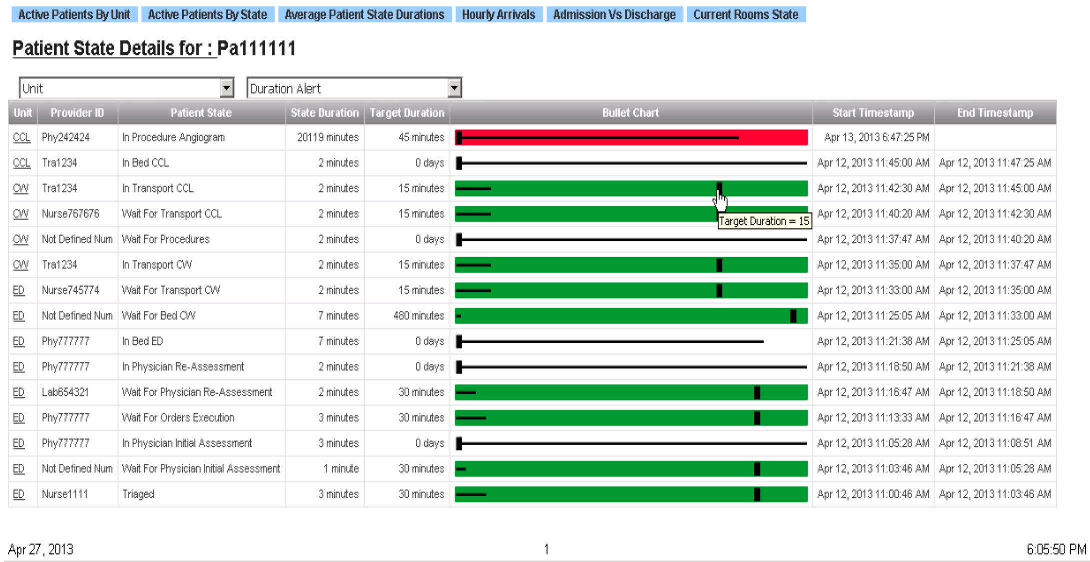


Figure 27 Number of patients in each state

Figure 28 is a sample real-time report. The report shows the states and durations accompanied by the defined target durations and the unit of the patient beside offers the ability to drill down from the unit to individual rooms. Care providers can drill down from unit to room to see the room the patient is in and quickly resolve the problem if this patient was waiting for a service.



Unit	Provider ID	Patient State	State Duration	Target Duration	Bullet Chart	Start Timestamp	End Timestamp
CCL	Phy242424	In Procedure Angiogram	20119 minutes	45 minutes		Apr 13, 2013 6:47:25 PM	
CCL	Tra1234	In Bed CCL	2 minutes	0 days		Apr 12, 2013 11:45:00 AM	Apr 12, 2013 11:47:25 AM
CW	Tra1234	In Transport CCL	2 minutes	15 minutes		Apr 12, 2013 11:42:30 AM	Apr 12, 2013 11:45:00 AM
CW	Nurse767676	Wait For Transport CCL	2 minutes	15 minutes		Apr 12, 2013 11:40:20 AM	Apr 12, 2013 11:42:30 AM
CW	Not Defined Num	Wait For Procedures	2 minutes	0 days		Apr 12, 2013 11:37:47 AM	Apr 12, 2013 11:40:20 AM
CW	Tra1234	In Transport CW	2 minutes	15 minutes		Apr 12, 2013 11:35:00 AM	Apr 12, 2013 11:37:47 AM
ED	Nurse745774	Wait For Transport CW	2 minutes	15 minutes		Apr 12, 2013 11:33:00 AM	Apr 12, 2013 11:35:00 AM
ED	Not Defined Num	Wait For Bed CW	7 minutes	480 minutes		Apr 12, 2013 11:25:05 AM	Apr 12, 2013 11:33:00 AM
ED	Phy777777	In Bed ED	7 minutes	0 days		Apr 12, 2013 11:21:38 AM	Apr 12, 2013 11:25:05 AM
ED	Phy777777	In Physician Re-Assessment	2 minutes	0 days		Apr 12, 2013 11:18:50 AM	Apr 12, 2013 11:21:38 AM
ED	Lab654321	Wait For Physician Re-Assessment	2 minutes	30 minutes		Apr 12, 2013 11:16:47 AM	Apr 12, 2013 11:18:50 AM
ED	Phy777777	Wait For Orders Execution	3 minutes	30 minutes		Apr 12, 2013 11:13:33 AM	Apr 12, 2013 11:16:47 AM
ED	Phy777777	In Physician Initial Assessment	3 minutes	0 days		Apr 12, 2013 11:05:28 AM	Apr 12, 2013 11:08:51 AM
ED	Not Defined Num	Wait For Physician Initial Assessment	1 minute	30 minutes		Apr 12, 2013 11:03:46 AM	Apr 12, 2013 11:05:28 AM
ED	Nurse1111	Triaged	3 minutes	30 minutes		Apr 12, 2013 11:00:46 AM	Apr 12, 2013 11:03:46 AM

Figure 28: Patient State Durations versus Target Durations in BI Portal

4.3.4 Results

We briefly summarize the integrated approach as shown in TABLE 6 for evaluation purposes described in chapter 5. The table shows the number of user interfaces such as forms or coaches used in the process model. The performance of the process model that includes the number monitoring tools used such as tracking points (flags), tracking groups, and timing intervals. Then, Implementation in terms of the number of integration and system services implemented in the process model. Finally the number of patient states that can be covered in the process model for monitoring.

There were 22 human interfaces (Forms) in the BPM implementation and 18 identified patient states. There was no use of built-in BPM support for performance monitoring. However, there was large scale use of integration services (43) and undercover agents (27) largely to manage the interactions with external systems for performance monitoring.

TABLE 6: INTEGRATED CASE STUDY RESULTS

User Interface	Coaches/Forms	22
Performance	Tracking points	0
	Tracking groups	0
	Timing intervals	0
Implementation		
Integration Service	Inbound operations	14
	Publish operations	14
	Web services Integration	15
General System Service		28
Undercover agents	Attached to MIE	27
States	Total Patient states	18

4.4. Standalone Approach

In the second phase of the case study, a standalone simplified BPM model was developed for monitoring the ACS clinical pathway followed the standard BPM methodology described in Section 2.4.2 with no use of external systems for performance monitoring.

4.4.1 Performance Monitoring Architecture

Figure 29 illustrates the performance monitoring architecture of the standalone simplified approach. The process server database stores the process instance data definitions that were created by the process designer which is read by the process server and executed which create instances that it keeps track of. The process portal displays BP human interfaces and the instance dashboard which simply presents the list of instances and simple built-in process instance reports with a minimal instance data.

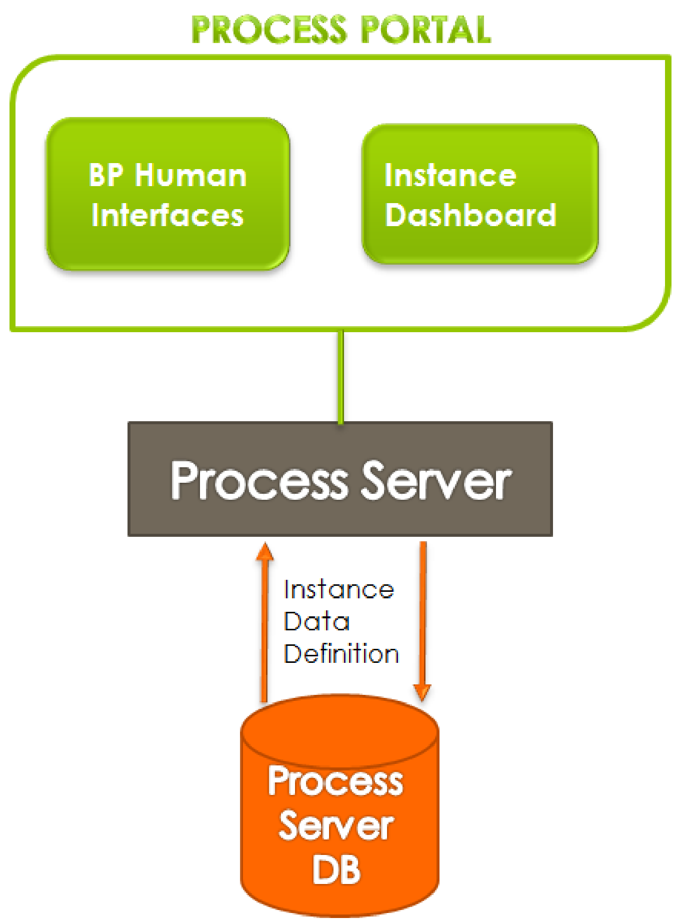


Figure 29 Standalone Performance Monitoring Architecture

4.4.2 Business Process Model

Figure 30 and Figure 31 shows the same steps of the integrated ED and CW process model described Section 4.3.2. The main difference in the standalone process model is that all the external dependencies eliminated from the process model and has no system lane only the actors. For clarification, Figure 30 comparable to Figure 21 in the integrated approach and Figure 31 comparable to Figure 24 in the integrated approach.

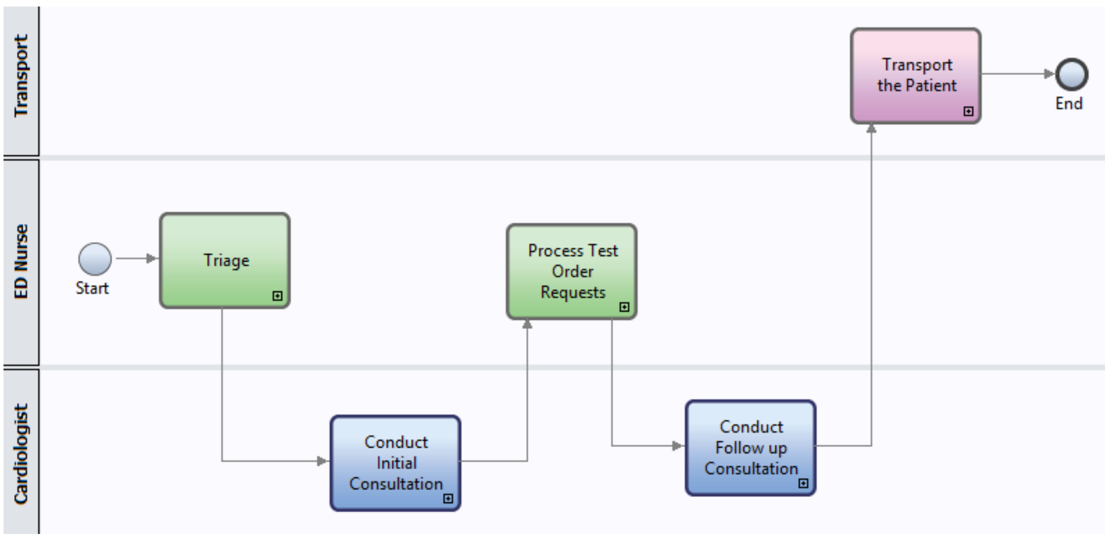


Figure 30 Standalone ED Process

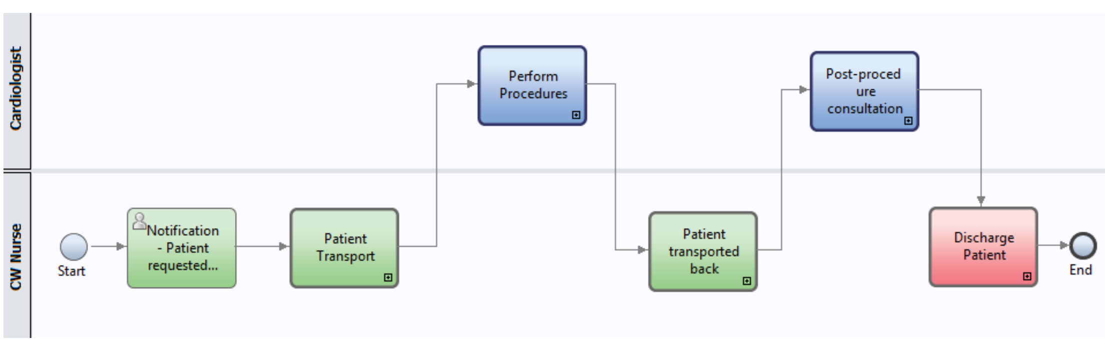


Figure 31 Standalone CW Process

4.4.3 Performance Reports

Process Portal provides a feature for viewing built-in dashboards and act on the performance of individuals, teams, and processes. The following built-in dashboards Process Performance Dashboard and Team Performance Dashboard described below are included in process portal.

4.4.3.1. Process Performance Dashboard

Simply, by exposing the business process definition performance metrics BPM built-in dashboards provides Process Performance Dashboard along with monitoring features by enabling due date for the process instance to determine whether an instance is at risk besides instances that are at risk of becoming overdue are shown in process portal, based on the average completion time of the process.

Process performance dashboard indicates the status of the active instances (patients) of particular processes and provides an overview of the processes responsible for. As shown in Figure 32 the main page is divided into two main sections:

a) **Quick Stats** provides an overview of the instances (patients) that are in progress. This section includes the average patient duration, and the total number of patient in progress, which are categorized as overdue, at risk, and on track patients.
b) **Turnover Rate** provides rate overview of patients who arrived and discharged from the hospital. The trend line indicates how the care process

is performing and whether the work on it is catching up or falling behind based on the difference between the patient arrival and discharge rates.

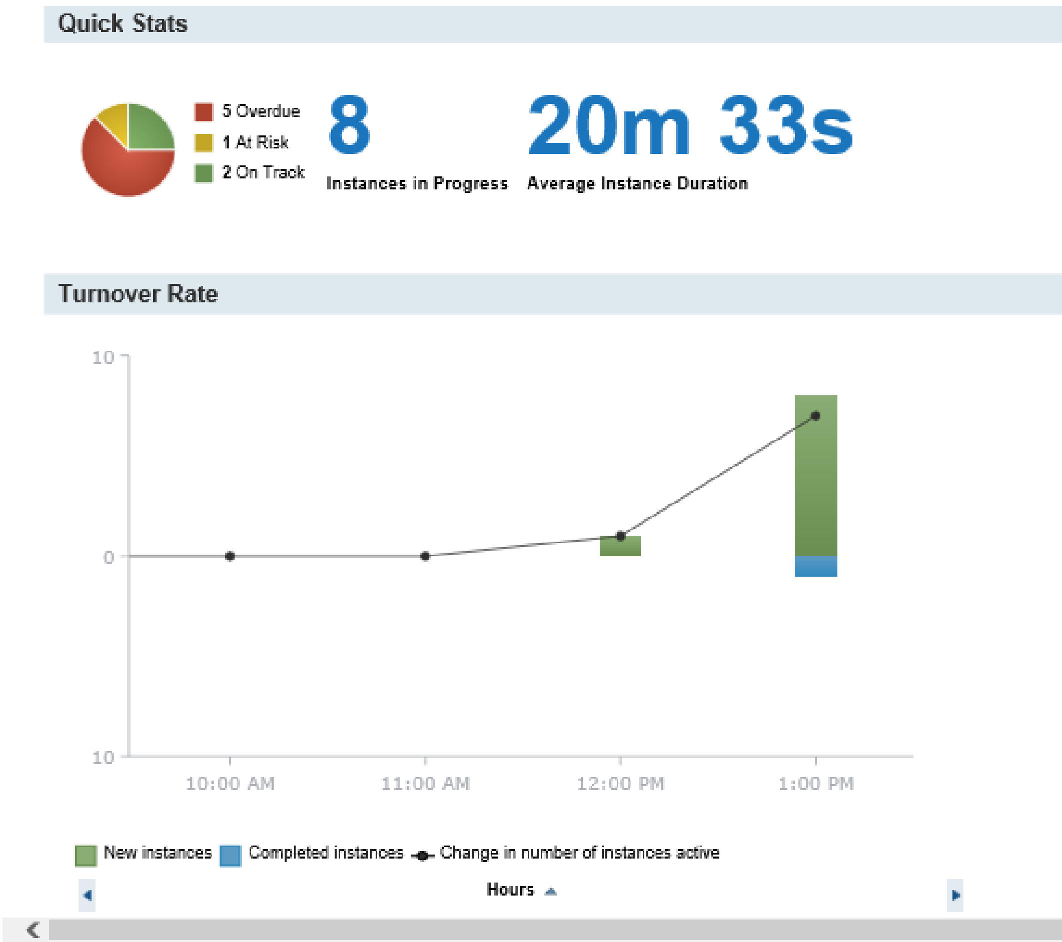


Figure 32 Standalone Process Performance Dashboard

4.4.3.2. Team Performance Dashboard

The team performance dashboard indicates the team status of the tasks and how the health organization teams are performing regarding their workloads for team manager giving the ability to manage the workload for the team and individual whether the team is catching up or failing behind on their work. As shown in Figure 33, a task can be in one of three possible states On Track in green color, At Risk in yellow color, or Overdue in red color.

IBM BPM dynamically determines whether a task is At Risk by using the average time taken to complete the task and the task due date.

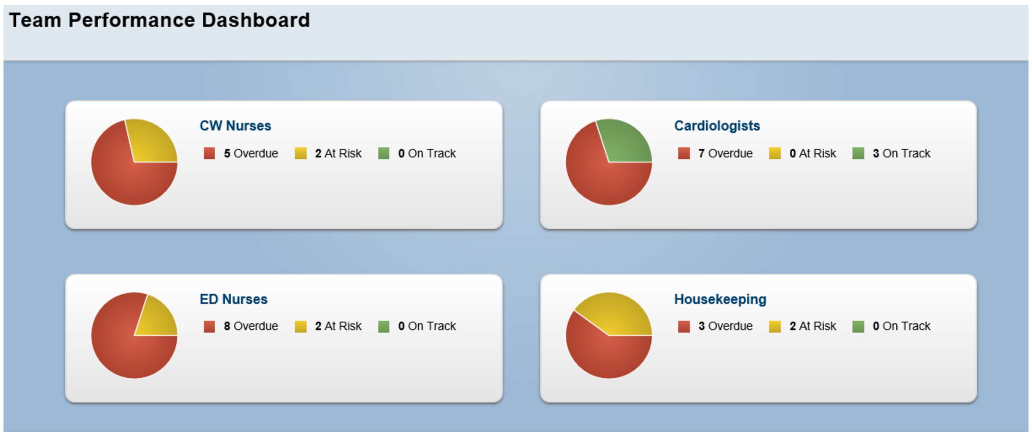


Figure 33 Standalone Team Performance Dashboard

By drilling down in each individual team an overview page is provided. Overview page divided into two main sections:

a) **Quick Stats** Provides an overview of the tasks that are assigned to the team such as (ED Nurse, CW Nurse, Cardiologists and Housekeeping staff). As shown in Figure 34, this section includes counts for the open tasks and today's completed tasks. The open tasks are categorized as overdue, at risk, and on track.

b) **Turnover Rate** Provides an overview of the rate at which tasks are started and completed over time. As shown in Figure 34 , the trend line indicates whether the team is catching up or falling behind with its work based on the difference between the task arrival and completion rates.

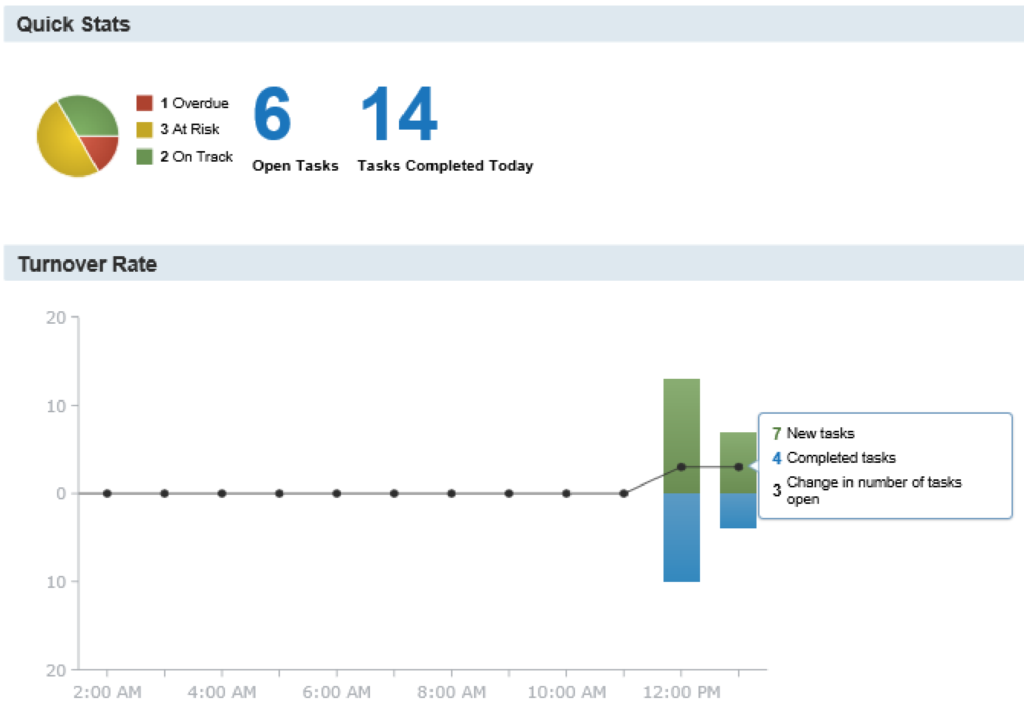


Figure 34 Standalone ED Nurses Performance Dashboard

4.4.4 Results

We briefly summarize the standalone approach as shown in TABLE 7 for evaluation purposes described in chapter 5.The number of BPM Interfaces (Forms) is about the same as the integrated approach (26), but the number of identifiable patient states is dramatically reduced (7 states instead of 18). This obviously does not give fine-grained reporting of service and wait states.

However, the implementation was greatly simplified in that all service invocations were eliminated. And the build in reporting, while crude still does give visibility on key metrics like arrivals and turn-over rate.

TABLE 7: STANDALONE CASE STUDY RESULTS

User Interface	Coaches/Forms	26
Performance	Tracking points	0
	Tracking groups	0
	Timing intervals	0
Implementation		
Integration Service	Inbound operations	0
	Publish operations	0
	Web services Integration	0
States	Total Patient states	7

4.5. Optimized Approach

In the third phase of the case study, a full optimized BPM model was developed for monitoring the ACS clinical pathway followed generic methodology we have proposed for integrating performance monitoring with BPM, described in chapter 3 with no use of external systems for performance monitoring.

4.5.1 Performance Monitoring Architecture

Figure 35 illustrates the performance monitoring architecture of the optimized approach. We include TP in the BPD in the Process Designer which are saved to the Process Server DB. The Process Server executes those BPDs and based on the TPs it interacts with the PDW to save the monitoring data.

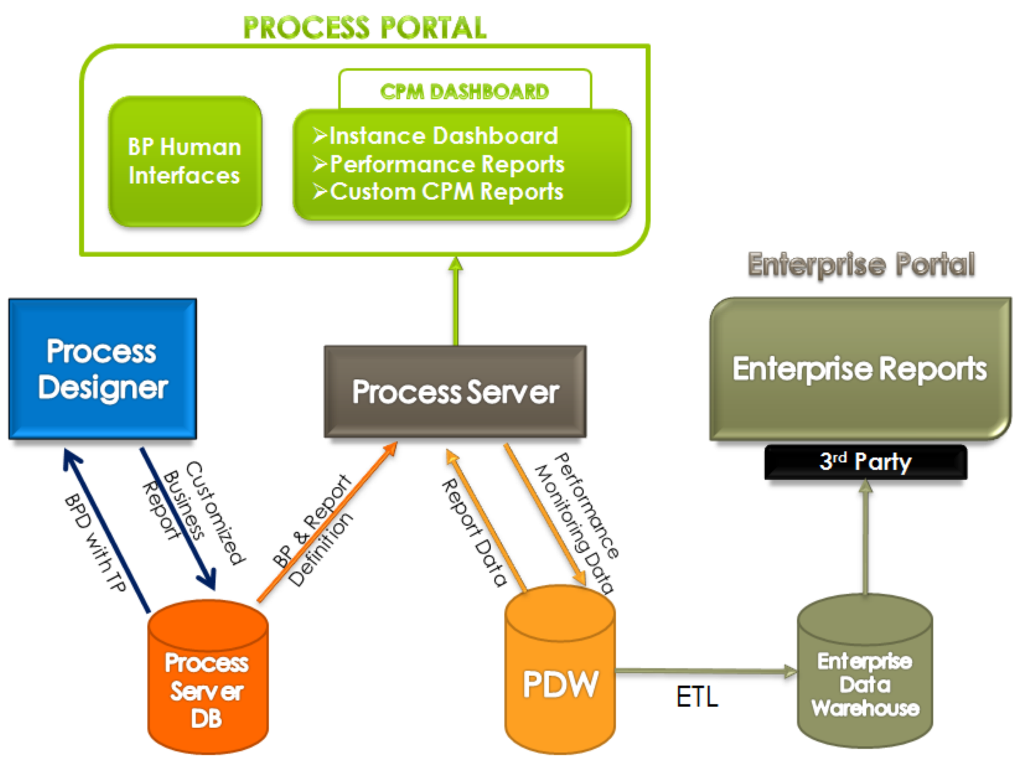


Figure 35 Optimized Performance Monitoring Architecture

We also created Customized Business Reports in the Process Designer that were saved to the Process Server DB. The Process Server then executes those reports using the monitoring data in the PDW and displays custom CPM Reports in the CPM Dashboard in the Process Portal.

Finally, it is possible to ETL monitoring data from PDW to the Enterprise Data Warehouse to support Enterprise Reports in the Enterprise Portal as described in section 3.8.3 using Third Party Tools.

4.5.2 Business Process Model

In this section, we summarize the key elements of the business process model that was built for the prototype. The business process model was built by precisely following the methodology that was detailed in chapter 3.

Figure 36 shows the departmental separation of the optimized process as described in Section 3.5.1 This was not supported in either the integrated or the standalone prototypes.

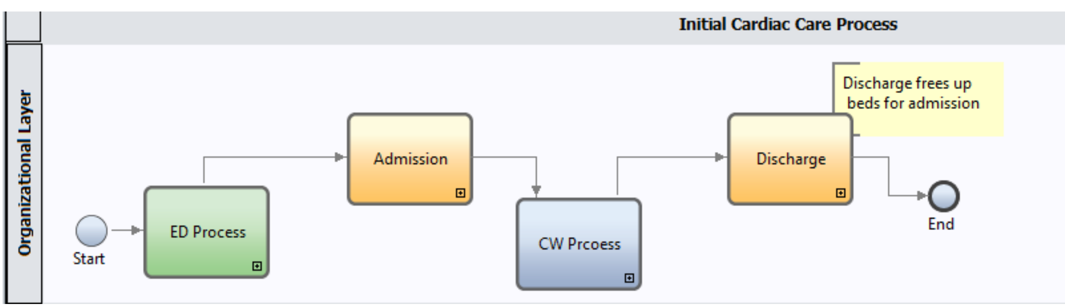


Figure 36 Optimized Organizational Care Process

Figure 37 presents the ED Process model in the optimized approach. The key features of this model comparable to the integrated (Figure 21) the standalone (Figure 30) is the ability to explicitly realize the relationship between each activity and states that belong to by using vertical lanes for grouping activities according to its state. Also, adding tracking points in the process model to capture wait time and service time for performance monitoring and driving up CPM dashboard.

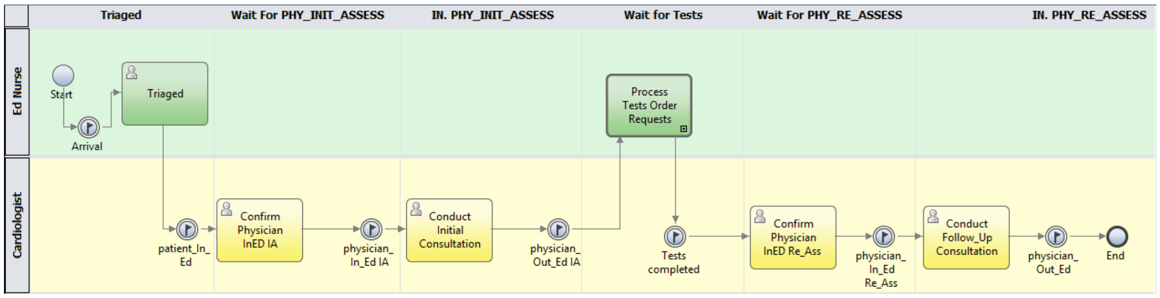


Figure 37 Optimized ED Process

Figure 38 presents a nice overview that neither the standalone nor integrated approach had which is critical to understanding wait times because of the organizations handoffs. Having tracking points and flexible message event triggering mechanisms made it much easier to deal with than the external dependencies in the integrated approach such as sending events to SME and receiving events from RTLS comparable to Figure 23.

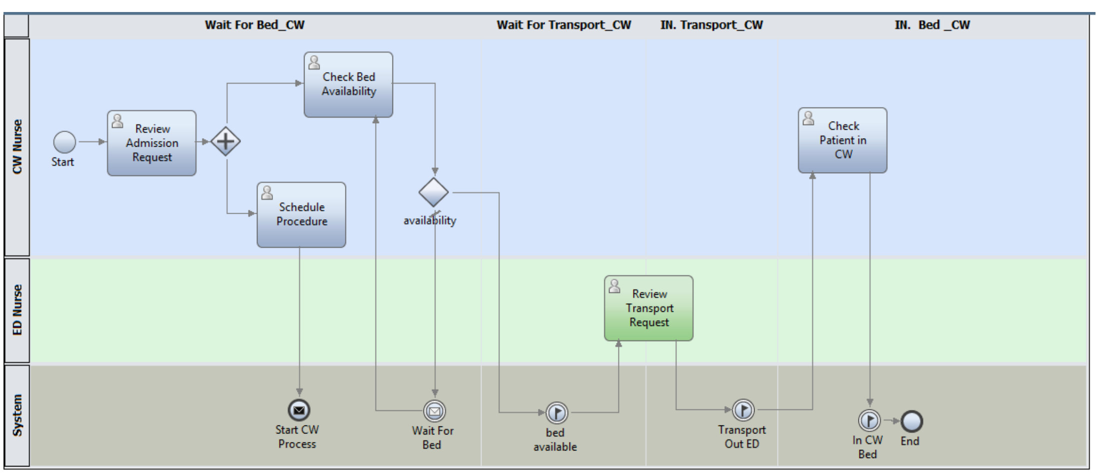


Figure 38 Optimized Admission Process

Moreover, we see the same principle at work in the examples shown in Figure 39 (compared to Figure 22) and Figure 40 (compared to Figure 25) where there are all sorts of special event messages and undercover agents and other dependencies to handle the test order request or perform the procedure.

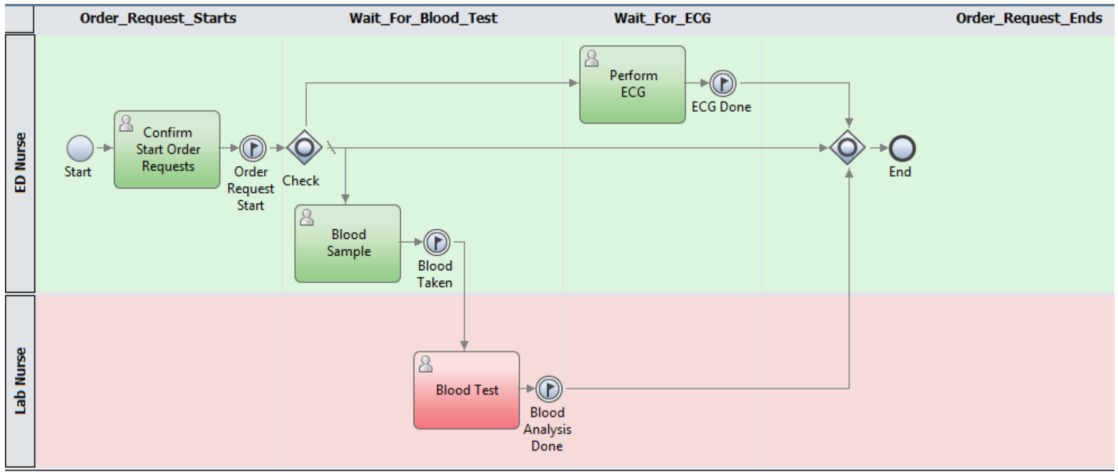


Figure 39 Optimized Sub-Process Test Order Request

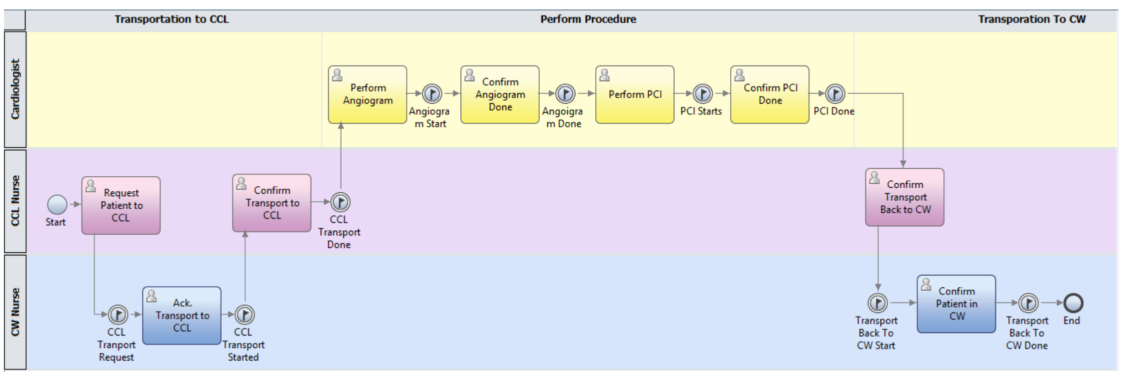


Figure 40 Optimized Process Perform Procedure

4.5.3 Performance Reports

In the optimized performance reports, we were able to do all the same reports as shown Figure 26, Figure 27 and Figure 28 that the integrated approach has. In addition, we were able to have very nicely reports integrated directly into the process itself as shown in Figure 41 where the reporting was integrated with the actual ability to click on the task and do it and Figure 42 where we can see and click on the tasks that are in alert states in different parts of the process where bottlenecks are occurring.

4.5.3.1 Task Report Page

Figure 41 presents the task report page which enables the user to keep track of tasks. The active tasks are grouped according to their states and ordered based on due dates. The left side of the dashboard displays a historical representation of the states of a team tasks. In this example, Ed Nurse has either to register patient upon arrival or triage patient as shown in the task report dashboard for ED Nurse team there is one overdue task marked with a red icon and one at risk task associated with a yellow icon and two due today associated with the green icon.

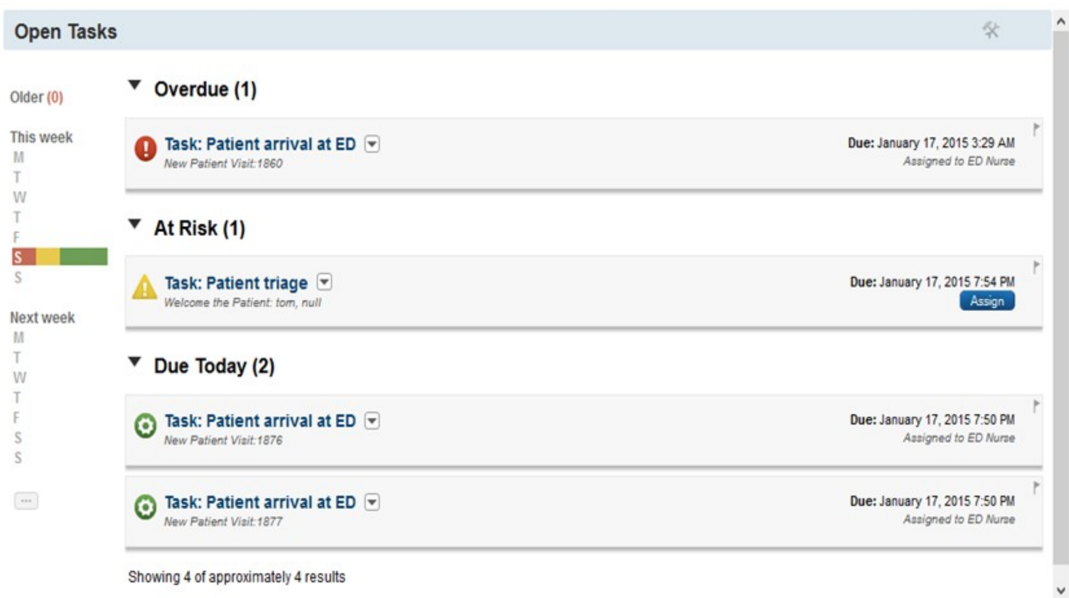


Figure 41 ED Nurse Task Page Report

In addition, the dashboard gives the ability for a team manager to reassign overdue or at risks tasks to the specific user because it is integrated into the process portal and in fact a process report definition is no different than a process definition.

4.5.3.2 Process Status Diagram Report

Figure 42 display the ED care process diagram with process status at the left side and the Instances in Progress at the right side that lists all the patients in progress starting with the longest wait time.

The main benefit of this report is to allow the users to simply visualize the overall status of the tasks, where they currently are, and what states they are currently in. This allows the users to quickly figuring and identifying where the bottlenecks are. In other words, based on the status indicators information, you can identify which tasks are causing bottlenecks. For example, as shown in the figure below gives an indication of how many patients are waiting to be preceded how many at risks and how many are overdue.

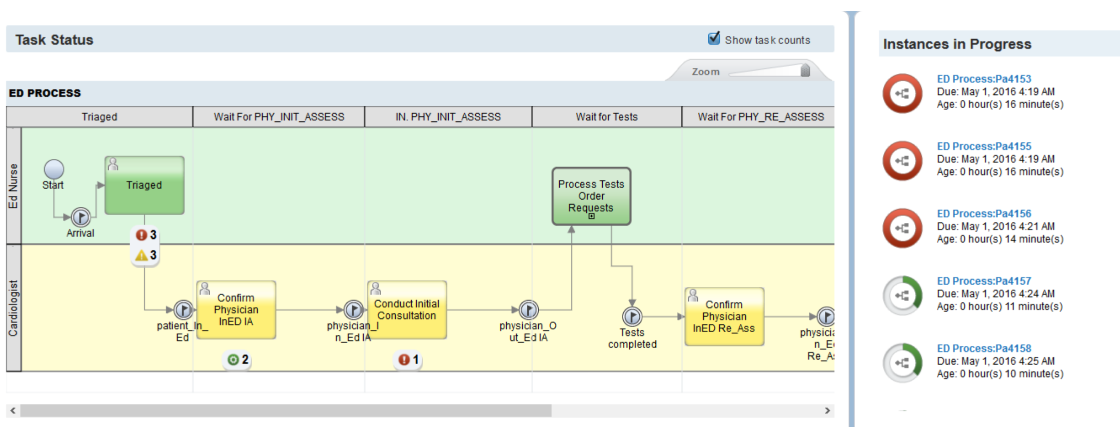


Figure 42 Optimized Process Status Diagram Report

4.5.4 Results

We briefly summarize the optimized approach as shown in TABLE 8 for evaluation purposes described in chapter 5. There are significantly more user interfaces (33 versus 22), but the identification of states is equally fine-grained as with the integrated approach (20 versus 18). More importantly, the implementation is significantly simpler that the integrated with only 3 undercover agents used. There is significant effort put into leveraging BPM performance monitoring flags and intervals (41) but this is much less complicated than the building the rules and correlating events in the CEP for the integrated approach. Moreover, the performance monitoring is clearly defined in the context of the business process model.

TABLE 8: OPTIMIZED CASE STUDY RESULTS

User Interface	Coaches/Forms	33
Performance	Flags	29
	Tracking groups	3
	Timing intervals	12
Implementation		
Integration Service	Inbound operations	0
	Publish operations	0
	Web services Integration	0
General System Service	DB2 Queries/MIE	6
Undercover Agents	Attached to MIE	3
States	Patient states	20

Chapter 5. Evaluation

In this chapter, we use the results of our case study to evaluate our approach. In particular, we compare the results of our three prototypes as described in chapter 4, and then we use the evaluation criteria we identified in chapter 3.2 to compare the Features, Developer Skills, Technology Costs and Implementation Complexity of the three prototypes.

5.1. Results

The key points we want to focus on in the results for our three prototypes are patient states and forms. Patient states are critical because for care process monitoring we want to have very fine-grained precise monitoring of each state in the process especially identifying wait states. Forms are important in terms of the cognitive burden of care providers. Part of the motivation for the integrated approach was not to require extra work in order to monitor. At the same time, it was also important to reduce the complexity of the underlying implementation, as this would make it hard to develop and maintain such applications.

TABLE 9 Summarize our case study results. The integrated approach presents a precise granularity and good identification of the states by covering 18 patient states, and a minimum impact on the user interfaces with 22 forms. While the standalone approach could not achieve the fine grain granularity by only cover 7 patient states comparing to the integrated and has a few more forms. Whereas, the optimized approach is more complex in terms of the user interfaces with 11 more forms than the integrated but nice granularity covering 20 patients, and no need to involve external technology.

In terms of using BPM performance monitoring features in the implementation, the integrated and the standalone has none while the optimized approach has 29 tracking points, 3 tracking groups, and 12 timing intervals to be able to capture the wait and service times and display it in the care process management dashboard. However, the integrated leveraged a complex set of external technology (Message Broker, CEP, SME, OLAP Database and their own customized Dashboard) to achieve the same.

TABLE 9: COMPARISION CASE STUDY RESULTS

Approach		Integrated (Baarah A. H., 2013),	Standalone (Dickman,Gilmore, & Schume, 2012)	Optimized
User Interfaces:	Coaches (Forms)	22	26	33
Performance:	Tracking Points	0	0	29
	Tracking Groups	0	0	3
	Timing Intervals	0	0	12
Implementation:	Integration Services	43	0	0
	General System Service	28	0	6
	Under Cover Agents	27	0	3
States:	Wait & Service States	18	7	20

In terms of the implementation, the integrated approach is complex having 43 integration services, 28 general system services because it rely on external sources to be able to capture the wait and service state for monitoring while the standalone has none, whereas the optimized approach has few more general services comparing to standalone but the implementation is simpler and nicely organized comparing to the integrated.

Figure 43 is a radar chart comparing the three approaches for the purpose of better presenting the results. It shows quite well the tradeoff in terms of footprint. Standalone has the smallest footprint but does very little in terms of monitoring states. Integrated has a large footprint and does well in monitoring states. Optimized has a footprint in the middle but does just as well as Integrated at monitoring states.

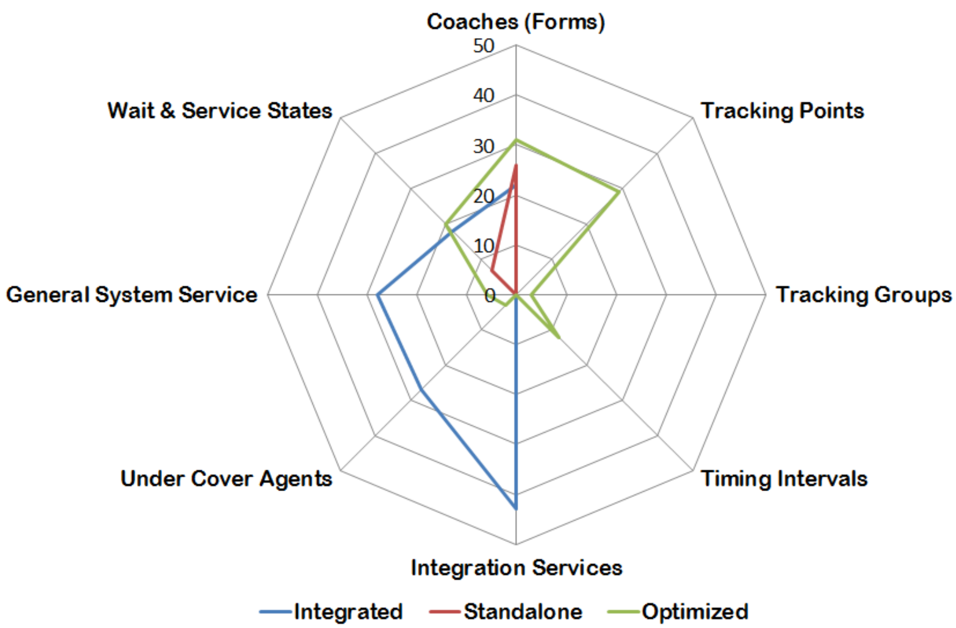


Figure 43 Radar chart comparing the approaches

To conclude, the standalone is less accurate in terms of identifying wait and service states and the integrated is more complicated in terms of the implementation. The optimized is as accurate as the integrated and almost as simple as the standalone. It does have more user interfaces but most of the extra interfaces are quite simple.

5.2. Features

Based on the criteria outlined in Section 3.2.1, TABLE 10 summarize our evaluation of following our generic methodology for care process monitoring in each of the three approaches: the integrated, standalone and optimized.

The integrated approach covers all the features but struggles in cross-organizational transitions. This is significant because this is typically where most bottlenecks happen and are difficult to detect. It is also where most of the complexity introduced by the integrated approach occurs. The standalone approach struggles in all features. Whereas, the optimized approach which is comparable in complexity to the standalone approach following our generic methodology you will get all features up and running and it is especially well suited for handling cross-organization transitions. It does, however, require more human inputs.

The advantage of the optimized is simplified like standalone with just a little more complexity but much smarter in order to get the same feature set as the integrated.

TABLE 10: FEATURES EVALUATION TABLE

Features	Integrated	Standalone	Optimized
Fine grain granularity for wait states and service states	✓	✗	✓
Detailed performance reporting of metrics eg. Wait Times	✓	✗	✓
Minimize human inputs	✓	~	~
Integrated 3rd party reporting	✓	✗	✓
Cross organizational transitions	~	✗	✓

5.3. Developer Skills

TABLE 11 lists all the skills required that was specified in (Baarah A. H., 2013) alongside the BPM Message Events skills, Tracking Points skills and Performance DB skills. The integrated approach requires sophisticated BPM skills, CEP, enterprise reporting, RTLS, and Message broker handler event skills and RTLS/CEP. While, the standalone approach require simple developer BPM skills. Whereas the optimized approach is the same as standalone with BPM message events, tracking points and performance DB skills added. The key thing is that the optimized only requires the minimal set of directly related skills beyond standalone that are part of the BPM tool for performance monitoring (Message Events, Tracking Points, and Performance DB). In particular, Message Events are a simple mechanism for handling organizational transitions. The integrated, however, requires mastering brand new and different technologies (RTLS, Message Broker, CEP, Enterprise Reporting) that are general purpose and adapt them to care performance monitoring.

TABLE 11 DEVELOPER SKILLS EVALUATION

Skills Required	Integrated	Standalone	Optimized
BPM Standalone	✓	✓	✓
BPM Message Events	✗	✗	✓
BPM Integration Services	✓	✗	✗
CEP (Complex Event Processing)	✓	✗	✗
Enterprise Reporting	✓	✗	✗
RTLS (Real Time Location System)	✓	✗	✗
IBM Message Broker	✓	✗	✗
BPM Tracking Points	✗	✗	✓
BPM Performance DB	✗	✗	✓

5.4. Technology Costs

TABLE 12 indicates everything that was specified in (Baarah A. H., 2013) also we had the process performance database.

The integrated approach requires 6 software tools and 4 servers alongside the 3 different databases. While the standalone approach only requires one software tool and 1 server alongside the performance database. Whereas, the optimized approach is same as the standalone plus the report database which is much cheaper in terms of the number of licensed software, hardware, and databases in comparison to the integrated approach.

TABLE 12 TECHNOLOGY COSTS EVALUATION

	Integrated	Standalone	Optimized
Software Tools	IBM Business Process Manager (BPM)	IBM Business Process Manager (BPM)	IBM Business Process Manager (BPM)
	Ekahau RTLS		
	IBM WebSphere Business Events		
	Generic BI Application		
	IBM Message Broker		
	Complex Event Processing Event		
Hardware	4 servers required	1 server required	1 server required
Database	Report DB	Process Performance DB	Report DB
	RTLS DB		Process Performance DB
	CEP DB		

5.5. Implementation Complexity

TABLE 13 shows the comparison of implementation complexity between the integrated, standalone and optimized as explained in Section 3.2.4. You can see that the number of process activities is about the same the number of activities is slightly less in the standalone and optimized rather than the integrated approach because they needed to have a less special activity to manage the interaction with external systems and the optimized is even better because our structuring makes it simpler. In terms of human interfaces that people have to interact with, the integrated has 22 and there is 4 slightly more in the standalone, whereas in the optimized there is 11 more in order to get the precise fine-grained capture so that looks a little bit more complex.

However, the decision event processing is greatly simplified in the optimized with far fewer events and much less complexity. Also, there much less complexity in trying to do the reports outside of BPM that require low-level hard coded and low-level custom enterprise reports and very effective report inside BPM nicely integrated. The system integration was much more for the integrated including RTLS, SME, Message Broker and Enterprise Report System while greatly simplified in both standalone and optimized.

Moreover, in terms of developer effort, the implementation duration of the integrated approach took 2 graduate students including the thesis researcher and terms of the implementation duration it took almost 8 months /long time/ to implement regarding hard coding GRAILS application code and SQL query for reports, with custom code CEP rules and Event handler. While the standalone and optimized took a single BPM developer 2 to 3 months for each to implement.

To conclude, you can see on balance that both standalone and optimized are clearly simpler than the integrated in terms of implementation complexity and developer efforts, whereas the standalone paid a heavy price in terms of its features, while the optimized was able to obtain the same feature as the integrated with less implementation complexity and less developing effort on BPM that is easier to manage you can get better results.

TABLE 13: IMPLEMENTATION COMPLEXITY

Business Process Model Complexity factors:	Low	Medium	High	Integrated	Standalone	Optimized
Process Activities	15	30	60+	49 🟡	38 🟡	36 🟡
Coaches (user interfaces)	10	15	20+	22 🔴	26 🔴	33 🔴
Decisions / Events	1	5	6+	9 🔴	6 🟡	4 🟢
Reports	4	6	8+	0 🟢	4 🟢	7 🟡
System Integrations	2	3	4+	4 🔴	0 🟢	1 🟢
Developer Efforts:						
Implementation Duration	10 weeks	14 weeks	20 weeks	34 W 🔴	10 W 🟢	19 W 🟡
Developer Hours	900-1500	1500-2500	2500-5000	5700 🔴	1680 🟢	3024 🟡
Number of Developers	2-3	3-4	4-5	3 🔴	1 🟢	1 🟢

Chapter 6. Conclusions and Future work

6.1. Conclusions

The key methodological point in our research is that we built performance monitoring into the BPM in a structured fashion while in the integrated approach they built a separate application model. Our focus was on structuring and simplifying the implementation complexity of the business process model, while integrating care process monitoring into the business process model. There were no attempts to simplify the care process itself or what the care providers monitored.

However, what we both agree with is that we should explicitly model performance monitoring. The problem with the standalone approach is it is hard to understand or figure out what process and what is performance monitoring. However, in the integrated approach, there was much mysterious and complicated processing in order to deliver and receive events from external systems, so to some extent, it also suffered from the unwanted mixing of process and performance aspects in the business process model. Only the optimized was able to integrate both in a simple manner that kept the two aspects clearly separated.

In practice, we have not proved that our optimized approach is better than the standalone or integrated approach because we have not tested it yet on enough different types of users and processes. However, in the laboratory according to the results we have showing that our optimized approach has the potential to be better than the standalone and the integrated approach.

To conclude, our research is based on a Design Science research, If you expect that our experiment in the lab reflects reality reasonably well and reasonably justify the criteria, then this experiment has shown the advantage of our optimized approach that is simplified like standalone approach with just a little more complication but much smarter in order to get the same feature set as the integrated approach.

6.2. Future Work

Since our research is based on a Design Science research and is an early research. This research has been demonstrated in the laboratory and we felt that there is a potential in our optimized approach. Also, we deliberately set up integrated vs. standalone vs. our optimized approach to maximize the contrast between them to prove that there is a potential in our optimized approach. Many opportunities for extending the scope of this research remain:

- Explore the relationship between the integrated and optimized approach in more detail. At the level of integration, there is a need to provide data to the enterprise data warehouse for enterprise reporting and there may be advantages to some care processes to receive events in real time from RTLS or other systems.
- Apply our generic methodology into more care process monitoring applications at other hospitals with other care processes to ascertain that our approach is practical. Thus, more developers are required alongside us to follow our methodology and build better tool support and documentation.

- In the event the BPM requires receiving events from other systems, we should investigate how to structure and define that interaction in a systematic manner (possibly by extending our current methodology. e.g. RTLS system to know the location, Notifications or Alerts from Enterprise Reporting that initiates business processes.

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