# Integrating Business Process Management to Model Context in Healthcare: A case study using perioperative processes

By

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# Abstract

A growing number of initiatives in recent studies have continued to pursue improvements in e-business through the use of Business Process Management (BPM) methods and tools. However there are still some limitations that need to be addressed. While BPM has been beneficial in healthcare, there are issues around context. These involve a clear need for approaches that facilitate the understanding of context when implementing healthcare processes.

This thesis introduces a BPM framework and its supporting methodology for representing and modeling context for information systems design. Scenario compositions are developed as a mechanism for linking descriptive workflow information and graphical models representing many viewpoints involved in the system development and use processes. Design patterns are used as a common information platform to bridge different context representation formats. By combining scenarios and design patterns representing context, chains of relations between context, their triggering factors, and their influences on user actions can explicitly be described and modeled.

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## List of Acronyms

| Acronym | Definition |
| --- | --- |
| BPM | Business Process Management |
| BPD | Business Process Diagram |
| EMR | Electronic Medical Record |
| HIS | Health Information System |
| HIT | Health Information Technology |
| HL7 | Health Level Seven |
| IT | Information Technology |
| ICT | Information and Communication Technology |
| ICU | Intensive Care Unit |
| OMG | Institute of Medicine |
| OR | Operating Room |
| PACU | Post-Anesthesia Care Unit |
| PAU | Pre Admission Unit |
| RN | Registered Nurse |
| SDA | Same Day Admit |
| SDC | Surgical Daycare |
| SDCU | Surgical Daycare Unit |
| SIMS | Surgical Information Management System |

# Chapter 1: Introduction

Business processes are executed in an environment in which changes are usual, and modeling perspectives that aim to represent and understand them are necessary (De La Vara, Ali, Dalpiaz, Sánchez, & Giorgini, 2010). Context, defined as any information that can be used to characterize the situation of the entities that are considered relevant to the interaction between a user and an application, including the user and the application themselves (Dey, 2001) should therefore be taken into account when executing a business process. If context is analyzed when executing a healthcare process, then identification of all its variants and definition of how the healthcare process should be executed in them can be facilitated.

An integrated business process management (BPM) methodology is essential to better model context and understand its role in process execution. The BPM lifecycle contains several iterative steps with a goal to improve the quality of business processes in an incremental way (Hill et al., 2006; Havey, 2005; van der Aalst et al., 2003). Figure 1 is a BPM life cycle proposed by Weske, (2007) which gives an overview of a typical model-driven lifecycle, starting with the design and analysis of business processes. Design means explicitly modeling, designing, simulating and redesigning the process as the organization learns what is possible (Smith & Fingar, 2006).

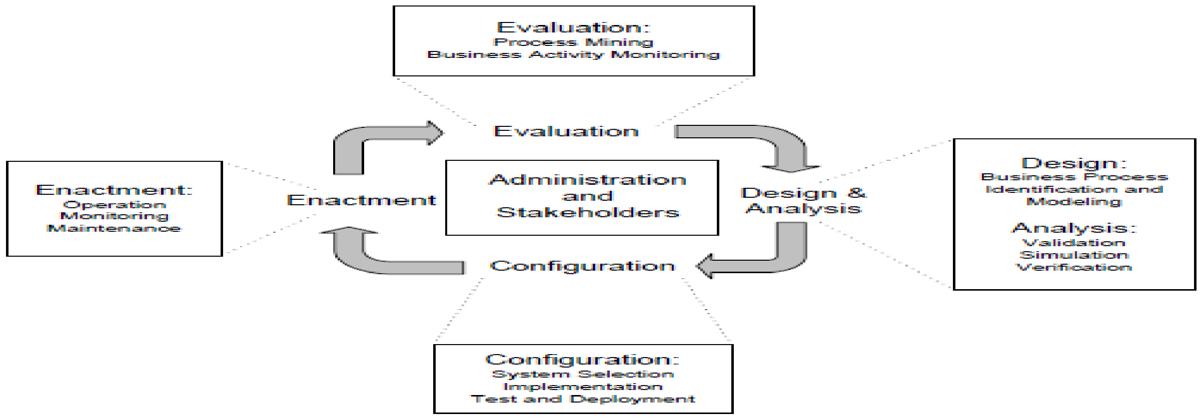


**Figure 1: BPM Life cycle (Weske, 2007)**

Usually, the focus of the design phase of the BPM lifecycle is to identify, review, validate, and represent business processes as process models (Weske, 2012) and (van der Aalst, ter Hofstede, & Weske, 2003). We believe this phase also offers opportunities for the explicit modeling of context so as to evaluate and design a system that facilitates the execution of healthcare processes in their associated context along diverse dimensions. To support the evolution of context modeling in healthcare, the objective of this study is the conceptual modeling of context in the healthcare sector based on the philosophy of business process models. In this work, we use a case study from which we establish scenarios, develop a set of patterns that represent context, and assess how well Business Process Modeling Notation (BPMN) can model them. Our intention when modeling context is that of facilitating the visualization and understanding of the activities that are carried out in the fulfilment of healthcare processes.

## 1.1 Problem Statement and Motivation

The healthcare environment is a complex sociotechnical environment where a well-designed technology may fail because of contextual issues (Kuziemsky & Bush, 2013) and (Sittig & Singh, 2010). The ability of organizations to successfully manage context greatly relies upon the effectiveness of systems that support healthcare processes that are constantly changing and the ability of process participants to understand and reason about the constantly changing business processes (Ramesh, Jain, Nissen, & Xu, 2005). Further, different healthcare units, even within the same healthcare organization contain different processes because of differences in the nature and purpose of the work performed. Explicit representation of context is therefore helpful for understanding and executing healthcare processes at various levels of healthcare. This research is motivated by the need to develop an integrated BPM framework together with a methodology that helps us to better understand and model context.

## 1.2 Outline of the Thesis

The content of this thesis is divided into five chapters. In chapter 1, an introduction of Business Process Management and context as they relate to healthcare is described. In addition, a brief explanation regarding the importance of using BPMN as a useful language for modeling context is also presented.

Chapter 2 is a review of the relevant literature that has been carried out in the areas of context modeling and business process management. This chapter also defines the underlying concepts for the issues addressed in this thesis by providing background information on context within healthcare, accompanied by a description of the modeling languages that could potentially be used to model context. A number of studies have been performed on context; all of which provide detailed reviews on various languages and modeling methods associated with context modeling.

Chapter 3 presents and discusses our proposed integrated BPM framework and methodology for modeling context in healthcare using several iterative stages.

Chapter 4 uses the case study: "Coordination of perioperative care processes" to implement the stages of the proposed methodology. Also in this chapter, different types of models and representations of context based on patterns are used to illustrate our approach to model context.

Finally in Chapter 5, we present a discussion of the research followed by a summary of our contributions, the research limitations, and possible future extensions to the thesis.

## 1.3 Contributions of the Thesis

The main contribution of this study is an integrated BPM framework together with a methodology that helps us to better understand and model context. The framework describes how BPM with its comprehensive end-to-end set of activities can better model context in order to better design and evaluate HIT to support different contextual information and issues. The methodology of the framework is based on four stages; context analysis, development and modeling of scenarios, identification and selection of patterns and, representation of context in BPMN. Each stage contains an objective, a task and an output that is vital for designing and modeling context. In addition to the framework, we also developed a number of basic contextual patterns that we used for the representation of context in BPMN. We also provide a summarized table of the most used patterns in a process environment such as healthcare from three perspectives: process or control flow perspective, data perspective and resource perspective. These perspectives provide the basis for motivating design choices in modeling context. In our final contribution, we operationalized (i.e. is expressing the stages of the methodology in practical or operational terms) the four stages of our proposed methodology to illustrate our concept of modeling context using a case study. Operationalization is the process of putting the concepts of interest into operation or of operating on those concepts in order to "measure" them, both individually and/or in relation to other concepts (Martin, Cohen, & Champion, 2013).

During the operationalization of the proposed methodology, we found that representing the use of an information system or application with a set of user interaction scenarios can make the use of the system explicit, and in doing so positions the design and evaluation of the system toward a broader view on how to model context. Such a broader view of context has led us to answer the following research questions:

- How can context be better modeled by the integration of BPM?
- Can a BPM framework be developed to meet these modeling requirements?
- How can patterns be used for modeling context?

# Chapter 2: Literature Review

The literature review for this study involves the review of scholarly journal articles, books and conference papers strategic to BPM and context. Of all the papers reviewed, an opinion that remained constant is BPM is an emerging approach that has been used successfully in many industries, but very rarely has been applied to healthcare (Hess, 2009), (Mans, Schonenberg, Song, Aalst, & Bakker, 2009) and in particular, context modeling. Given the considerable range of contributing theories the literature review is segmented to review the concepts below:

## 2.1. Integration and Interoperability

The support of healthcare processes is usually closely related to application integration. The reason is that a typical healthcare information system is characterized by many different departmental systems, that are usually optimized to support different medical disciplines, but not for cross-departmental processes (Lenz & Reichert, 2007). The need to consolidate the data produced by these ancillary systems to support cross-departmental processes promotes the need for integration for data and message interchange in healthcare. Monteiro, (2003) confirms that “poorly co-ordinated and largely independent work processes are integrated in an effort to remove redundant operations, sort out ambiguity and cut back on secondary, administrative overhead”. In addressing issues of process support in healthcare, Lenz, Peleg, & Reichert, (2012) and Namli & Dogac, (2010) reason that integration provides the basis for IT-based support of healthcare processes. According to El Azami, Malki, & Tahon, (2012), for integration to be fully accomplished, the three essential factors of data, functions and workflow are necessary. Lenz & Kuhn, (2003) and Leisch, Sartzetakis, Tsiknakis, & Orphanoudakis, (1997) introduce the additional components of interoperability and standardization as essential to integration.

Interoperability, on the other hand ensures the integration of data and processes to support collaboration and other healthcare activities and allows disparate applications within diverse healthcare facility to "talk to and understand" one another (Lau & Shakib, 2005). Kutvonen, (2005) emphasizes that facilitating interoperability of Business Process Management activities must be seen in the context of collaborative systems. Khan, Hussain, Latif, Afzal, Ahmad, & Lee, (2013) provide a view that though interoperability enables healthcare systems to communicate, and exchange data accurately and effectively, the broader goal of interoperability can only be achieved when standards are practiced

## 2.2. Business Process Management (BPM)

A business process is a "coordinated chain of activities intended to produce a business result" (Becker, Kugeler, & Rosemann, 2007) or a "repeating cycle that reaches a business goal" (Debevoise, 2005). People from different units and organization are usually involved to complete an end-to-end process. In the setting of healthcare, Ruiz, et al., (2012) define business process as a set of activities that deliver value to the customers in healthcare, (e.g., to patients and staff members). Processes can be simple and restricted to a functional unit of an organization or complex and cutting across several business partners (Lenz & Reichert, 2007). The complexity of the healthcare environment requires much unit-to-unit cooperation to complete a process and often massive integration between different information systems. However, legacy software applications are generally designed based on different functional units of organizations, hindering integration (Bruce Silver Associates, 2006). Lenz &

Reichert, (2007) categorize business processes in healthcare into medical processes and organizational processes. For this thesis, we classify healthcare organizational processes as business processes that are executed in the clinical environment. This definition of process is consistent with the definition in Alter & Roche, (1999) that a "business process is a related group of steps or tasks that use people, information, and other resources to create value for internal and external customers".

Business Process Management (BPM) on the other hand is the management of diverse and cross-organizational processes using methods and tools to support the design, execution, management, and analysis of business processes (Pourshahid, et al., 2009). BPM is also defined by van der Aalst, ter Hofstede, & Weske, (2003) as 'a field of knowledge at the intersection between business and information technology, encompassing methods, techniques and tools to analyze, improve, innovate, design, enact and control business processes involving customers, humans, organizations, applications, documents and other sources of information'.

Smith & Fingar, (2006) emphasize that BPM not only encompasses the discovery, design and deployment of business processes, but also the executive, administrative and supervisory control over them to ensure that they remain compliant with business objectives for the delight of customers. In healthcare, BPM is used to represent healthcare processes so as to design systems that are suitable to support those processes (Benyoucef, Kuziemsky, Rad, & Elsabbahi, 2009).

## 2.3. Context

Several definitions of context have been proposed, however, there is no real agreement on the definition of context as it is used in many research fields (Coutaz & Rey, 2002) and

(Henricksen, Indulska, & Rakotonirainy, 2002). Dey, (2001) defines context as any information that can be used to characterize the situation of the entities that are considered relevant to the interaction between a user and an application, including the user and the application themselves. This definition is adopted by most researchers and considered the most complete definition. Using Dey's definition and based on their conception about context in relation to its descriptors, Ejigu, Scuturici, & Brunie, (2007) consider the term context as an operational term whose definition depends on the interpretation of the operations involved on an entity at a particular time and space rather than the inherent characteristics of the entity.

Chaari, Laforest, & Flory, (2005), however contend that the definition of context by Dey does not separate the data related to the context of an application. They believe that the separation of the data is crucial to designing a system responsive to context. To this end, Chaari, Laforest, & Flory, (2005) extended the definition of Dey by defining context as a set of external parameters of an application that may affect its behavior by defining new views of its data and services. Strang, Linnhoff-Popien, & Frank, (2003) define context as the set of all context information characterizing the entities relevant for a specific task in their relevant aspects. They further classify context information as any information which can be used to characterize the state of an entity concerning a specific aspect. An entity is defined as a person, a place or in general an object. An aspect is a classification, symbol, or value-range, whose subsets are a superset of all reachable states, grouped in one or more related dimensions called scales, and context situation is the set of all known context information. The definitions of context and context information by Linnhoff-Popien, & Frank, (2003) are very similar to other definitions of context by Dey, (2001), but refine the expressiveness by introducing the terminology of an aspect.

According to Born et al. (2009), context defines the environment in which a business process is used. In applying the concept of context, Novak, Brooks, Gadd, Anders, & Lorenzi, (2012) explain that a technology by itself does not structure the activities of individuals in organizations, and should be adapted to the specific context of use by knowledgeable organizational actors. Pascoe, (1998) simplifies the definition of context by stating that context is a subset of the physical and conceptual state that has interest to a particular entity.

In BPM, context can be classified into several categories reflecting the nature of the information observed and treated. UN/CEFACT, (2003) introduced the concept of business context and group context into categories such as: business process context, roles context, roles support context, system capacity context etc. Saidani, Rolland, & Nurcan, (2015) term the categorization of context as important to identify the context elements that are related to the actor, process, resources and the business environment so as to better represent them in BPM.

Koppel, et al., (2005) applied a conceptual integration of context with process models to model inconsistencies or distortions among three realities in order to derive a procedure for identifying context relevant to a given process. They proposed that to improve an HIT, organization of problems into a systematic typology that can be understood and remedied is crucial. Kuziemsky & Kushniruk, (2014) on the other hand emphasize that regardless of how well HIT is designed; there is frequently a chasm between the ostensive dimension and performance dimension (actual measurable circumstances of HIT usage). The identification of specific performance contexts could better position healthcare to account for these contexts as part of HIT design and evaluation. Challenged by the complex notion of context, Sato, (2004) represents context through “a pattern of behavior or relations among variables that are outside of the subjects of design manipulation and potentially affect user behavior and system performance".

In the healthcare setting, McCormack, Kitson, Harvey, Rycroft-Malone, Titchen, & Seers, (2002) used the term context to refer to the environment or setting in which people receive healthcare services. Such an environment has boundaries and structures that together shape the environment for the delivery of healthcare. According to Chin, (1985), the environment in which healthcare practices occur can be seen as 'multiple-clusters and multiple-systems environment'. Chin reasons that components of an organization can be clustered in a variety of ways, from straightforward environments that are simple and plain with no clear salient features that represent the uniqueness of a particular environment, through to a turbulent environment where there are multiple clusters and multiple systems. Each has its own dynamic interaction with the environment as well as having multiple interactions with the total environment. Thus, the environment is seen as a collection of 'force-fields' that are constantly changing and never remain static (McCormack, Kitson, Harvey, Rycroft-Malone, Titchen, & Seers, 2002).

In addition to the various definitions that present context as a set of information that characterizes a situation, Zhou, Zhang, Zeng, & Qian, (2010) uniquely define context as any information characterizing the situation of a task session or an interaction between a user and his/her service world. They categorized context as user context, service context, process context and peer context and provide a summary of the definition of context that states that context does not only encompass information about the user, but also the condition under which the resources and service providers operate. While we adopt the definition of context in (Dey, 2001), we do, however, extend this notion of context to include the definition of context in (Zhou, Zhang, Zeng, & Qian, 2010) for the purpose of this thesis.

## 2.4. Context Modeling

Graphically documenting and displaying business processes in healthcare to analyze and optimize clinical processes during requirements elicitation for clinical information systems and for general process quality improvements is called Business Process Modeling (Staccini, Joubert, Quaranta, Fieschi, & Fieschi, 2001). This is a structural method that helps participants analyze processes and find possible points of improvements.

Context modeling on the other hand allows the description and the structuring of contextual situation of a task session or an interaction between a user and his/her service or tasks (Saidani, Rolland, & Nurcan, 2015). Context modeling addresses special requirements of ubiquitous computing environments like distribution, heterogeneity of context sources and resource-constrained devices. According to Ejigu, Scuturici, & Brunie, (2007) context modeling deals with how contexts are collected, organized, represented, stored and presented. In addition to defining context modeling, Ejigu, Scuturici, & Brunie, (2007) also argue that entities in pervasive environments need to be context-aware so that they can adapt themselves to changing situations. This requires domain independent context models for context representation, and context management and interoperability.

Reichle, et al., (2008), provide that a context model provides an unambiguous definition of the context artifacts, their representations, and usage. Business process modeling notations should therefore be able to model these aspects of a process. Reichle, et al., (2008) further propose that context models should not be monolithic, but rather be flexible and extensible. New applications and possibly new context nodes shall be allowed to enter the system. As the applications and their context needs evolve, so should the context model.

A multitude of classifications have been proposed for context models based on the data structure used for the description and exchange of context (Chihani, Bertin, & Crespi, 2013) and (Bettini, et al., 2010). Strang and Linnhoff-Popien, (2003) assess the most appropriate context approaches based on the data structures used for representing and exchanging context information to include key-value pair, markup scheme, graphical, object oriented, logic based and ontology based models. According to the evaluation of Strang and Linnhoff-Popien, (2003), the most promising assets for context modeling are found in ontology based models.

Mathisen & Krogstie, (2012) emphasize that the implementation of traditional process modeling in healthcare is challenging in many respects. They apply process modeling to capture and describe the decision requirements (i.e. knowledge, expertise, goals, resources and information requirements communication and coordination needs) related to the perception, comprehension and projection of a situation leading up to a critical decision. The aim of Mathisen & Krogstie, (2012) was to investigate how they could model these requirements as extensions to conventional process modeling languages such as BPMN and address the areas representing aspects of coordination, communication and decision making in clinical processes. Neumuth, Loebe, Herre, & Neumuth, (2011) developed a unifying framework for surgical process modeling by using common underlying formalization. However, a shortcoming of this framework is that it views surgical processes as very standard and does not consider how context influences the processes.

Honle, Kappeler, Nicklas, Schwarz, & Grossmann, (2005); Lei, Sow, Davis II, Banavar, & Ebling, (2002); and Schmidt, Aidoo, Takaluoma, Tuomela, Van Laerhoven, & Van de Velde, (1999) emphasize the importance of integrating meta-data into the context model. In addition, Honle, Kappeler, Nicklas, Schwarz, & Grossmann, (2005) provide that meta-data enable important aspects like the assessment of the quality of context information and data cleansing and offer more flexibility when dealing with context information. In the approach of Honle, Kappeler, Nicklas, Schwarz, & Grossmann, (2005), meta-data are associated to context information at object level as well as at attribute level.

### 2.4.1. Process Modeling Languages

Process models can be created or presented by using many different techniques or languages such as Business Process Modeling Notation (BPMN), (OMG, 2011), YAWL (Ter Hofstede, van der Aalst, Adams, & Russell, 2009), BPEL, and UML activity diagrams (Object Management Group, 2007). These languages are very different from one to another, since each one has a different focus for representing the behavioural aspects of an organization (Dufresne & Martin, 2003). Among the languages for modeling business processes mentioned in the literature, none contain explicit elements for modeling context. While extended workflow models for handling context information have been developed under the term of context-aware workflows (Wolf, Herrmann, & Rothermel, 2009), (Wieland, Kaczmarczyk, & Nicklas, 2008) and (Ardissono, Furnari, Goy, Petrone, & Segnan, 2007), the workflows in themselves are not context providers (Wieland, Nicklas, & Leymann, 2011). This shows that a context model for BPM is needed.

Many comprehensive approaches for context model specification and management like the Context Modeling Language (CML) and its associated software engineering framework (Henricksen & Indulska, 2006) and Augmented World Language (AWML) (Grossmann, Bauer, Honle, Kappeler, Nicklas, & Schwarz, 2005) are currently presented. While a shortcoming is that many of these languages do not properly capture context, a review of these languages can help in determining the appropriate language needed to model and represent context as a result of the plethora of requirements that may arise in contemporary healthcare processes. BPMN attempts to articulate context by offering not only a predefined set of elements and relationships, it also attempts to answer the famous W5 questions of modeling - Why, What, Who, Where and When (Ruiz, et al., 2012). An answer to the why helps with specifying the requirements of business process model behind a process (Pourshahid, et al., 2009) and answers to the last four questions are useful in defining context.

#### 2.4.1.1 Augmented World Modeling Language (AWML)

The Augmented World Modeling Language (AWML) supports the modeling and management of standardized and extensible context models (Grossmann, Bauer, Honle, Kappeler, Nicklas, & Schwarz, 2005). The AWML is based on the Nexus context management platform with an objective to integrate various local context models to a common view for applications. The core of the NEXUS platform is the Augmented World Model (AWM) that serves as a common, yet extensible integration schema (Nicklas & Mitschang, 2004). The AWM provides the whole location context for context aware applications. This includes the representations of static real-world objects such as houses, streets and offices, mobile objects such as human users, cars and trains, but also virtual objects with which the real world is augmented. Examples for such virtual objects are virtual billboards; virtual Post-its or virtual kiosks (Bauer, Becker, & Rothermel, 2002).The augmented world model is described using the AWML. Objects in AWML have attributes that give their geometry relative to some coordinate system. The AWML not only models geographic location and the geometry of objects, but also symbolic descriptors of the objects such as room numbers and explicit relationships between objects, such as the part-of relation (Bauer, Becker, & Rothermel, 2002).

The objects to be modeled in this thesis contain very different levels of detail. AWML is not deemed a suitable language, as the data objects of the AWML are mostly related to geographic location, geometry of objects, and symbolic descriptors of the objects such as room numbers and explicit relationships between objects (Bauer, Becker, & Rothermel, 2002). These data objects do not comprise methods or behaviors (Grundspenkis, Morzy, & Vossen, 2009) that are especially important when integrating context data from diverse sources.

#### 2.4.1.2. Business Process Modeling Notation (BPMN)

Business Process Modeling Notation (BPMN) is one of the most widely used process modeling notations developed by the OMG which offers a range of notational detail to capture quite complex business processes. One of its strongest features is its simplicity in providing a language easy to understand and usable by people with different roles and training (Magnani & Montesi, 2009). Ruiz, et al., (2012) describe BPMN as the industrial standard for modeling business processes and further emphasize that while BPMN models can be used to support communication between domain experts and computer scientist. BPMN also aims at serving as a communication bridge between business users, who are devoted to the process design, and technical people, who are responsible for the process implementation, both using their own terminology and ontology.

White, (2009) identifies four main categories of the elements of a BPMN diagram: flow objects, connecting objects, swim lanes, and artifacts. These basic elements provide support for modeling sequence flow, roles, activities, events, and process hierarchies (Weske, 2012). Despite its easy to understand nature and potential for modeling context based on the concept of patterns, the analysis provided for BPMN in (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005) and (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2006) outlines that BPMN still lacks support for (or provide limited support for) some workflow and other business process patterns.

#### 2.4.1.3. Business Process Execution Language (BPEL)

Ter Hofstede, van der Aalst, Adams, & Russell, (2009) describe BPEL as the combination of microsoft's XLANG and IBM's web services flow language and term it a language that marries two fundamentally different approaches to the specification of executable business processes. According to Weske, (2012), BPEL uses a block structuring where business processes are specified in terms of self-contained blocks that are composed to form larger more complicated blocks. The language can be used to characterize both abstract processes and concrete processes (Weske, 2012). Abstract processes describe the externally visible behavior of a business process. They mainly serve communication purposes, so operational details are disregarded (Weske, 2012). Ter Hofstede, van der Aalst, Adams, & Russell, (2009) consider BPEL a clear step forward in terms of its support for the specification of control flow dependencies. However, the language provides no support for the involvement of human participants in the execution of business activities (Ter Hofstede, van der Aalst, Adams, & Russell, 2009) that are context dependent. In addition, the language also lacks components for modeling and representing the constructs of context in a language independent way.

### 2.4.1.4. Context Modeling Language (CML)

Context modeling language and its associated software engineering framework presented by Henricksen & Indulska, (2006) provides a graphical context modeling approach to assist designers with the task of exploring and specifying the context requirements of a context-aware application. It provides modeling constructs for describing types of information (in terms of fact types), their classifications (sensed, static, profiled or derived), relevant quality meta-data, and dependencies amongst different types of information. CML allows fact types to be annotated to indicate whether ambiguous information is permitted (e.g., alternative location readings), and whether historical information is retained. It also supports a variety of constraints, both general (such as cardinality of relationships) and special-purpose (such as snapshot and lifetime constraints on historical fact types).While this context modeling approach is complemented by a model-driven development approach that offers an application program interface (API) for the application developer and a methodology for the development of context application (Henricksen & Indulska, 2004), it does not address the issues of heterogeneity regarding representation of context (Reichle, et al., 2008). API is a set of routines, protocols, and tools for building software applications (Bisso & Maki, 2006). APIs specify how software components should interact and are used when programming graphical user interface (GUI) components (Bisso & Maki, 2006).

### 2.4.1.5. Yet Another Workflow Language (YAWL)

YAWL is another business process modeling language, which addresses some of the limitations of other existing languages for modeling workflow patterns (Van der Aalst & Ter Hofstede, 2005). YAWL was established in the context of the Workflow Patterns Initiative and provides comprehensive support for both control flow and resource patterns (Ter Hofstede, van der Aalst, Adams, & Russell, 2009). Despite its support for modeling, analysis and enactment of flexible processes through the use of worklets (Adams, Ter Hofstede, Edmond, & van der Aalst, 2005), YAWL lacks a better approach to process analysis and enactment (ter Hofstede, van der Aalst, Adams, & Russell, 2010) and employs the use of worklets that have not shown applicable to context modeling & representation

The modeling languages described above are very distinct from one to another and as such, each one has a different emphasis for representing processes in an organization. (Dufresne & Martin, 2003). Table 1 is a comparison of the different modeling languages which establishes a general overview of the current landscape of the modeling languages.

**Table 1: Comparison of the different modeling languages**

| Language | Focus | Limitation | Suitability |
|---|---|---|---|
| Augmented World Modeling Language (AWML) | Management of standardized and extensible context models. | Attributes are mostly related to geographic location, geometry of objects, and symbolic descriptors of objects such as room numbers, etc. | Does not appear to model or represent contextual attributes that involve a method or behavior. |
| Business Process Execution Language (BPEL | Provide web service a textual and executable language targeted at application developers. | Less suited for direct use by humans to design, manage, and monitor the business processes that are enacted by process-aware information systems. | The language lacks components for modeling & describing the constructs of context in a language independent way. |
| Business Process Modeling Notation (BPMN) | Provide a comprehensive, integrated notation for process modeling of business processes. | While direct support for the majority of control-flow patterns and data patterns is effective, support for the resource patterns is scant. | Potential for modeling context based on patterns. |
| Context Modeling Language (CML) | Provides a graphical context modeling approach, to assist designers with the task of exploring and specifying the context requirements. | Does not address issues of heterogeneity regarding representation of context. | Not suited for specifying the context requirements of the disparate systems in healthcare. |
| Yet Another Modeling Language (YAWL) | Provides comprehensive support for both control flow and resource patterns. | Lacks a better approach to process analysis and enactment and have not been shown to model context. | Employs the use of worklets that have not shown applicable to context modeling & representation. |

## 2.5 Health Information Technology

There is an increasing consensus among healthcare experts that health information technology (HIT) can significantly contribute to improve healthcare quality (Kohn, Corrigan, & Donaldson, 2000). According to Medicare Payment Advisory Commission, (2004), delivering quality health care requires the integration of complex information from many different sources. Thus, increasing the ability of physicians, nurses, clinical technicians, and others to readily access and use the right information about their patients. This potential to improve care makes broader diffusion of IT desirable. In general, HIT allows healthcare providers to collect, store, retrieve, and transfer information electronically. However, more specific challenge of IT is its inability to provide a seamless flow of information along healthcare processes (Ash, Berg, & Coiera, 2004). One of the reasons for these difficulties is that healthcare processes are subject to contextual reasoning (Kuziemsky & Bush, 2013). Therefore, while we can model and design HIT, it is contextual issues that prevent these systems from working as expected.

According to (Jones, Rudin, Perry, & Shekelle, 2014), while strong evidence supports the use of HIT systems, insufficient reporting of context of use makes it impossible to determine why some HIT implementations are successful and others are not. Consequently, a responsive HIT infrastructure is required in order to facilitate a rapid and adequate support to newly arising needs (Smith & Fingar, 2006). Born, Kirchner, & Müller, (2009) reasoned that a higher consistency and reusability of process knowledge can be achieved from HIT by introducing formalized context categories.

## 2.6. Research Knowledge, Challenges and Gaps

Smith & Koppel, (2014), and others have shown that context is essential for understanding how HIT interacts with healthcare process where it is used. However, there is still much less knowledge about the broader challenges regarding the use of BPM to model context. In addition to the challenges of BPM, Table 2 provides a synopsis of the existing knowledge and gaps pertinent to this thesis.

**Table 2: Research Knowledge, Challenges and Gaps**

| Topics | Knowledge | Gap |
|---|---|---|
| BPM | Models and simulates to identify, automate, execute, and manage business processes. While many languages exist such as BPEL, YAWL etc. none of them explicitly model context. These languages are very structure oriented while context is needed to shape the behavior. | Managing and understanding context within the healthcare environment. |
| Context Modeling | Permits the description and the structuring of contextual information. | Addressing healthcare modeling demands involving context. |
| Interoperability | Supports communication and co-operation between IT systems at different levels. | Poorly defined at the process level that is influenced by context. |
| Context | Information used to characterize the situation of a task that is considered relevant to the interaction between a user and an application. | Significant gap between the IT in place and contextual dependencies. |
| Health IT | Enables integrated and comprehensive data to be provided in good time. | Inherent complexities involved in utilizing HIT to implement context to support healthcare delivery. |

# Chapter 3: Research Methodology

Design science research is the primary methodology used in this research to understand the problem domain and thereby achieving a solution (Peffers, et al., 2006). Design science research addresses research through the building and evaluation of artifacts designed to meet identified business needs, where purposeful artifacts are built to address problems and evaluated with respect to the utility provided in solving those problems (Hevner, et al. 2004). In other words, design science research uses a cyclical model of designing, building, and evaluation of outcomes in order to develop constructs, models, or methods (Hevner, et al. 2004). Results from design science research can involve developing a model or framework which can be evaluated against the research objectives or developing new research questions. In this research, we applied the seven guidelines of design science methodology in order to produce a viable artifact leading to a solution based on relevance and importance to business problems, (von Alan, March, Park, & Ram, 2004). The guidelines consist of: (i) Identifying a clear description of the problems from prior research and a case study, (ii) Developing the framework as a design artifact; (iii) Validating the use of the framework through an appropriate scenario (Bell, De Cesare, Iacovelli, Lycett, & Merico, 2007), (iv) Providing clear contributions in the areas of the design artifact, design construction knowledge (i.e., foundations), and/or design evaluation knowledge (i.e., methodologies), (v) Applying rigorous methods in both the construction and evaluation of the designed artifact, (vi) Solving problems by utilizing available means to reach desired ends while satisfying laws existing in the environment, and (vii) presenting the methods to both technology-oriented as well as management oriented audiences.

Identifying a clear description of the problems and providing a solution was carried out through a case study at a Canadian hospital conducted to achieve this objective. A case study is defined as an empirical inquiry that investigates a present day phenomenon within its real-life setting (Yin, 2013). Case studies emphasize the rich, real-world setting in which the occurrence of interest occurs (Dul & Hak, 2008). The indicated objective of the research requires the in-depth study of context on healthcare processes in its real-life setting. Therefore, a case study is an effective research strategy that allows BPM method to be presented and utilized by means of close collaboration with the people in the field (Gibbert, Ruigrok, & Wicki, 2008). The close connection with reality is considered important to make sure the BPM method is effective and purposeful to address practical problems.

We also used content analysis as the analytical method for analyzing the data collected from the case study. Content analysis is a systematic and objective means of describing and quantifying phenomena (Krippendorff, 2012). Content analysis allows the testing of theoretical issues to enhance understanding of the data. It also allows inferences to be made which can then be corroborated using other methods of data collection (Stemler, 2001).Through content analysis; it is possible to distil words into fewer content related categories (Krippendorff, 2012). It is assumed that when classified into the same categories, words, phrases and the like share the same meaning (Cavanagh, 1997).

This method was modified in this study, because an initial categorization of the data was already known, based on the findings of Ash, Berg, & Coiera, (2004) and Kuziemsky and Bush (2013). As with a typical Content Analysis, the data from the transcripts were reviewed in detail as demonstrated in Appendix C. Rather than generating codes, however, a matrix of the overarching issues that a health information system seems to foster were placed into two main categories in Table 4: those in the process of information management and those in the communication and coordination process that the SIMS is supposed to support. These categories were stated in Ash, Berg, & Coiera, (2004) as dominant causes of of unintended consequences. Categorization of these issues is helpful in modeling context which as a result can lead to the avoidance of the unintended consequences of these subtle silent errors. Each transcript was reviewed, and direct quotes (see Appendix B) from each participant, as they relate to the two main categories were manually recorded to the matrix under the appropriate sub-categories. Data that indicated a contextual issue, but did not fit into one of the pre-defined categories were classified and set aside for further analysis. The results of this analysis can be found in Table 4: "Categories of Contextual Issues" (which describe the categories and sub-categories of the contextual issues experienced by participants at the Canadian Hospital) that SIMS was required to improve as part of perioperative care delivery.

Basically, content analysis was useful and aided us in understanding the complexity of context in the healthcare environment. The contextual issues that were perceived by participants to affect the SIMS implementation at the Canadian Hospital where the research took place are summarized as: 1) Data entry and retrieval retrieval, 2) Data visualization including different ways of representing data, 3) Cardinality of viewing multiple computer screens, 4) Data accumulation over time 5) Individual coordination, and 6) Group coordination.

Following the use of content analysis, we formulated an iterative approach in developing a context framework that allowed us to address identified contextual issues and gaps in order to achieve the modeling requirements described in chapter 4. The framework is then validated by the case study to demonstrate how BPM technology, and its associated patterns, can represent and model context.

## 3.1 Integrated Framework and Methodology for BPM

This section presents our integrated framework with its two types of core models: the entity model and the meta-model, BPMN as the context modeling notation and the methodology for modeling context. The use of an integrated framework increases the capability of BPM to manage context in order to improve processes, resulting in increased control of processes by an organization. In additional, an integrated and tool-supported methodology is essential for BPM projects to help users who are modeling business processes and validating them (Pourshahid, et al., 2009).

The framework is centered around a set of novel conceptual foundations and starts with the entity model that identifies and defines the main entities that generate context in the healthcare environment. The Meta-model which is the core component of the framework, describes and defines the concepts for creating context models and, the methodology outlines and describes the main stages the thesis follows to model context. Figure 2 is an overview of the Framework. The value of this framework is not only that it provides an instrument for modeling context; it also provides a basis for motivating design choices in context modeling. Each section of the framework is described according to the section numbers in the framework below:

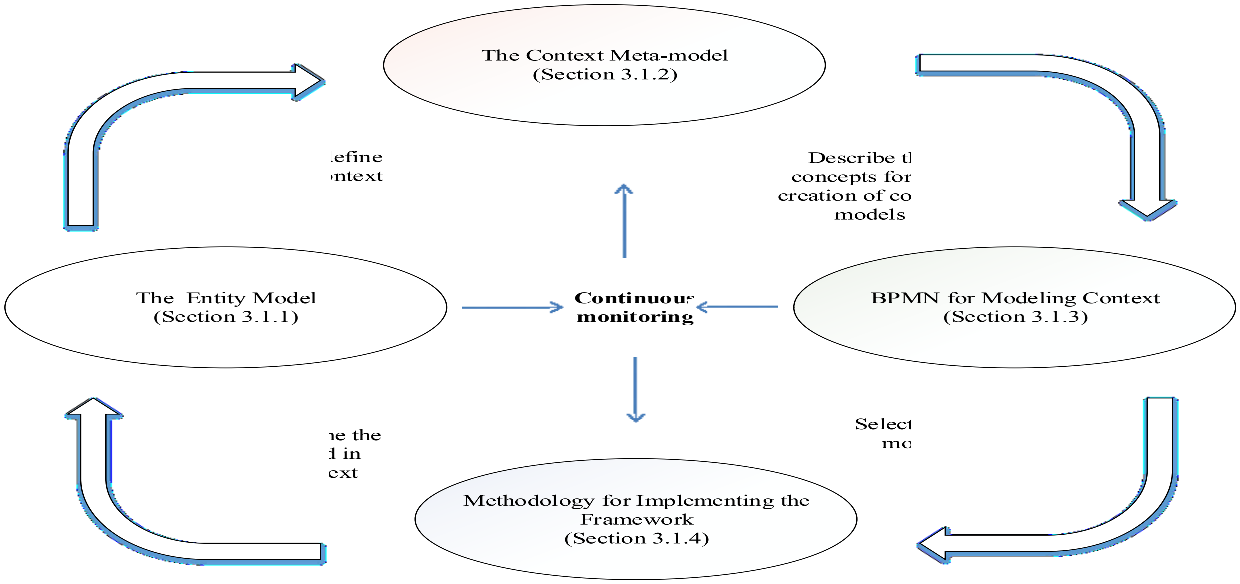


**Figure 2: Framework for using BPMN to understand and model context**

### 3.1.1 The Entity Model

In the healthcare environment, "context information and elements such as data can originate from a wide variety of sources, leading to heterogeneity in terms of quality, persistence and use" (Henricksen, Indulska, & Rakotonirainy, 2002). In order to design an appropriate framework that allows context to be analyzed for modeling, identification and classification of the main entities that generate context, the variants belonging to the workflows and human tasks as well as their interrelations should be taken into account. Classifying the source of context in relation to a class of entities (Coutaz & Rey, 2002) is important in a context modeling process where context representation depends on these entities and the relationships created between them (Ejigu, Scuturici, & Brunie, 2007). Such a classification helps designers and users to derive an understanding of context and the state of all workflows, services and tasks that are executed (Ejigu, Scuturici, & Brunie, 2007). The entity model in figure 3 integrates a set of well-defined entities that are common to the healthcare environment. Each entity of the model is described below:

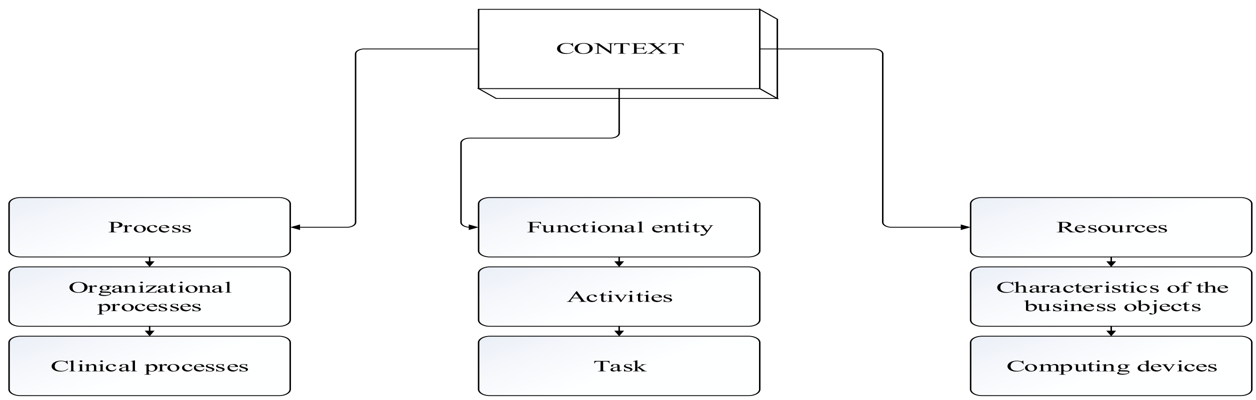


**Figure 3: Entity Model**

The entity model presents context as the main output or core element of the context entities: Process, Functional entity, and Resource. It can be defined as the reification of the environment, that is, the entities that provide the surrounding in which a system operates (Finkelstein & Savigni, 2001). In the diagram, context is said to influence the requirements of each entity and the variants each entity can adopt to meet its requirements. Moreover, context is by nature variable in these paradigms and it calls for new approaches, (in our case modeling) to create a system that can adapt to context changes. Each context entity in the diagram in figure 3 contains context elements that are a result of the process, the functional entity and the resource that are essential for representation in BPM. Context can be classified into several categories reflecting the nature of the issues observed and treated. The categorization of the contextual elements based on the immediate entity can improve context modeling. The context entities in figure 3 are discussed below and can be extended according to the business needs of the organization.

**Process:** accounts for the contextual factors that may characterize a business process (Saidani, Rolland, & Nurcan, 2015). In various studies, there is a lot of confusion stemming from different perspectives on what healthcare processes are (Lenz & Reichert, 2007). For healthcare processes, a division can be made between organizational processes (e.g. clinical workflows like medical order entry), and medical diagnosis and treatment processes (Lenz & Reichert, 2007). In Reddy, Gorman, & Bardram, (2011), medical diagnosis and treatment processes are considered multidisciplinary patient-care processes. These are good examples of context since they require a wide range of interactions within and across healthcare and departments in diagnosis and treatment (Wu , Wang , & Yun , 2009)

**Functional entity**: applies to a class of entity (e.g. operating room) that carries out the tasks within a function. Entity is something or an organ that exists as a distinct, independent or self-contained unit (Functional Model Working Group, 2009). The functional entity utilizes activities, tasks and sub-processes that compose the process, such as task duration or documentation. While the model uses the term functional entity to apply to a class of entity, such as the operating room or pre-admit unit in healthcare, the emphasis relates to the "nature of the tasks or activities performed" (Functional Model Working Group, 2009).

**Resource**: is characterized as human (e.g., a nurse) or non-human (e.g., materials, computing devices etc.) (Russell, van der Aalst, ter Hofstede, & Edmond, 2005). The material resource usually concerns the context of business objects such as "fit of the resources", "availability of the resources", integration of the available resources, as well as features concerning usability. In any type of task, a resource plays an important role that contains a contextual implication. Thus, tasks are always connected to the available business objects. On the other hand, the human resource reflects the relationship between actors: such as the "quality of communication and relationships between the interacting actors", "coordination and collaboration with actors hierarchically nearby or across the organization, etc. Such relationships contain contextual implications that impact the organization.

### 3.1.2. The Context Meta-Model

The context meta-model in figure 4 is the core component of the integrated framework in figure 2 that allows the creation and execution of context models. The meta-model represents the context domain and definitions. In addition to capturing a wide range of the concepts of context, the meta-model also serves as a good foundation for the evaluation of context. The constructs of the meta-model are related through the business process. This relationship expresses the fact that a business process is not executed unless one or more contextual conditions are met. This underpins the influence of context on the implementation of a process (Saidani, Rolland, & Nurcan, 2015). Additionally, the meta-data is associated to both the context elements and the context entity. This association of the meta-data is in line with the description in (Honle, Kappeler, Nicklas, Schwarz, & Grossmann, 2005) that meta-data provide a suitable way to deal with the special properties of context. In figure 4, the context entity allows the structuring of context. An entity is demonstrated in figure 3 to be a resource, process, actor etc. Context element represents any element that denotes context. It also provides information about the context entity. Context information on the other hand is any information used to characterize the state of an entity concerning a specific aspect (Strang, Linnhoff-Popien, & Frank, 2003). In BPM, contextual information refers to information reflecting the changing circumstances and having an impact on business process design and execution (Saidani, Rolland, & Nurcan, 2015). The actor's implementation of a task, the manner in which data is used, transferred and shared by a resource are examples of contextual information. Representation refers to the internal representation of context. Each context element contains information that has a representation. For example, in (Strang, Linnhoff-Popien, & Frank, 2003), each representation in their ASC model called aspect aggregates one or more dimensions and each dimension relates to a certain context element, or context value. This means that internal to an organization, context is defined through the context element. Context attribute is a measurable characteristic which makes context clearer. Each context entity is represented by a set of context attributes.

Business process patterns represent the predefined constructs that provide the basis for modeling context (Bergholtz, Jayaweera, Johannesson, & Wohed, 2004). Finally, context model provides an explicit definition of the context elements, their representations, and the relationships between them. While each context model could have single or multiple associated representations that can describe the objectives of one or multiple processes, each context model is also a use case constructed as a result of one or multiple processes.

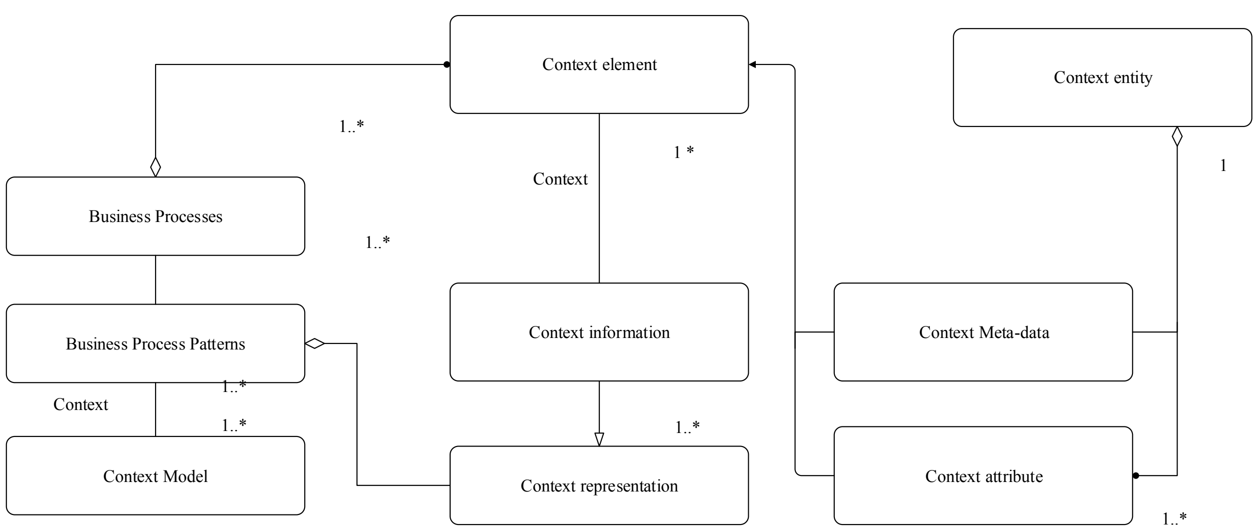


**Figure 4: Context Meta-Model**

#### 3.1.2.1 Context Modeling Approach

Finding an existing context model suitable for our purpose proved challenging. Much of the work in the relatively evolving concept of context is concerned with providing either frameworks that support the abstraction of context information from sensors or high level models of context information that can be queried by context aware application (Henricksen & Indulska, 2006). While these approaches can help to simplify system design and promote reuse of functionality, Henricksen & Indulska, (2006) and others argue that an infrastructure-centered view leads to abstractions for describing and programming with context that are not the most natural ones and are also based on context models that are informal and lacking in expressive power. Moreover, these approaches do not also support heterogeneity regarding the representation of context to an adequate extent (Reichle, et al., 2008). Ease of development based on the use of patterns, one of our key methods, is only addressed sufficiently by Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, (2005), but their concept is not based on addressing the needs of the healthcare environment like heterogeneity of context sources and data and, interaction with IT resources.

Our goal therefore is to develop a framework that integrates a set of well-defined context modeling approach with an appropriate notational support. Strang et al, (2003) provide a good approach for context modeling that explicitly addresses heterogeneity with regard to different representations of context, but their approach does not provide an elaborate development support. The context modeling approach by Henricksen and Indulska (2006) fulfills several of our stated needs. Their context modeling approach is complemented by a model-driven development approach and a methodology for the development of context application. The approach which addresses context from three levels, (conceptual, management and implementation) is in agreement with our goal. Because of that, we adopted the concepts of the nexus context model in (Grossmann, Bauer, Honle, Kappeler, Nicklas, & Schwarz, 2005) and the CML in Henricksen and Indulska (2006) and extended our model for our needs to a BPM context model.

### 3.1.3 BPMN for Modeling Context

One of the most important facets of the integrated framework in figure 2 is its modeling notation- BPMN. Our particular interest in the use of BPMN is based on the following: (1) it is a rich language that allows the modeling of context based on the concept of patterns, (2) it provides "definition to a multitude of business scenarios, ranging from process choreographies to inter-organizational process orchestrations, service interactions and workflow exceptions" (Recker, 2008) and, (3) it provides a graphical notation to express business processes in a Business Process Diagram (BPD). Silver, (2009) emphasized the possibility to model different events and exceptions for routing a process in the book "BPMN Method and Style". This matches well with healthcare processes, which have many exceptions (Lenz & Reichert, 2007) and tend to be very context dependent (Kuziemsky & Bush, 2013). Thus, designing and creating context models must be based on a notation that facilitates context. While most of the current important graphical notations (some of which are referred to in the literature review) "do not contain explicit elements for modeling context" (Wieland, Nicklas, & Leymann, 2011), a good practice to overcome the difficulties of modeling context is, therefore, to use the concept of patterns which are mostly expressible and supported in BPMN diagrams (Bergholtz, Jayaweera, Johannesson, & Wohed, 2004). Moreover, BPMN brings additional features not traditionally associated with graph-oriented languages (Dijkman, Dumas, & Ouyang, 2007). These include the ability to define: sub-processes that may be executed multiple times concurrently; sub-processes that may be interrupted as a result of exceptions and context; and (iii) message flows between processes. BPMN solution is therefore considered more suitable for reasons of completeness including the multiple ways of capturing patterns (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005).

#### 3.1.3.1 BPMN Notational Elements

The use of the notational elements of BPMN is crucial in modeling contextual patterns. This strong momentum can lead to the development of a wide range of solutions and approaches for BPM. Given the complexity of context in the healthcare environment, we do not claim or plan to be exhaustive in the use of BPMN. This is due to the reasoning that BPMN specification itself misses many formal aspects and its flexibility and occasional ambiguity may be used to adapt to different execution methods (Magnani & Montesi, 2009).

The complete BPMN toolkit defines thirty-eight distinct language constructs plus attributes that can also prove useful in modeling context. These are grouped into four basic categories of elements (BPMI, 2006): Flow Objects, such as events, activities and gateways, are the most basic elements used to create BPDs. Connecting Objects are used to inter-connect Flow Objects through different sorts of arrows. Swim lanes are used to group activities into separate categories for different functional capabilities or responsibilities (e.g., different roles or organizational departments). Artifacts may be added to a diagram where appropriate in order to exhibit other related information such as processed data or other comments. Figure 5 below demonstrates a selected set of core elements from BPMN that can also prove useful in modeling context. Detailed information on BPMN can be reviewed at BPMI.org.

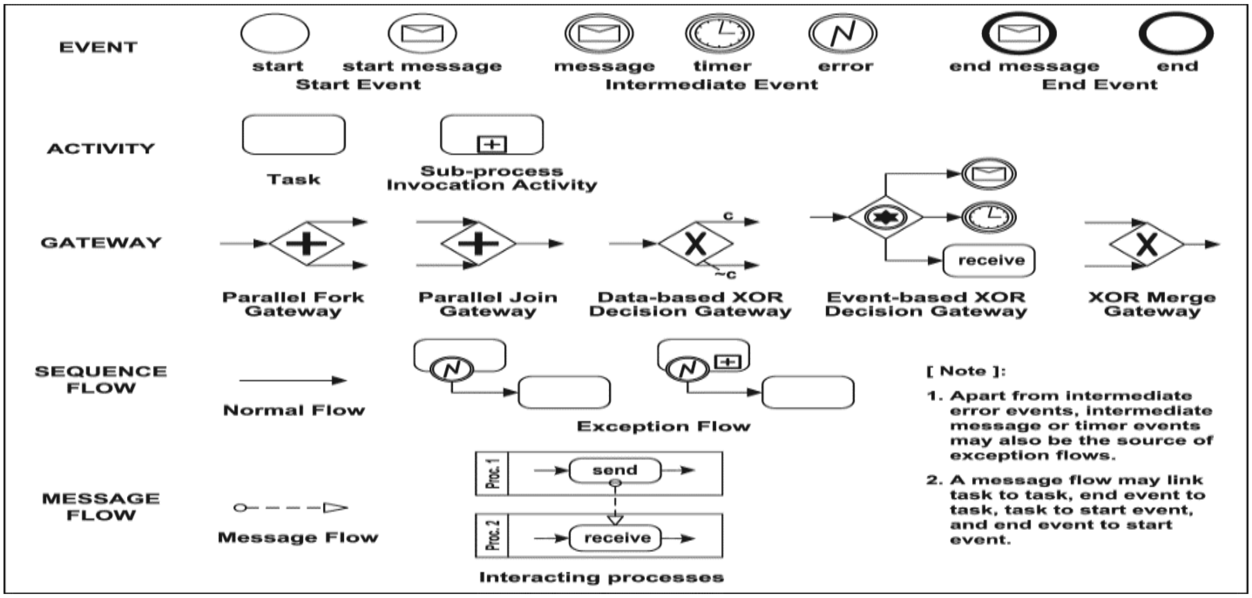


Figure 5: BPMN elements (Dijkman, Dumas, & Ouyang, 2007)

### 3.1.3.2 BPMN support for contextual Patterns

The workflow specification of an organization can be understood in a broader sense, from a number of different perspectives (Jablonski & Bussler, 1996). For example, the manner in which data is used and transferred, the aspects of process control etc. Each perspective consists of a number of patterns which provide a taxonomy of generic, recurring concepts and constructs relevant to modeling and representing context. To this end, we characterize BPMN support for context in the healthcare environment from three perspectives: process or control flow perspective, data perspective and resource perspective. A brief description of each of the three perspectives, including the possibility of BPMN to support each perspective is provided below.

#### 3.1.3.2.1 Control-flow or Process Perspective in BPMN

The control-flow perspective or process perspective (Barros, van Der Aalst, Ter Hofstede, & Kiepuszewski, 2003) deals with the order in which activities and events are allowed to occur and permit the flow of execution control, e.g. sequence, choice, parallelism and join synchronization in the healthcare environment. It provides an essential insight into a workflow specification's effectiveness. The data flow perspective rests on it, while the organizational and resource perspectives are ancillary. Basically, control-flow patterns that are a result of the control flow perspective are divided into five categories (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005): Basic control-flow patterns; advanced branching and synchronization patterns; structural patterns; multiple instances patterns; state-based patterns; and cancellation patterns. BPMN is said to support all of the basic control flow patterns. A detailed list of the basic control flow patterns and a description of the various ways in which control flow patterns are captured in BPMN can be found in (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005) and (Barros, van Der Aalst, Ter Hofstede, & Kiepuszewski, 2003).

#### 3.1.3.2.2 The Data Perspective in BPMN

The data perspective deals with a variety of distinct ways in which data elements can be defined and utilized in the healthcare environment. Generally, data is utilized in an organization based on a series of characteristics that occur repeatedly in different workflow paradigms. These characteristics are defined by a total of 40 data patterns relevant to the data perspective of an information system. These patterns are described in four distinct groups (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005): data visibility, data interaction, data transfer, and data-based routing, which characterize the manner in which data elements can influence the operation of other aspects of the workflow, particularly the control flow perspective. BPMN provides support for the representation and handling of most data perspectives. A complete overview and detailed descriptions of BPMN support for the data perspective can be found in (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2006) and (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005).

#### 3.1.3.2.3 The Resource Perspective in BPMN

Resources are required to perform tasks for specific cases or work items. A resource is an entity that is capable of doing work and can be classified as either human or non-human, (e.g. computer) (Russell, van der Aalst, ter Hofstede, & Edmond, 2005). The resource perspective generates patterns that are grouped into a number of categories: creation patterns refer to the various restrictions (e. g. range of resources that may execute the work item) that can be defined for a work item. push patterns focus on the distribution of task items and refer to the ability of the system to offer or allocate work items; pull patterns refer to a situation where the resource takes the initiative to allocate or start a work item after the allocation of a work item; detour patterns, refer to where pre-existing work allocations are interrupted either by the workflow system or at the instigation of the associated resource; visibility patterns, deal with which work items are visible and who can see them; and multiple resource patterns refer to multiple resources working on the same work item. The resource perspective is supported minimally in BPMN and its modeling is outside the scope of BPMN (White, 2004). A complete overview of the resource perspective is found in (Russell, van der Aalst, Ter Hofstede, & Edmond, 2005) and (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005).

### 3.1.4 Methodology for Implementing the Framework

Design science is inherently iterative, and the search for the best or optimal design is often intractable for realistic information systems problems (Hevner, et al. 2004). Design is essentially a search process to discover an effective solution to a problem. Problem solving can be viewed as utilizing available means to reach desired ends while satisfying laws existing in the environment (Simon, 1996). Moreover, a design artifact is complete and effective when it satisfies the requirements and constraints of the problem it is meant to solve (Hevner, et al. 2004). To this end, the methodology for implementing the framework uses an iterative set of tasks to model context in order to effectively understand them. The outcome of the methodology is a result of series of iterations meant to determine the desire solution to the problems of context. This process agrees with the concept in Hevner, et al. (2004) that design-science research efforts may begin with simplified conceptualizations and representations of problems. As available technology or organizational environments change, prior assumptions made may become invalid and revised.

The methodology has four stages as shown in Table 3. Each stage contains an objective, a task and an output that is vital for designing and modeling context. The initial stage of the framework is context analysis: that deals with examining and reasoning context. Variations in context can influence a healthcare process and imply that healthcare process execution has to evolve. Context analysis is an ongoing task that allows the identification of the facts that specify if a context applies. Stage two of the methodology is the development and modeling of scenarios which is of central significance to the presented approach. Scenarios are used to define tasks. The third stage is the use of patterns as a proven solution to express and define context. The fourth stage of the methodology is based on the representation of context in BPMN. The various stages of the methodology are described in detail in table 3 below.

**Table 3: Methodology for Modeling Context**

| Stage | Objective | Task | Outputs | Modeling tool & Notation |
|---|---|---|---|---|
| Context analysis | Allowing for a systematic way to recognize contextual elements from a set of tasks an actor may execute to reach a goal. | ▪ Identify context elements | Context elements, models | None |
| Development and Modeling of Scenarios | Concurrently abstracting and documenting user activities and modeling of those activities; including the analysis and capturing and understanding of the context so as to improve them. | ▪ Analyze the setting<br>▪ Identify the agents or actors<br>▪ Determine the objectives of the actors<br>▪ outline sequences of actions and events | Contextual scenarios<br><br>Scenario models | BPM tool |
| Identification of Patterns | Identifying and selecting the patterns that best fit the contextual factor. Patterns support the modeling of context. | ▪ Identify the related patterns<br>▪ Determine if the pattern can be broadly implemented<br>▪ Identify potential areas of additional functionality | Patterns | BPMN |
| Representation of context in BPMN | Providing a description of how context is managed in BPMN. | ▪ Representation of context and processes | Context flows, Data flows, Process flows | BPMN |

#### 3.1.4.1 Context Analysis

A best practice in BPM is to develop projects in an incremental and iterative manner (Pourshahid, et al., 2009). This practice has been adopted in our methodology. The first iteration, which is based on the relative importance of the process, is context analysis. In analyzing context, much attention is given to identifying some of the processes and entities that are characterized by both context and intense coordination activities among the healthcare units. Context analysis allows for a systematic way in discovering alternative sets of facts that influence a business process (Ali, Dalpiaz, & Giorgini, 2010). Context analysis enables us to understand context, to reason about it and to determine the context elements that influence the process, the functional entity and the resource. Here, our analysis of context follows a well-designed approach and is focused on developing a context model based on sample sets of user scenarios and preferences. In the analysis, interactions among actors and resources, the channel used for each interaction, the type of information transferred and received during interaction is reviewed. By this, a list of the most relevant types of context such as the type of information and data transferred from one resource to another can be compiled. This enables most of the basic types of context to be mapped directly to process patterns while some derived context types, such as data cardinality can be better represented as context situations.

#### 3.1.4.2 Development and modeling of scenarios

The second stage of the methodology inherits a dual approach; that is scenarios are developed from which graphical models are drawn concurrently. A scenario is a story-based description that can communicate well to a wide range of audiences and carry rich information (Sato, 2004) including context description. Scenario-based methods have been adopted for interactive systems development in order to accommodate richer and deeper insights into human experience and task situation (Carroll, 2000). Use case scenarios have been used in object-oriented system development as a starting point of system analysis. In general, our use of scenarios is to describe the actual actions and event sequences of a process and create formal models based on said actions and sequences. In addition to scenarios enabling reflections about context, and occurrences, models are concurrently developed to systematically review a wide range of contextual issues and provide the basis for designing and managing complex, distributed and heterogeneous systems (UN/CEFACT, 2004). Once a scenario model is built, changes that enrich the functionality of the system can be incorporated directly. The concept of scenario is crucial to our presented approach. Owing to the robust human involvement in the healthcare environment, scenarios are a good means to drive processes that are fundamental to defining context.

#### 3.1.4.3 Identification and Selection of Patterns

In the third stage of the methodology, BPM process patterns are identified and selected from the scenarios to be applied to models. Patterns represent solutions to problems that have been proved to be useful in different settings and can be reused (Birukou, Blanzieri, & Giorgini, 2006). Patterns serve as a predefined template for a set of interrelated activities between two agents (Bergholtz, Jayaweera, Johannesson, & Wohed, 2004) and can provide a means for modeling complex context in healthcare. While it can be extremely difficult to identify a pattern that fits a given situation, identifying and selecting the right pattern for a given situation can ease design decisions (Issaoui, Bouassida, & Ben-Abdallah, 2015). In the identification and selection of patterns, the primary concern is how well a contextual problem that an actor encounters can be mapped to the required patterns. As a result, we associate patterns with scenarios based on the satisfaction of some pre-specified requirements proposed in (Gamma, Helm, Johnson, & Vlissides, 1994), for example 'intent'. According to Gamma, Helm, Johnson, & Vlissides, (1994) 'intent' contains a short statement that answers the following questions: What does the design pattern do? What is its rationale and intent? What particular design issue or problem does it address?" Besides abstractions of situations a scenario is also considered as actions that require execution on objects, or a description that enables the reflections of a problem, occurrences and task situation (Sato, 2004). While actions have attributes, which are features that can be useful for the analysis of the actions, a problem is therefore vital as it (problem) describes where and when to apply the pattern. In summary, a scenario contains the description of the task that triggers the pattern to be used to solve the task.The selective use of patterns to illustrate context has the potential to improve the understanding of process execution. This ensures that the identified patterns have a wide-ranging applicability across the healthcare workflow implementations.

#### 3.1.4.4 Representation of Context in BPMN

In the fourth stage of the methodology, a representational approach is used to outline how context is characterized in BPMN based on identified patterns. Representation provides a variety of distinct ways contextual patterns are defined and utilized in BPMN. It provides a filtering lens that facilitates insights into the potential capability of BPMN in providing a complete and clear description regarding how a contextual pattern is managed. Representation is the production of meaning through language (Hall, 1997). Systematically expressing context based on patterns in BPMN builds up a comprehensive picture of the scope and suitability of this language based on the three perspectives outlined in section 3.1.3.2 above. The use of BPMN in this stage follows its focus on business processes and its primary goal of providing a notation that is readily understandable by all business users (Magnani & Montesi, 2009)." More importantly is, BPMN support for four main categories of business processes (White & Miers, 2008): Orchestration: represent a specific view of organizational process and a description of how the organizational process participants go about things; Collaboration: a collection of participants and their interaction; Choreography: the expected behavior between two or more business participants; Conversation: The logical relation of message exchanges

At this stage of the methodology, the context models are developed and, with the output produced so far from the various stages, it becomes possible to experiment with how the representations adopted can be used to design an interactive system that fits the need of users. Following this stage, a further step of the methodology if required will be the need to perform monitoring which will be required to determine whether the organization has implemented appropriate measures to understand and manage context. Otherwise, we have developed a complete working model that facilitates context.

# Chapter 4: Implementation

In an attempt to illustrate proof of concept including the iterative approach of the proposed methodology and framework described in chapter 3, we will now apply it to a case study of a perioperative information system. A hospital's perioperative processes provide a good example for BPM modeling of context because it 'requires multidisciplinary, cross-functional processes to be accessed within complex, fast-paced, and critical situations, the hospital environment' (McCusker, Dendukuri, Cardinal, Katofsky, & Riccardi, 2005).

## 4.1. Description of the Case study

In the case study, Kuziemsky & Bush, (2013), conducted a longitudinal study of a perioperative system called the Surgical Information Management System (SIMS). SIMS was implemented across all perioperative areas, in the five different surgical sites of the integrated hospital system. The intended focus of the study was how SIMS served an underlying role as a coordinator between people, processes or departments. Preliminary findings identified that while SIMS did work well at coordinating some tasks, it also caused issues in other tasks.

### 4.1.1. Data Sources

The data sources are non-participant field observations and participant interviews at a Canadian Hospital. The non-participant field observations and participant interviews were carried out in order to understand the care process interactions with SIMS across all perioperative areas. Appendix A is a detailed table of the participants involved in the interviews. From April 2012 to June 2013, 150 hours of non-participant observations was conducted across all the clinical areas and campuses. Eight (8) interviews and three (3) focus groups were also conducted with different categories of users including anaesthetists, nurses and managers. Semi-structured interviews were had either individually or in a focus group setting with twenty (20) clinical users (four anesthesiologists and 16 nurses) of the perioperative system approximately two years after its implementation. Interviews were recorded and later professionally transcribed. A total of two hundred and twenty-nine (229) pages of transcripts were produced. Observational data focused on how different agents (e.g. registered nurses (RNs), unit clerks, physicians, residents) and processes interacted with SIMS. Observations took place over eight (8) months and involved over 1050 hours of observations.

## 4.2. Data Analysis

This is a secondary analysis of data from the case study. It is an acceptable method (Cheng & Philips, 2014) that is based on the utilization of existing data collected for the purposes of a prior study, in order to pursue a research interest which is distinct from that of the original work (Heaton, 2008). In addition, we used thematic examination techniques to examine data generated from the case. Thematic examination described in Boyatzis, (1998) is a method that is used as a means to identify, analyse, encode, and report themes within qualitative information. This examination considered the six steps that include: data familiarization; generating codes; themes search; theme review; defining and naming themes, and report production (Braun & Clarke, 2006).

Regarding a typical thematic analysis, the data from the transcripts were reviewed in detail. Rather than generate codes, however, a matrix of the perioperative processes that SIMS had difficulty in handling is developed in Table 4. Within each of the perioperative process categories are sub-categories of specific processes that we classify as context. Each context was evaluated to understand the perceptions of the participants on issues of system usage and resource interaction with regard to data visualization and data retrieval. In order to describe possible or actual action of each context, scenarios are developed from the case study to facilitate the detection of occurrences and depict system internal activities that are not directly visible to the user.

Following a further review of transcripts that were gathered for the case, direct quotes (see appendix B) from each participant were also used to determine the direct impact of the SIMS technology on users and the perioperative process flow. Data that were indicated to have impact on users and the conditions that users were faced with when using a resource were further examined to verify if these constraints were the result of socio-technical issues or contextual fit. Adverse impacts of SIMS for example were categorized to include:

- SIMS significantly increasing the workload of the perioperative unit,
- The workflow is convoluted following the integration of the SIMS, and
- Collaboration and communications are impeded

## 4.3. Results

Following the review of the case, we modeled the overall process to understand the perioperative context. Figure 6 shows the overall perioperative model. A patient's perioperative experience with the hospital starts with a visit in the Pre-Admission Unit (PAU) between two to six weeks in advance of his or her surgery. Patients are either assessed by a nurse alone, or, depending on their clinical condition, a nurse and an anesthesiologist. Any necessary tests (i.e. blood work, diagnostic imaging, electrocardiogram are coordinated during the PAU visit. On the day of the patient's surgery he or she is presented to the Same

Day Admission (SDA) or Surgical Day Care Unit (SDCU) where their preoperative care takes place prior to going into the Operating Room (OR). Following surgery, patients are taken to the Post Anesthetic Care Unit (PACU) for immediate care following their surgery. Patients who are returning home on the same day as their surgery are returned to the SDCU for continuing care until they meet the discharge criteria. Patients who are being discharged the following day may be returned to the PACU for overnight care, if their surgery has taken place at the general campus of the hospital. Patients who are being admitted following their surgery are transferred from the PACU straight to the accepting ward (unit). In certain circumstances, a patient may be transferred directly from the OR to an Intensive Care Unit (ICU).

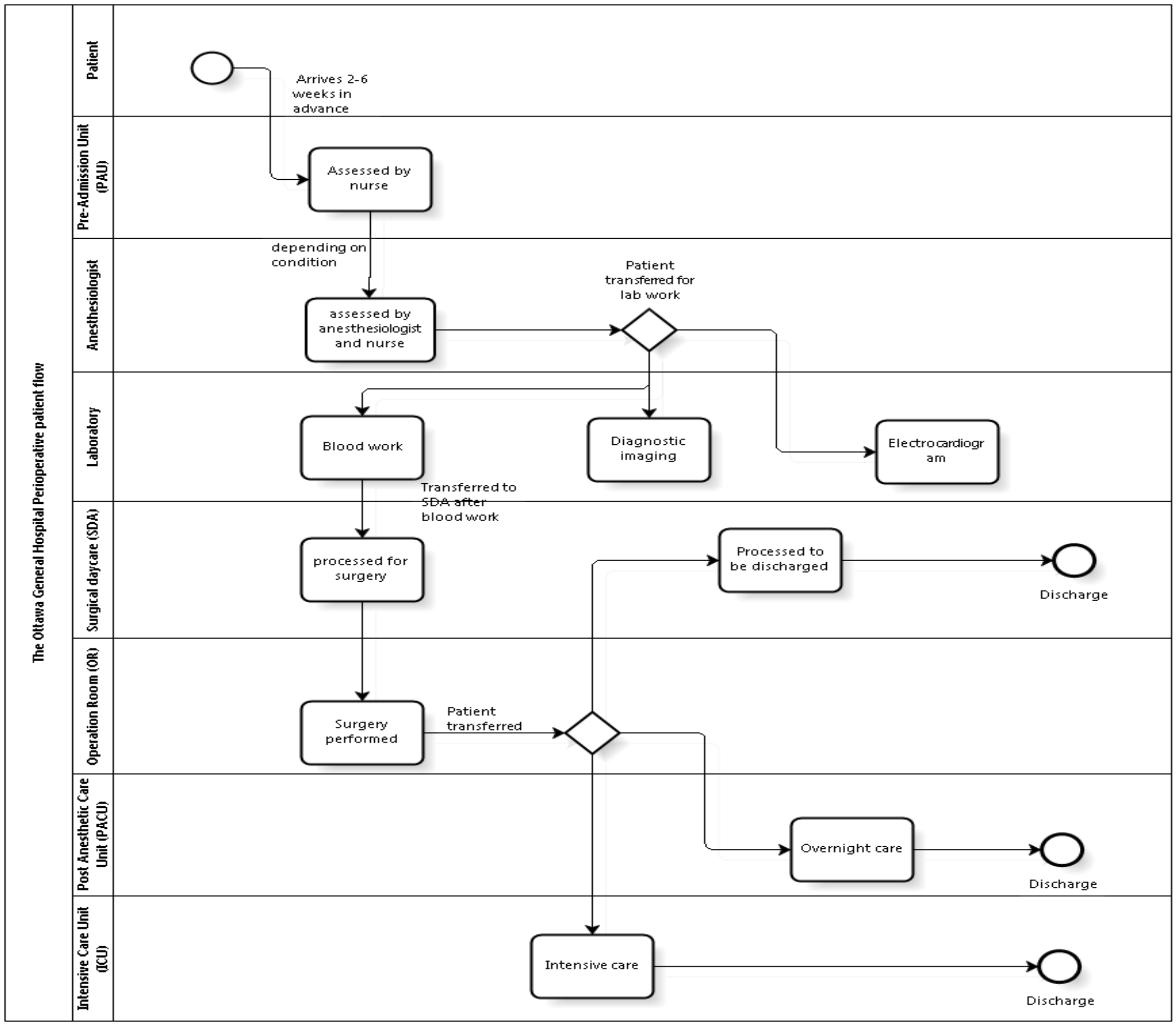


**Figure 6: Overview of the Perioperative Environment**

## 4.4. Context Analysis

Following the modeling and examination of the perioperative process, context analysis, the first stage of the methodology was performed to analyze work activities at each level of the perioperative process. The analysis allows the identification of context emanating from the various perioperative entities. Perioperative entities are defined to include resources (human: nurses, doctors and non-human: computers and other devices), process and the functional entity. Each entity has a unique way of presenting context in the form of data or information.

Though Figure 6 represents a model of the overall perioperative process, it is when specific work activities at each level of the perioperative process are drilled down to lower levels of detail when context, such as the management of critical mass of integrated information, coordination and collaboration activities for managing the exchange of information and, specific work procedures become a problem in SIMS.

To address the problems of context, the interactions among actors and resources revealed in the case study, the channel used for each interaction, the types of information including data transferred and received during staff interaction were analyzed. By this, a list of the most relevant types of context such as the type of information and data transferred from one resource to another is compiled and summarized into two "overarching contextual issues" (information management and coordination and communication in Table 4). These overarching contextual issues are categorized in Ash, Berg, & Coiera, (2004) as sources of medical errors. Each contextual issue in Table 4 also contains sub-categories of context that SIMS was required to improve as part of perioperative care delivery.

**Table 4: Categories of Contextual Issues**

| Context Issues | Sub categories of Context |
|---|---|
| **I. Information management** | a. Data entry and retrieval<br>b. Data visualization including different ways of representing data<br>c. Cardinality of viewing multiple screens<br>d. Data accumulation over time |
| **II. Coordination and collaboration** | e. Individual coordination<br>f. Group coordination |

## 4.5. Developing scenarios, Selection of Patterns and Context modeling

The remaining stages of the methodology in Table 3 are applied in this section to provide an understanding of the two overarching contextual issues from the case study: information management and coordination. The stages are demonstrated in sections 4.6.1 and 4.6.2. During our work on the proof of concept illustrations, we did not have access to any existing computer-based data sources related to context, apart from the data provided in the case study. Based on the information retrieved from the case study, we have generated artificial values to continue with the rest of the case study and exercise all the stages of the methodology.

### 4.5.1 Development and Modeling of Scenarios

Since business processes usually span organizational structures, their analysis introduces specific requirements that go beyond the use of business process tools (Nicholls, 2006). Capturing or depicting business process with scenarios enables context to be defined. As shown in the illustrations in sections 4.6.1 and 4.6.2 below, we extracted scenarios from the case that are used to highlight context as they appear in different perioperative processes. Each event within a scenario is seen as a step that is typically associated with a particular process operation. This shows that a scenario is a good source for understanding the contexts within a specific event. For each scenario, we also provide a table of definition and then use BPMN to graphically model the contextual scenario.

### 4.5.2 Selection of Patterns

Pattern selection requires a deep knowledge of patterns and recognition of situations where a pattern can be applied (Sommerville, 2004). To identify patterns that fit a specific context, we have applied the interactive method proposed in (Issaoui, Bouassida, & Ben-Abdallah, 2015) and (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005). This method allows the selection of patterns through a set of questions during the analysis of case scenarios to facilitate their comprehension. For each scenario in sections 4.6.1 and 4.6.2, a suitable pattern or a list of patterns is selected for a given problem based on the contextual issues extracted from the scenario. Each pattern is then used as a basis to model context in BPMN. This process is used repeatedly in all of the illustrations in sections 4.6.1 and 4.6.2.

### 4.5.3 Representation of Context in BPMN

In addition to modeling context based on an object based approach (i.e. context is structured around a set of entities, with each describing a physical or conceptual object such as a person or communication channel, representations), the illustrations in sections 4.6.1 and 4.6.2 provide a descriptive analysis of how BPMN supports, and represents contextual patterns. Representation is a narrative of how contextual patterns are captured in BPMN.

## 4.6 Description of the Contextual Issues

In this section of the thesis, we use the two overarching contextual issues in Table 4: information management and coordination to illustrate the stages of the methodology. The stages are development of scenarios and models, identification of patterns, and representation of the various ways in which context is supported and managed in BPMN.

### 4.6.1. Information Management

As we have described in Table 4 above, information management contains four categories of context that must be modeled. From the case study, we observed that to perform their services, clinicians are profoundly dependent on information collected and shared between multiple healthcare units. While SIMS added value to the work of clinicians and healthcare processes by presenting new modes of streamlining processes, it also brought new challenges due to context.

To understand these challenges, we developed models of context based on scenarios from the case study. Each scenario describes an activity from a context entity in the case study. Each context is then mapped to a BPM process pattern in order to be appropriately represented in BPMN. Additionally, we have also included a table of definition of each pattern used in the analysis. The definitions of the patterns are referenced from (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005) and simplified to suit the contextual elements identified from the case study.

#### Scenario 1: Pre-Admission Unit (PAU)

This scenario is based on the retrieval and entry of a patient's data in an electronic medical record system which was not fully integrated with other perioperative systems. In PAU, the activities usually start with the nurse assessing a patient on arrival for surgery and thereafter entering the patient's data in SIMS. However, when the patient would arrive for surgery, the pre-op assessment data would not be in SIMS but rather in the hospital electronic medical record (EMR) program. This occurred because the patients' surgery date was often not known at the time of pre-op, resulting in the data being transferred into the EMR and not SIMS. This made the retrieval of patient data more cumbersome as an RN may have to look in two different systems.

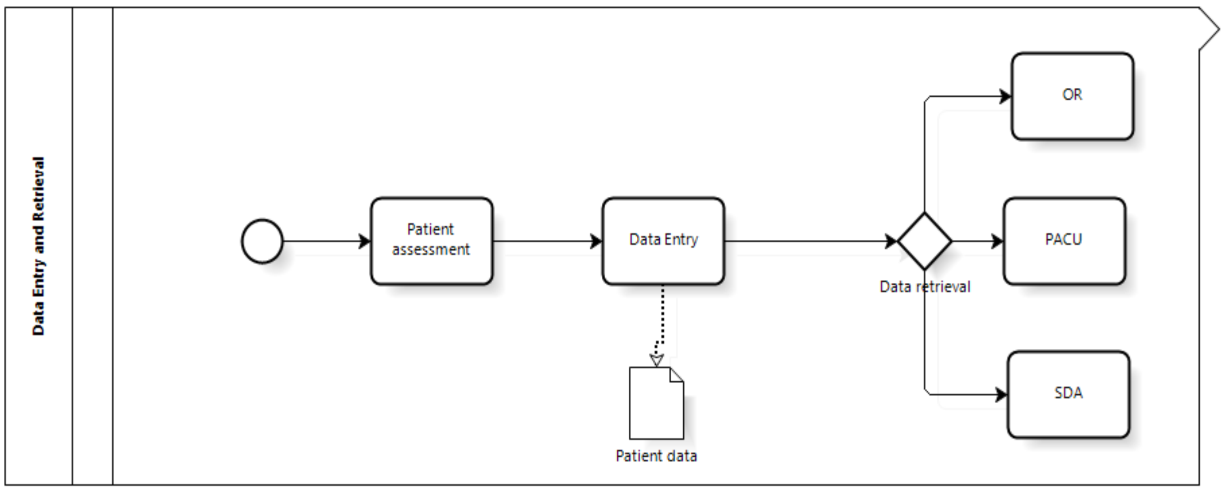


**Figure 7: Data entry and Retrieval**

**Issues:**

The SIMS module in the perioperative unit was not always integrated across other areas of the healthcare environment. While data from PAU went into the EMR, the people in SDA, OR, and PACU were required to separately access data from both SIMS and the EMR system. This resulted in SIMS being constraint in supporting data retrieval by other units, as it (SIMS) did not enable cross module messaging to support real time sharing of patient data and discussion about a patient's case.

**Patterns**

- Data interaction

**Representation:**

The scenario model in Figure 7 demonstrates the contextual issues of data entry and retrieval that correspond to pattern of data interaction that BPM supports in a variety of ways:

- Explicit integration mechanisms: this is where the workflow system provides specific constructs for accessing data in the external environment and,
- implicit integration mechanisms, where access to external data occurs at the level of the programmatic implementations that make up tasks in the workflow process and is not directly supported by the workflow engine.

On issues of unknown data (for example, a patient's surgery date not being often known at the point the pre-op record is integrated into the hospital medical record system), BPMN have not been shown to model unknown data elements such as an unknown patient surgery data. However, known data elements such as a patient's surgery date are task data elements that can be defined and accessed based on the perspective of an execution of a task or activity. Such data elements are supported in BPMN based on the concept of identifying and defining generic constructs for data representation and handling.

**Table 5: Definition of Scenario 1 Patterns**

| Pattern | Definition |
|---|---|
| Data Interaction | The ability to communicate data elements between one task and another within the same case. |

**Scenario 2: Same Day Admission (SDA)**

This scenario involves the visibility of data across the different perioperative units. On the day of surgery, a patient is usually transferred from PAU or SDA to the OR. Because each perioperative area had its own SIMS module which was not always integrated across other areas, the data was split into two modules in the OR (i.e., OR manager and Anaesthesia Manager). Anesthetists documented in the Anesthesia Manager module which was integrated with the module used in PACU and therefore documentation by the anesthetists could be seen in PACU. However, in the OR, nurses were entering medication in the OR Manager module which did not integrate with the module used in PACU. So while nurses in PACU could see what medications the anesthetists gave in the OR, they could not see what medications RNs were giving in the OR.

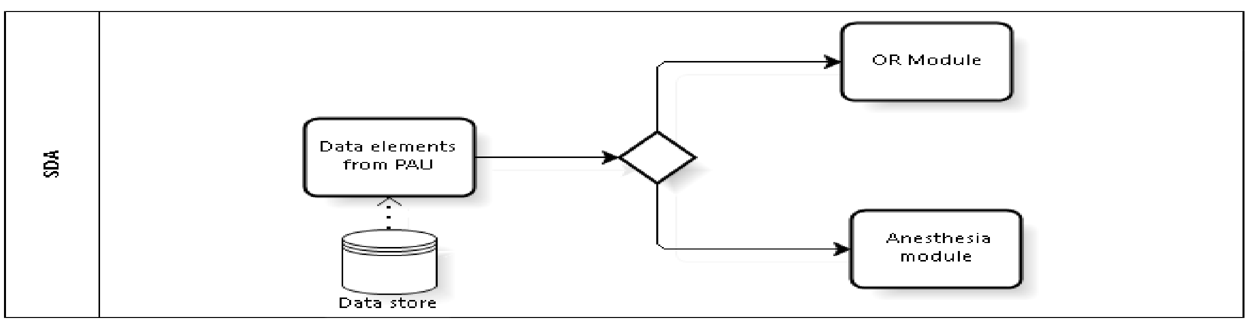


**Figure 8: Data split between OR manager module and Anesthesia manager**

**Issues:**

Each perioperative area had its own SIMS module which was not always integrated across other areas. Therefore data or documentation regarding medications that the OR nurses were entering in the OR Manager module could not be seen or accessed by nurses in PACU and vice versa. While integration is considered a major factor in this scenario, SIMS did not always allow necessary data to be available to support certain contexts of data entry. This made important data to be missed.

**Patterns**

- Data visibility
- Data interaction
- Sequence flow
- Case data
- Workflow data
- Block data
- Integrated control and data channels
- Distinct data channels
- Parallel split

**Representation:**

BPM provides a variety of distinct ways in which data elements can be defined and utilized with respect to data visibility. Contextual data elements are bound to a specific workflow construct (e.g. a task or a block) and this binding defines the scope in which the data element can be accessed. More generally, it also influences the way in which contextual data elements may be used, e.g. for communication with other perioperative units.

The issues of data visibility and data interaction between tasks (i.e., between OR and PACU and vice versa) that nurses in the OR faced are patterns that can be addressed by BPMN in three different ways:

- through integrated control and data channels or;
- through distinct control and data channels or;
- through the support of global shared data.

While the scenario model in figure 8 depicts a data split between modules of OR and the anesthesia, it is worth noting that BPMN has not been shown to model data ( Müller & Rogge-Solti, 2011), and the representation of data split has not been shown to be supported in BPMN. Though BPMN uses split (parallel split, OR-split) to represent execution constraints of activities, BPMN does not provide a modeling solution or a proposal on how to either structure a system's modules or develop an appropriate support for split in components of software regarding modules that are not integrated (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005).

However, BPMN can address issues of general shared data and data interaction through integrated control and data channels by means of the construct of data object associated to sequence flows (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2006). In scenario 2, the representation of the shared data and data interaction between OR and PACU can be supported in BPMN through an integrated control and data channels by means of data object constructs associated to sequence flows as illustrated in figure 9 below.

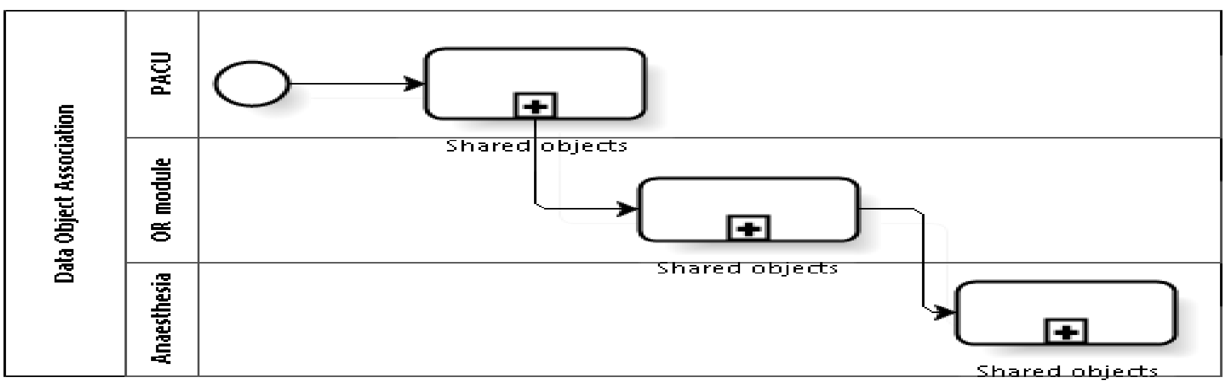


**Figure 9: Data object association to sequence flows**

Similar to data interaction patterns, data visibility patterns characterize the various ways in which data elements can be defined and used within a process. With data visibility, a determination has to be made on which data element from OR is visible to PACU and who can see them. In general, this is determined by the main construct to which the data element is bound as it implies a particular scope in which the data element is visible and capable of being utilized. Case data, task data and workflow data are data elements that tend to be specific to a task or a patient case, and in general are made accessible to all components of the patient case during execution.

With workflow data as an exception, BPMN represents data visibility patterns such as case data and task data elements through the attribute ‘Properties of a Process and a task’ respectively. These properties are local; hence they are only for use within the task.

**Table 6: Definition of Scenario 2 Patterns**

| Pattern | Definition |
|---|---|
| Split: Parallel split | A division of a single line of control into multiple lines of control which can execute concurrently. |
| Case data | Data elements that are specific to a process instance (e.g. a patient) which are accessible to all components of the process instance during execution. |
| Workflow data | Data elements accessible to all components (e.g. all perioperative units) in all cases. |
| Block data | Tasks which can be described in terms of a corresponding sub-workflow. |
| Integrated control and data channels | This is where both control flow and data are passed simultaneously between tasks utilizing the same channel. |
| Distinct data channels | This is where data is passed between tasks through clear data channels which are distinct from the process control links within the workflow. |
| Global data store | Where tasks or units share the same data elements (typically through access to globally shared data) and no explicit data passing is required. |

### Scenario 3: Operating Room (OR)

This scenario deals with the handling of multiple task data. The OR is a multi-tasking environment where patient care and data entry are separate tasks. In the OR, the anesthetist must attend to the patient (i.e. medication administration, changing IV bags, monitoring vital signs and flow rates) while also documenting the data for each intervention in SIMS. When the patient leaves the OR there is a data merge into SIMS but the OR manager data goes into a separate hospital emergency medical record system called OASIS.

**Issues**
SIMS does not contain a component for handling multiple task data and for merging patient data.

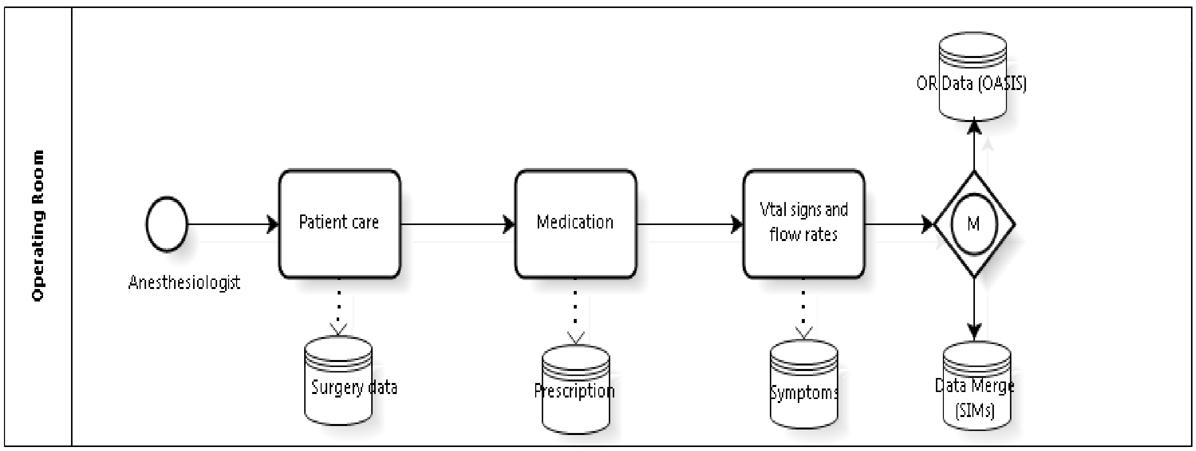


**Figure 10: Generic Multiple Task Instance focused on data**

**Patterns**

- Multiple task instances

**Representation:**

The scenario model in figure 10 is a generic representation of multiple task instances. Modeling patterns of multiple instances is based on the condition that multiple instances are known ahead of time - Priori Knowledge (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005). Thus, for the instances to be modeled, the number of task instances required for a case has to be known beforehand at design time. Once the design is initiated, the instances become independent of each other and run concurrently. Subsequent activities can only be triggered after the instances are synchronized at their completion.This means that, in the case of scenario 3, the number of activities and tasks that the anesthetist will require to do in caring for the patient will have to be known beforehand in order to design a task solution to manage multiple tasks. In a complicated environment such as healthcare, determining all the activities of the anesthetist beforehand will be unlikely. However, a workaround solution that utilizes the notion of multiple instance activities that are executed in sequence was proposed in White, (2004). That is, the evaluation of whether the activity "record patient medical" will be spawned-off is done only when the 'surgical activities' are completed as shown in figure 11 below.

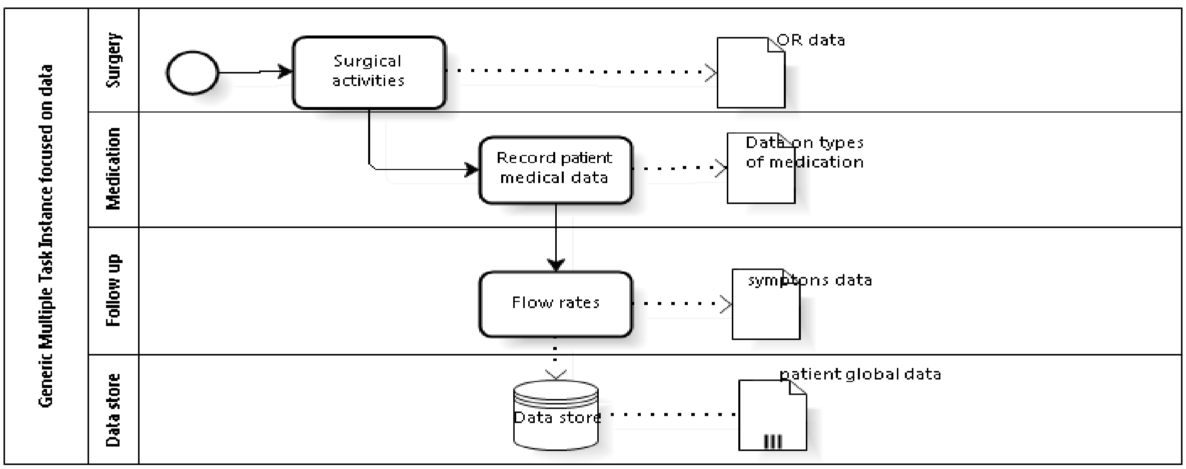


**Figure 11: Sequence pattern for multiple instances**

With respect to data merges, BPMN has not been shown to model data merges per se. This is based on the reasoning that data modeling is not a BPMN goal (OMG, 2011). However, BPMN can support the modeling of merge patterns. In BPMN, gateways are used in diagrams both to separate flows and to recombine them. BPMN applies Exclusive OR (XOR) Decision/Merge to model data-based decisions and merges based on data elements (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2006). An exclusive OR represents a decision to take exactly one path in the flow. More than one path cannot be taken as they are mutually exclusive. The elements that manipulate data in BPMN are "Item-Aware elements”. These elements allow the storage and transmission of items during the process flows. “The data structure these elements hold is specified using an associated Item Definition”. The item definition involves the specification of the data that are stored or transferred (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2006).

**Table 7: Definition of Scenario 3 Patterns**

| Pattern | Definition |
|---|---|
| Multiple instance with a priori knowledge | Within a given process instance, multiple instances of a task can be designed, if the required number of instances is known beforehand. |

### Scenario 4: Operating Room Data visualization and selection

This scenario involves the interaction of nurses and anesthetists with a detailed list of medication or medical data. In the historical paper based system, cocktails were written out by hand. While SIMS was designed to improve the complexity of the various cocktail drugs by having a drop down menu listing the drug cocktails, these menu options were long lists of text and percentages. The anesthetists pointed out that it was cognitively taxing to go through the long lists of text while searching for the correct cocktail.

**Issues**

SIMS did not provide a simpler means of filtering a long list of medical data to suit a certain context of a patient’s anesthesia cocktail. Furthermore, because many of the cocktails had similar drug names with varying concentrations, this presented the opportunity for an entry error.

**Patterns**

- Data interaction

**Representation:**

Data search, data filtering and data access from a list of group data are contexts (data interaction patterns) that are not explicitly modeled by BPMN. Although BPMN directly supports some aspects of data interaction patterns such as data elements flowing to and from a block, the group construct in BPMN is used purely for visualization purposes (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2006) and (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005). BPMN lacks the focus to model how data are handled or selected from objects in a group. BPMN does not contain construct for data filter or data search which makes access to data easier for users. The reasoning is, data models are not part of the BPMN notation ( Müller & Rogge-Solti, 2011). While data objects can be represented, business process diagrams are not data flow diagrams, and that data objects do not have any direct effect on process flows. Searching through a long list of data and selection may not be considered business processes that can be modeled. Thus, BPMN has not been shown to represent connection between a list and the data they transform.

Notwithstanding, a workaround on handling data such as long lists of text and percentages would be to use 'Input and Output Sets' as lists containing instance specific data and the Loop Counter for indexing these lists so that every instance gets its "own" data space. The instance specific data and the general task data can in this case be divided into different Sets. This workaround solution is, however, partial. Additionally, BPMN has also not been shown to provide modeling solution to constructs such as how people physically interact with: data, a computer resolution, and drop down menu of a computer device. This is due to the reasoning that BPMN is constrained to support only the concepts of modeling that are applicable to business processes. Modeling from the perspective of resolution, and drop down menu of a computer device are components of the resource perspective that may be out of scope for BPMN.

**Table 8: Definition of Scenario 4 Patterns**

| Pattern | Definition |
|---|---|
| Data interaction | Deals with the various ways in which data elements are managed and passed between components within a process and also with the operating environment (e.g., data transfer between a component of a process and an application, and filtering of data for a particular task). |

## Scenario 5: Data Growth and Cardinality of viewing multiple screens

This scenario involves nurses handling an increase in patient data, including the need to view multiple computer screens to access data in various systems. Early in a patient's perioperative process, when the patient is assessed in the Pre-Admit (PAU) or Same Day Admit (SDA) units, there is limited data on the patient and data retrieval is easier because there is less data to access or scroll through. By the time the patient comes out of surgery and goes to PACU, there is a lot of additional data about medications, symptoms, vital signs etc. Nurses in PACU acknowledged that information retrieval was challenging because of the growth of data and the fact that data may be in different places, they would have to switch between different computer screens and among multiple computer windows to get all of the information; which resulted in a loss of overview.

**Issues**

Two contextual issues resulted from scenario 5. (1) Rapid growth of data made data retrieval challenging due to the fact that data was in different places, and (2) the computer screens used to view data contained limited resolution.

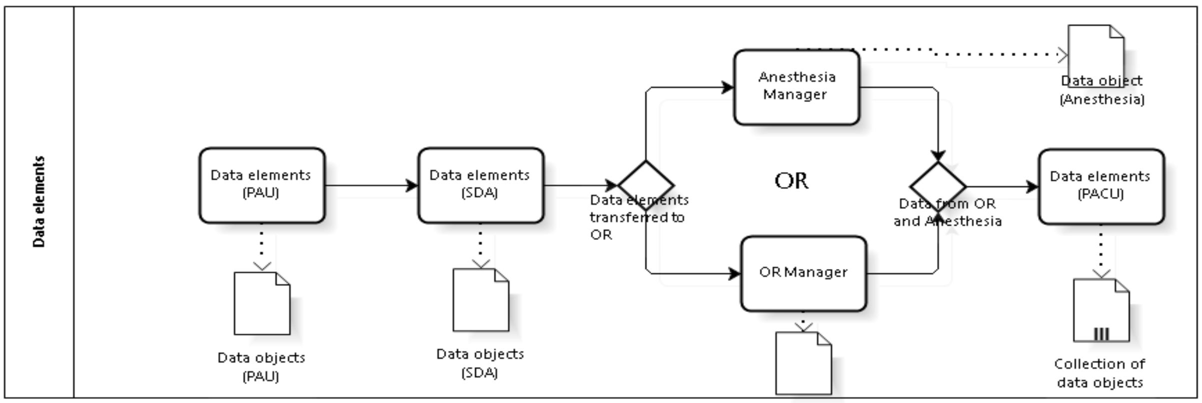


**Figure 12: Generic depiction of Data Growth**

**Patterns**

- Data association
- Resource pattern
- Multiple instance data

**Representation:**

Consistent with the use of patterns, we have categorized the contexts data growth and cardinality of multiple computer screens as data association and resource patterns respectively.

BMPN addresses issues of data association by modeling how data elements are actually transferred from activities or events within a pool as illustrated in figure 12. By this, it is possible to retrieve data required for a case that are transferred to the data store. Association model makes it easier to identify the activity that transfers data to a data store and the activity that is to receive the incoming data from a data store (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005). With data association, the transfer of data from OR to PACU can be made easier as PACU can identify elements that relate to a patient in the data store.

Contextual connotations such as data growth, data quantity, or data accumulation, are not shown to be supported in BPMN. Though BPMN supports the way in which data elements are actually transferred between one process element to another (e.g. data elements transferred from OR to PACU), through the notion of the Input and Output Sets, it is not clear how aggregation of instance specific data can be achieved through modeling. The objective of BPMN is to support modeling concepts that are applicable to business processes. This leaves out aspects such as data growth or data accumulation which are not considered business process concepts. Similar to data cardinality, modeling the viewing of multiple screens that we classified as resource patterns are not supported in BPMN. Even though resources are needed to execute work items, modeling support for the resource perspective in BPMN is minimal. In White, (2004), it was acknowledged that the modeling of resources is outside the scope of BPMN. Resources are characterized as human (e.g., a nurse) or non-human (Russell, van der Aalst, ter Hofstede, & Edmond, 2005). In BPMN, the association of a particular action or set of actions with a specific resource is illustrated through the use of Pools and Lanes constructs commonly called swim lanes (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005). Pools and Lanes do not provide a means for representing subtleties such as limited screen resolution or nurses having to scroll back through many computer screens to access a patient's data.

**Table 9: Definition of Scenario 5 Patterns**

| Pattern | Definition |
|---|---|
| Multiple Instance data | Data elements needed to execute a particular task (where the task is able to be executed multiple times). |
| Data association | Association patterns provide guidance for modeling the associations that occur among objects within both the real world and the solution domains of computer applications. |
| Resource perspective | The ability of a resource (e.g., nurse) to view and manage the status of work within an information system. |

### 4.6.2 Coordination and Collaboration

In addition to constraints in information management, different coordination activities, especially the activities related to individual and group coordination were also not adequately managed by SIMS. In the case study, group and individual coordination involved a collaboration effort where different clinicians perform several related and intermittent workplace interactions, such as practitioners or different perioperative agents coordinating with data to complete a task and coordination issues because of different contexts. There are difficulties in providing modeling support to such intensive group and individual collaboration, so-called artistic (Hall & Johnson, 2009) or human driven processes (Harrison-Broninski, 2005) as they are not well structured.

Notwithstanding the difficulties in providing modeling support to such group and individual coordination, two methods, orchestration and choreography serve to provide broad solutions on how to coordinate and execute a series of tasks (orchestration) and how individuals and group interact with one another based on a set of agreed-upon principles or contracts (choreography). We have used these methods with BPMN to model occurrences of group and individual coordination in the case study. In fact business process choreographies were introduced as a mechanism to investigate business collaborations (Weske, 2007).

**Scenario 6: Individual coordination**

This scenario involves coordination of an individual task or involvement: Anesthetists vary in the drug cocktails they use for anesthesia. In the paper based system each anesthetist was responsible for recording their own drug cocktails since they were familiar with their medications. Writing down the drugs was a mental check for ensuring it was the correct cocktail.

**Issues**

SIMS is used by all anesthetists and needs to have drug lists that support all anesthetists, as there is no way to tailor SIMS for individual clinicians.

**Patterns**

- Communication pattern
- Coordination pattern

**Representation**

A common feature in most process modeling methods is the use of a graphical modeling language to describe a business process (Bider, 2005). In most of these languages, interactions are modeled through the specification of message exchange between participants. That is, coordination is modeled as mere 'connected' communicative tasks that are mixed with the specification of the non-communicative tasks. This means that improved support for individual coordination through an information system is only possible if the essence of the collaboration and coordination can be captured and understood (Hägglund, Scandurra, & Koch, 2010); (Reddy, Gorman, & Bardram, 2011) and (Andersson, Hallberg, & Timpka, 2003). For scenario 6 above, the attainment of an orchestration model for such an individual coordination was not possible in BPMN. In BPMN, coordination is the communications that are represented by message exchanges among participants and not with an individual coordinating his/her own activities. Communication is always a circular, two-way process (Jansen, 2008). Self-coordination such as data cataloguing or the recording of a drug cocktail is a contextual pattern that has not been shown to be supported in BPMN.

**Table 10: Definition of Scenario 6 Patterns**

| Pattern | Definition |
|---|---|
| Communication Pattern | A pattern that involves the passing of information from one person to another with the intention of getting a specific result by connecting and relating to others. |
| Coordination pattern | The communications that are represented by message exchanges among participants. |

**Scenario 7: Group Coordination**

This scenario involves team coordination including communication between units: While one of the main challenges of coordination of the perioperative units was moving from individual to group coordination, other challenges including the ability to coordinate communication between agents who were in different areas of the perioperative unit, and auxiliary systems like the laboratory system not integrated into SIMS existed.

**Issues**

SIMS was not designed to focus on human interaction or coordination such as how people request and fulfill commitments

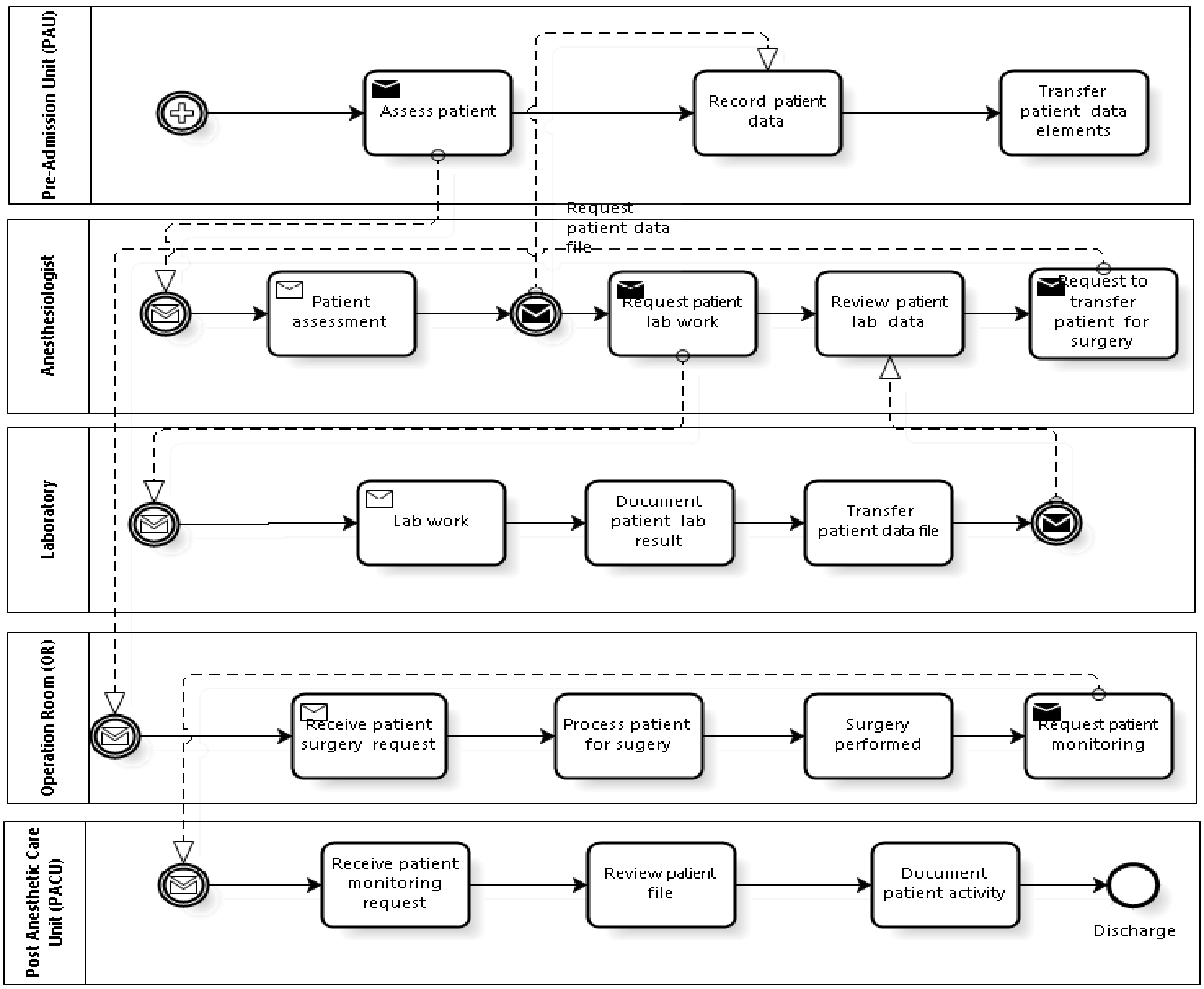


**Figure 13: Orchestration of Individual and Group Coordination**

Patterns

- Communication patterns
- Collaboration patterns
- Retrieve contribution pattern
- Aggregate activity loop pattern

**Representation**

The generic orchestration model in figure 13 shows, that a move from individual to group coordination activities can be modeled. The process follows a well-defined path that starts from the exchange of communication from PAU and ends with PACU. By coordinating as a group (team), people accomplish more than they would work alone (Gorman, 2014). The modeling of group coordination is achieved through communication patterns that are represented by message exchanges among the various groups and expressed as dotted lines in the diagram. In the model, orchestration provides support for group coordination by putting rigor on how the message exchanges that are extracted and conveyed by means of an aggregate activity Loop Pattern (Barchetti, Capodieci, Guido, & Mainetti, 2012). This pattern allows the need to extract structured information from activities carried out with tools, such as Skype, MSN, email, etc. which allow unstructured information to be conveyed. The activity loop pattern provides a messaging feature (which is absent in SIMS), that can allow a clinician to make a note about a patient's case and ask the anesthetist to review the patient's file and then come and see the patient when he is able to take a break from his current surgery. In addition to the aggregate Activity Loop Pattern, the model also makes use of the 'Retrieve Contributions pattern' (Barchetti, Capodieci, Guido, & Mainetti, 2012) which allows for coordinating the contributions of other units.

In the diagram in figure 13, the process for each individual unit is represented in 5 pools and referred to as an orchestration process, whose principal job is to build a flow of control around its interactions with other partners. Activities and processes of the orchestration process are coordinated by the orchestration by first defining the communication method between the orchestrated processes, the information types, variables, interfaces, communication channels, and message types and acting as an auto-operator or a central process to coordinate the execution of the triage in each of the patient flow, coordinating execution, management, and logging of process related data. Our model does not contain a conductor or a central process which is considered to usually have the utmost amount of communication and the highest number of connected processes as the actual representation of a centralized agent and their enactment using rules engines is outside the scope of BPMN.

It is also worth noting that in supporting coordination as depicted in the diagram, orchestration invokes a "conductor" that is responsible for coordinating execution. The "conductor" in orchestration plays the same role as a conductor in an orchestra. The conductor in an orchestra must know the entire musical composition in order to be able to lead all the musicians in the orchestra. In the context of the perioperative units represented by 5 swim lanes in figure 13, each lane plays the role of an individual perioperative unit participating in the orchestration, that must only know how to play its own instrument and its part of music, but also understand the direction of the conductor regarding when to start playing music and when to finish. Orchestration processes are difficult to model (Weske, 2007), particularly those faced with multifarious combinations of inbound events such as the perioperative processes in our case study. However, in support of process coordination, orchestration allows for easier coordination of the process activities once there is a single entity in control, and enables the efficient monitoring of message exchanges between the parties involved in the perioperative process.

**Table 11: Definition of Scenario 7 Patterns**

| Pattern | Definition |
|---|---|
| Aggregate Activity Loop Pattern | This pattern is used where there is a need to extract structured information from activities carried out with tools, such as Skype, MSN, email, etc. which allow unstructured information to be conveyed. |
| Retrieve Contribution | This pattern aims to model situations in which the message and data contributions that each unit must provide need to be collected in order to achieve a common goal. |

### 4.6.3 Choreographing the Individual to group interaction

In figure 13, we described how activities between each level of the perioperative process can be coordinated. However, we found that coordination and dependencies do not only exist between activities of the same process orchestration, but also between activities of different process orchestrations such as between PAU and the Anesthesiologist.

Process choreography addresses such interaction issues by playing a central role in ensuring interoperability between process orchestrations that are performed by participants at each level of the process flow. Choreography tells the complete story, so a participant can determine its role by isolating the parts in which it is involved. This is done by specifying the rules to be defined for the collaboration that each level of the perioperative process needs to comply with in order to collaborate with each other based on the business rules. Business rules are logical rules to be interpreted by a rules engine (Weske, 2012). We could not provide the actual representation of business rules and their enactment using rules engines as this was not in the scope of BPMN. However, in BPMN, interactions are the communications, in the form of message exchanges between two participants. This is where the choreography defines the ordered set of interactions between participants.

Choreography can be clarified through the analogy of dancers consisting of two or more groups who perform certain dance patterns jointly. The dancers all act on a predesigned and agreed upon patterns. At execution time, the dancers can execute their part of the dance patterns with no central controller who checks for compliance with the patterns in question.

## 4.7 Summary of BPMN Patterns

The sub categories of the contextual issues in Table 4 (categories of contextual issues) were modeled based on the use of a number of BPM process patterns summarized in Table 12 below. We found that by mapping context to the identified patterns in a form that is independent of the existing information system, a comprehensive treatment of the various patterns can be used as the basis for representing context. While many of the patterns in the outcome of the analysis can have multiple representations for context in BPMN, we have limited each pattern to the context that it particularly impacts. In Table 12, a "+" indicates that a contextual pattern can have direct modeling support in BPMN, "–" means lack of direct support for a contextual pattern, and "+/–" indicates partial support for a contextual pattern in BPMN. The specifics of the rating criteria used are described in (Russell, van der Aalst, ter Hofstede, & Edmond, 2005). Though a "–" indicates that there is no (direct) modeling support for the pattern by BPMN, this does not conclude that the pattern is not realized. More often, it is possible to realize the functionality of the pattern outside of the system by invoking an external program (Russell, van der Aalst, ter Hofstede, & Edmond, 2005).

While some of the patterns in Table 12 are predefined in Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, (2005), we have in addition developed eleven (11) new patterns that were derived from the case scenarios. These new patterns are classified under the following workflow perspectives:

Data perspective: patterns developed under the data perspective include - data accumulation, data merge, data growth, data search, data filters, data selection, data split and data quantity.

Resource perspective: patterns developed as a result of the resource perspective include: viewing of multiple computer screens and human interaction with computational agents.

The pattern - data cataloguing was developed as a result of coordination and collaboration activities. Each of the new patterns developed for this thesis is indicated in Table 12 with an asterisk*

**Table 12: Summary of Contextual Patterns**

| | Pattern | Scenario | BPMN | Section 4.4 Table 4 |
|---|---|---|---|---|
| | **Data Visibility:** | | | |
| | Task data | 1 | + | IA, IB, ID |
| | Case Data | 2 | + | IA, IB, ID |
| | Workflow Data | 2 | – | IA, IB, ID |
| | Multiple Instance Data | 5 | +/– | ID |
| | Data accumulation* | 5 | – | ID |
| | Data filtering* | 4 | – | IB |
| | Data merge* | 3 | – | IB |
| | Data quantity* | 5 | – | ID |
| | Data growth* | 5 | – | ID |
| | Data selection* | 5 | – | IB |
| | Data search* | 4 | – | IB |
| | Data split* | 2 | – | IA, IB, ID |
| | **Basic Control Flow** | | + | |
| | Sequence | 1 | + | IA |
| | Parallel Split | 3 | + | IB |
| | Simple Merge | 3 | + | IB |
| | Multiple Instances Patterns | | | |
| | Multiple instance with a priori Runtime Knowledge | 3 | + | IB |
| | **Resource Patterns** | | | |
| | Accessing data through multiple screen view* | 5 | – | IC |
| | Human interaction with data* | 5 | – | ID, IB |
| | **Collaboration Patterns** | | | |
| | Data cataloguing* | 6 | – | IIE |
| | Communication pattern | 6 | + | IIE |
| | Aggregate Activity Loop | 7 | + | IIF |
| | Retrieve contributions | 7 | + | IIF |

# Chapter 5: Discussion

Modeling context in healthcare raises a number of requirements and challenges for process-oriented healthcare information systems. In particular, information management, and coordination on different levels are needed. In our case study, the healthcare information system (SIMS) did not adequately meet these requirements. This, in turn, has led to our thesis developing a proposed framework that facilitates modeling representations and workarounds to reduce the overall effort for modeling context and enable a model-driven system evolution. Our concepts are presented using the case study in chapter 4 and are sufficiently generic to include other types of context. In providing an approach for modeling context, we first started from the definition of context modeling and acknowledged that context must be defined in relation to a process. This led to the extension of our context model for BPM and its components which can be compared with other approaches from two perspectives: modeling and methodology. We also include a discussion of our experiences and outcomes from applying the methodology to the perioperative environment.

The integrated framework on page 27 can also be used in other settings such as risk management. Its stages can help an organization better address external and internal factors, risk categories, and risk interdependencies. The framework can appeal to both management and organizations because it can be applied to various types of organizational processes, and the risk categories (process, behavioural, and ownership) are general enough that they are not product or service specific. To this end, the framework can be used to review systematically a wide range of potential risks and integrate related concepts to enrich an organization's risk analysis. The concept of risk can be viewed as a set of potential scenarios in a specific external or internal environment (Lavoie, 2011). A detailed multi-source analysis might encompass more than one risk scenario within a specific risk, therefore requiring other aspects of the framework to be considered in subsequent stages of the analysis. Moreover, the framework can show contextualized risk factors and indicators that should be considered during the representation stage. The monitoring stage when required can allow management to identify new and emerging risks once typical inherent risks have been identified. Overall, the framework can help an organization better assess and prioritize risks as well as determine the most effective risk response and control strategy.

## 5.1 Context Modeling

We observed from the case study that while SIMS partially supported aspects of clinical workflows, its management of context was inherently limited. Context management in the healthcare environment must reflect the specific characteristics of such environments, e.g. coordination, transfer of data, and integration of contextual sources. Organizational processes (which basically show less variability and dynamics) and medical treatment processes are good examples of context and coordination since they require a wide range of interactions within and across healthcare and departments in diagnosis and treatment (Wu, Wang, & Yun, 2009) and are part of the fundamental work procedures in clinical practice (Lenz & Reichert, 2007). Context modeling is therefore crucial in representing context in order to execute healthcare processes.

Unlike traditional approaches to context modeling which were primarily concerned with requirements for the model (Henricksen & Indulska, 2006), our approach to context modeling allows us to graphically represent context and explore the option of closing the formality gap by using patterns as a fundament to describe contextual situations. This enables the implementation of clinical service or task interoperability on the context level (Strang & Linnhoff-Popien, 2003).

Kuziemsky, Nøhr, Aarts, Jaspers, & Beuscart-Zephir, (2013) emphasize that good understanding of a business process is key to successful context modeling. Our conceptual modeling of context is implemented to facilitate the development of an interactive information system that supports the management of contextual issues, and to permit the analysis and re-engineering or improvement of them based on the good understanding of the healthcare processes.

## 5.2 Methodology

Our proposed approach applies stages that are common in modeling context but it also provides some enhancements such as its expressiveness. While a number of context models have been presented in the literature, none of them, to an adequate extent supports all of the requirements to model context in the healthcare environment. Our approach which presents a comprehensive and integrated approach for context modeling in the healthcare environment, does not recommend concentrating on small-grained details that limits the big picture that combines the advantages of existing approaches and addresses the need for supporting effective interactive system design. Throughout our approach, we compare our approach with the related literature in order to clearly demonstrate the need to develop an extensible context framework.

The methodology of Henricksen and Indulska, (2006) whose work provides elaborate support for reasoning on context information and has led to the creation of the CML shares many steps with ours. However, in our work, modeling is used to facilitate heterogeneous integration and the graphical representation of context which can enable the visualization and understanding of the activities that are carried out in the fulfilment of healthcare processes.Similar to our work, Mans, (2011) is also concerned with assessing alternative ways of providing support for healthcare processes. However, their approach is limited to the use of workflow management systems, and does not make provisions for the graphical depiction of the process steps and thus designing a system to support them.

## 5.3 Experiences with context in the perioperative environment

We applied our methodology to the perioperative processes in our case study and observed the following practical points:

- We constructed a set of scenarios from the case study and pattern them to a collection of BPM process patterns developed for assessing control-flow, data transfer and merger and resource capabilities. This was carried out with a focus on context modeling. The case study demonstrates that context, as a result of perioperative processes are complex and managing these processes can be achieved through the presence of models that can essentially help both perioperative managers and developers share an understanding of the processes and other central conditions at the perioperative level before deriving a solution or designing an information system that is suited to manage context.

- We modeled the complex perioperative process in the case study. Within that process, issues to be addressed involved mapping context elements of information management, and coordination to the appropriate BPM process patterns that are relevant for modeling. Mapping of context with process patterns serves as a basis for representing context in BPMN and focusing on the extreme cases without excluding in-between solutions.

Business process patterns aim to capture the various ways in which context can be represented and utilized. By defining context in a form that is represented by patterns, we were able to determine a comprehensive modeling representation of the contextual issues including their data perspective. Moreover, our context model, which comprises several diagrams, helped demonstrate the scalability of the approach but also some limitation in terms of ease of modeling human task and human interaction with IT resources. While a task can be represented in the context model, (Wieland, Nicklas, & Leymann, 2011), the ease of modeling human task and human interaction is limited in BPMN.

- Finally, while the utilization of BPMN as a modeling language in specific domains may prove to be difficult, the healthcare serves as a good example, since the nature of healthcare processes in a multidisciplinary hospital is inherently complex (Mans, Schonenberg, Song, Aalst, & Bakker, 2009). Nonetheless, BPMN proved to be effective in support of conditions of coordination. Our experience with the perioperative processes proved coordination processes can be graphically designed, as confirmed in (Russell, Ter Hofstede, & Mulyar, 2006), using design patterns of BPMN notation. We observed that in order to align the information systems to user needs, identifying and designing coordination processes in order to integrate them in the information system is crucial. A good understanding of the current processes with an aim towards a better process coordination is necessary to solve this problem. To do so, the best practices in the sector must be analyzed with the objective to redesign the existing business processes. We applied this concept to the case study through the use of choreography models and found that choreography is better utilized if the processes to be modeled are inter-departmental and span multiple departmental and organizational limits. Since healthcare processes are complicated, the means of managing this complexity is to consider processes as problems that can be separated into smaller and less complicated ones. This is where choreography seems better suited for supporting complexity as it allows reducing the overall process into sub-processes that can be described graphically with less technical facts (Weske, 2007).

## 5.4 Validating the patterns

To validate the applicability of the patterns, a broad range of offerings through a detailed review of a number of workflow systems, standards and web service composition tools identified under the "workflow umbrella" by (Georgakopoulos, Hornick, & Sheth, 1995) will be used. The results of the validation will indicate if the patterns identified in the study are applicable not only to workflow systems but that they are also relevant to process-oriented information systems more generally. Assessment of pattern support in existing tools can give a valuable insight into the operation of workflow and process oriented systems and if the identified patterns have a number of practical uses such as representing context, providing a means of assessing tool capabilities and, "if they offer the basis to identify functionality gaps and potential areas for enhancement" (Russell, van der Aalst, Ter Hofstede, & Edmond, 2005).

## 5.5 Challenges

Though our model helped demonstrate the scalability of our approach, we observed several challenges. Firstly, in most studies reviewed the most commonly used attributes of context are generally related to time, location and identity of healthcare staff member. Secondly, there still exist a gap between fundamental researches on context representation and actual context prototypes. Various studies on context are mostly based on prototypes and real applications are still lacking or difficult to find. This may be due to the difficulty of managing a distributed and complex system for context in healthcare. Thirdly, our use of BPMN to model context also faced some challenges. While our methodology proved that most contexts can be modeled, evolving context attributes such as data growth, data accumulation, and cardinality of viewing multiple screens by a clinician to access data were shown to be outside the scope of BPMN. This made it difficult to derive a workaround representation of such contextual attributes. Modeling patterns related to data interaction to and from a multiple instances task such as data interaction from OR to PACU could also not be achieved because the specific data for the task or sub-process with a "multiple instances marker are not yet specified in BPMN" (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2005).

The last point deals with the difficulties in building efficient models for the mediation of human perspectives. For example, modeling the resource perspective which involves how nurses interacted with clinical systems such as the viewing of multiple computer screens by a nurse to access shared or task data, had minimal or no modeling solution in BPMN. This is specified in (White, 2004), that modeling of resources is outside the scope of BPMN.

## 5.6 Limitations and Future Research

While our model has value in terms of its multiple perspectives and orientation, it has limitations. The model arose methodically based on context; however, it has not been independently tested. This needs to be done in diverse clinical units. It also requires testing with other applications to ascertain its relevance to other clinical information systems. The model, like others, is a simplification. The key variables of the model are somehow limited. More variables should be included to produce a more detailed model. Models are theoretical representations of the way systems or processes work and they tend to reduce complexities to provide explanations. They (models) are simplifications of a certain view of reality (Pidd, 2003) and a single model cannot effectively capture every aspect of complex healthcare delivery (Jun, Ward, Morris, & Clarkson, 2009). In this respect, the strength of this model is its capacity to highlight important features of differences; nevertheless its corresponding weakness is that it simplifies the implementation of context. Another limitation is that we implemented modeling elements of our framework using one specific BPM notation (BPMN). Many comprehensive approaches for context model specification and management such as Context Modeling Language (CML) and its associated software engineering framework (Henricksen & Indulska, 2006) and the Nexus context model (Grossmann, Bauer, Honle, Kappeler, Nicklas, & Schwarz, 2005) with the Augmented World Language (AWML) that supports the modeling and management of standardized and extensible context models are now available.

For future work, we will extend our context modeling approach to include implications for systems design and analysis of HIT such as the separation and distribution of contextual information across different systems.

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## Appendix A: Table of Participants Interviewed

| Participant Number | Candidate Role | Specialty |
|---|---|---|
| 1 | Anesthesiologist | Anesthesia |
| 2 | Registered Nurse | Formerly Same Day Admission Unit, now Pre-Admission Unit |
| 3 | Anesthesiologist | Anesthesia |
| 4 | Registered Nurse | Eye institute |
| 5 | Anesthesiologist | Anesthesia |
| 6 | Anesthesiologist | Anesthesia - Eye Centre |
| 7 | Registered Nurse | Post Anesthetic Care Unit |
| 8 | Registered Nurse | Operating Room |
| 9 | Registered Nurse | Post Anesthetic Care Unit |
| 10 | Registered Nurse | Same Day Admission Unit |
| 11 | Registered Nurse | Operating Room |
| 12 | Registered Nurse | Operating Room |
| 13 | Registered Nurse | Same Day Admission Unit |
| 14 | Registered Nurse | Operating Room |
| 15 | Nurse Manager | Operating Room |
| 16 | Registered Nurse | Post Anesthetic Care Unit |
| 17 | Registered Nurse | Pre-Admission Unit |
| 18 | Registered Nurse | Operating Room |
| 19 | Registered Nurse | Pre-Admission Unit / Post Anesthetic Care Unit |
| 20 | Registered Nurse | Post Anesthetic Care Unit |

**Appendix B: Summary of Interview Transcript**

| **Investigator** | **Participants' quotations** |
|---|---|
| What is integration like with other systems | Participants in every unit indicated that "data does not seamlessly transcend the patient's visit in a useful way. Users in the perioperative departments have had to use multiple systems which have partially interfaced data throughout the patient's operative appointments". Participants noted "a general lack of understanding of how information is transferred between these systems". |
| Describe the usefulness of the information found in the system | Participants from the OR indicated that "the system has information in pick lists which is stale, and needs to be updated (physician names, medication lists, etc.)". OR participants also indicated that "SIMS is missing critical information required in the event of an emergency (i.e. diagnosis), that must be shared with others". |
| Describe any changes required to support users | Interfaces between SIMS and other ancillary applications (i.e. lab, radiology) were promised at the outset of the implementation, but are still not functional. This would save the users a significant amount of time and frustration from having to use two systems simultaneously. |
| Describe communication patterns pre-post implementation | Anesthesiologists indicated that they "continue to be very frustrated from a handover perspective, since SIMS' summary record is so lengthy and detailed that it is difficult to retrieve the pertinent information". |
| Describe how data are presented in the system, and any thoughts you have about the presentation | Nurses from PAU, SDU/SDCU, and PACU, as well as by anesthesiologists reported that generally, "the types of new errors that were mentioned involved trouble finding information due to information overload, information missing from the chart, and trouble using the templates in SIMS". |
| Describe the data entry process | Anesthesiologists commented on a number of problems with the data entry process for medications. "The medication lists are unwieldy and difficult to use, and often the system freezes while medications are being entered". |

## Appendix C: Examination of the Case Contents

### Coordination and Collaboration Issues

| 1-1 Duplication of data entry required due to SIMS not integrated across all perioperative units? | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Duplication due to poor charting habits. | | | Yes | Yes | Yes |
| Duplication of data documented in an electronic system by clinicians in other areas of the perioperative unit. | | | Yes | Yes | Yes |
| Duplication of OR requisition in SIMS as well as on paper. | | | Yes | | |
| Duplication of paper documentation in an electronic system. | | | | | Yes |
| Initial duplication has reduced over time. | | | Yes | Yes | |
| No duplication. | Yes | | | | |

**Information Management Issues**

| 1-2. Collection of Information | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Additional clinical activities being prompted by the construction of the templates and lack of understanding of how to use them. | | Yes | Yes | Yes | Yes |
| Automatic data capture means that there is data in the system that would not have been included on paper. | | Yes | Yes | Yes | Yes |
| There are usability problems with the templates. Documentation style has had to change on account of templates, rather than free text. The intention of the message needs to fit within the context of a template item, and then it must be modified for accuracy by using a qualifying field. | | Yes | Yes | Yes | Yes |
| Implementation has improved charting quality and documentation of adverse events. Documentation is more descriptive than it was on paper. There is satisfaction with the content of the templates. | | | | Yes | Yes |
| There is a perception that because fields exist in the templates, all fields must be filled out, regardless of the patient's situation. | Yes | | | Yes | Yes |

**Integration and Information Management Issues**

| **1-3. Integration with other systems** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| The lack of data integration means that people are working without complete information, and patient safety is an issue. | Yes | Yes | Yes | Yes | Yes |
| Access to information is easy, or access to information has improved. | | | No | No | No |
| Data does not seamlessly transcend the patient's visit in a useful way. This results in perioperative users requiring multiple disparate systems. | | Yes | Yes | Yes | Yes |
| SDU/SDCU nurses have to phone the OR nurse to relay critical information, since the SDU/SDCU nurses cannot access the OR manager. | | Yes | Yes | | |
| OR Manager module does not transmit data to the module used by PACU nurses. | | | Yes | | Yes |
| PACU nurses cannot see what medications are given intra-operatively by other nurses including having access to a complete history of what takes place in the OR (i.e. surgical procedures used, outcomes). | | | Yes | Yes | Yes |
| The system does not allow for the sharing of really critical information immediately. Verbal communication is still required. | | Yes | Yes | | Yes |
| There is a lack of clarity about how information is transferred between systems, and between the perioperative units. | | Yes | Yes | Yes | Yes |
| Verbal communication is still required at the point of transfer. | | Yes | Yes | Yes | Yes |

**Information Management Issues**

| **1-4. Usefulness of the information found in the primary system (SIMS)** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| The anesthetic record is very busy, making it difficult to find required information. | | | | Yes | Yes |
| Information in the system is useful. | | Not entirely | Not entirely | Not entirely | Not entirely |
| Reporting on the system's information is a challenge. | | Yes | Yes | Yes | Yes |
| SIMS is missing critical information required in the event of an emergency. The missing information also causes workflow issues. | | | Yes | Yes | Yes |
| System has information in pick lists which is stale | | | Yes | Yes | Yes |
| System use does not interpret verbal communication in certain circumstances. | | | Yes | Yes | Yes |
| Usefulness of system information is augmented by the use of memo/addendum fields. | | | | | Yes |

**Workflow issues**

| **2-1. Description of changes to workflow** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| Clinical processes improved due to reminders within the application. | | | | Yes | |
| Improved Workflow - automated collection of vitals into the system. | Yes | | | Yes | Yes |
| No need to be at a particular bedside for documentation, it can be done from any terminal resulting in improved flexibility for movement within the department. | Yes | Yes | Yes | Yes | Yes |
| Clinical data not automatically collected in OR, however, it is possible for a case to start without SIMS actually capturing the data. | | | | Yes | |
| There is a perception that workload has increased following the introduction of SIMS. | Yes | | | | |
| Documentation in the system has compromised patient care during implementation. | | Yes | | | Yes |
| The use of the system has managed to slow down turnover rates. | Yes | Yes | | Yes | |
| During system crisis, nurses in PACU and other units are able to chart very quickly in order to have the required data on the patient. | | | | | Yes |

| **2-2. Changes in workflow in support of clinical policy** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| The documentation standards that existed on paper continue to exist electronically in SIMS. | | Not entirely | Not entirely | Not entirely | Not entirely |
| Perception that the documentation requirements have expanded due to government mandates which have altered processes and documentation (i.e. time-out and antibiotics on board at the right time). | | | Yes | | |

| **2-3 Changes in the location of work performed** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| Use of a computer and an iPad concurrently so that both systems can be seen. Anesthesiologists always take the iPad to the bedside to talk to the patient. | | | | Yes | |
| Anesthesia charting is not close enough to the patient | | | | Yes | |
| Computers were placed in the hallways of the OR to be used by the anesthesiologists, but the anesthesiologists prefer not use them. | | | | Yes | |
| Documentation at the bedside | | | | | Yes |
| Physical department move concurrent with SIMS | | | Yes | Yes | |
| System is easily accessible | Yes | | | | |
| No access to the system for follow-up phone calls by SDU/SDCU | | Yes | | | |

**System changes and Maintenance**

| 3-1. Level of system maintenance: expected vs. realized | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Legacy, stale information needs to be removed from the system (i.e. old physician's names from drop-down menus, old medications). This is routine maintenance required. | | | | Yes | Yes |
| Computer / application slowness, application freezing | Yes | | Yes | Yes | Yes |

| 3-2. Operational changes in system functionality | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Components removed from the templates that the nurses require. Their removal has added to the workload since nurses now have to manually add the items each time they want to use them. | Yes | Yes | | | Yes |

| 3-3. Number of computer terminals supported | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Workstations are installed at each bedside in SDU/SCDU and PACU which are routinely used | | Yes | | | Yes |
| Workstations in PACU do not support access to SDCU nurses working there. | | Yes | | | Yes |
| Terminals installed in the OR hallways are not required since nobody uses them. Anesthesia and nursing both have their own computers in the OR, therefore making computers in the hallway redundant. | | | Yes | Yes | |

| **3-4. Description upgrade issues** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| Software issues that the hospital is experiencing have been resolved in subsequent releases of the software (i.e. the multiple drug issue). | | | | Yes | |
| Concern that IT is overburdened already, and not able to take on changes to SIMS as well. Users suggest that the perioperative services needs to 'own' the changes | | | Yes | | Yes |
| Customization required is not available | | | | Yes | |
| Software installed is incapable of accomplishing some perioperative goals | | | | Yes | |
| System implementation should facilitate data analysis; however, these plans have not been fully realized. | | | Yes | Yes | Yes |

| **3-5. Training needs and programs** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| Basic computer skills need to be taught. | | | | | |
| Training methodology for new anesthesiologists (staff and residents) is not a formal class-room setting. There's a perception that younger residents do not need the formalized training session because they're more computer literate. | | | | Yes | |
| Residents who move from staff member to staff member may be useful in providing insight to staff members on how to use the system. | | | | Yes | |
| A new staff in PAU is trained by the clinical educator on a one day of training session. | | | | | |

| **3-6. Changes required to support users** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| Increased use of iPads for increased mobility. | | | Yes | Yes | |
| Request for added usability (i.e. date format, system moving you from field to field automatically). | | Yes | | | |
| Increased information in SIMS via interface. | Yes | | Yes | Yes | Yes |
| Personal customization of templates in SIMS. | | | | Yes | Yes |
| Need for improvement of reports in SIMS. | | | Yes | Yes | |
| Changes in software request for internal messaging. | | | Yes | | |
| Changes in software for the discharge button to be deactivated. | Yes | | | | |
| Software changes to display why patients are delayed. | | | Yes | | |
| Software changes to improve how medications are added to charts. | | | | Yes | |

| **3-7. System downtimes - scheduled and unscheduled** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| System not usable when the time changes (Daylight Savings Time) as the system was not designed to handle daylight changes. | Yes | Yes | Yes | Yes | Yes |
| System not usable during updates at night. | | | Yes | | |
| Users are upset when the system is unavailable, since they are less familiar with how to now document on paper. | | | | | Yes |

**Manual documentation**

| 4-1. Current use of paper for clinical documentation | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Anesthesia prefers to document on paper and later record the entry into the system after the fact, due to concerns about typing while treating a patient. | | | Yes | | Yes |
| Crucial activities still require paper documentation such as medications in PAU, implants in the OR, and recording of vitals. | | | Yes | | |

| 4-2. Printing and retaining documents | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| PACU is printing records for ICU physicians consulting activities. | | | | | Yes |
| SIMS records are printed to be sent to the ward whenever a patient is admitted. | Yes | Yes | Yes | | Yes |
| PAU report is still printed for historical reference and added to the patient chart. Anesthesia and PACU both refer to this printed document. | Yes | | Yes | | Yes |

**Communication patterns and practices**

| **5-1. Communication patterns pre-post implementation** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| Staff with weaker computer skills may have trouble using the computer and attending to the patient at the same time, since they have to focus on typing and using the computer system, which demands more attention than manual documentation. | Yes | | Yes | Yes | Yes |
| SIMS summary records are very lengthy and difficult to read. It is difficult to pull pertinent details out of the minutia. | | | | Yes | |
| Handovers by nurses are still done verbally. Referral to SIMS is mostly done via verbal communication. | | | Yes | Yes | Yes |
| The system has not made a difference in terms of the quality of handovers received from various individuals. They find that there are individuals who were historically good at providing handovers and some who were not so good, and that this has not changed. | | | | | Yes |
| Anesthesiologist finds that due to typing skills he relies more on verbal communication at hand-over than previously, since the notes he adds to SIMS are short and concise. | | | | Yes | |
| Perception that nurses in PAU made more telephone calls previously, because there was an assumption that the chart would not be read. | Yes | | | | |

| **5-2. Changes to patient care practices as a result of changes in coordination & collaboration** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| Anesthesiologists are more attentive to computer entered values as they did to manually documented values. No degradation of care. | | | | Yes | |
| Improved communication with the patient because people are routinely following a checklist. | | | | Yes | |
| SIMS may improve care because the anesthesiologist may be more proactive about how they deal with the peaks and valleys that are being captured automatically. | | | | Yes | |
| Perception that the system has not increased patient safety, as it pertains to transfers to the ICU post-operatively. | | | | Yes | |
| SIMS is a useful communication tool that facilitates information sharing between users and care delivery areas. | Yes | | | | |

**Perceptions on the use of the Health Information System**

| 6-1. How have opinions about the system changed over time? | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Initial opposition to the electronic record has declined over time. | | | | | Yes |
| People who opposed to the implementation at first have changed their minds about it since they have realized how easy it is to use. | | | Yes | | |
| Non-computer users prior to the implementation of the system are now proficient users of the system. | | | Yes | | |
| People are afraid that they're going to delete the record by mistake. | | | Yes | Yes | Yes |
| Perception that documentation in the system has overtaken patient care during implementation. | | | | | |
| Users love the system and feel that it is very simple to use and that it has met their requirements. There is a sense of not wanting to return to paper documentation. | | | Yes | | |

| 6-2. Emotional reactions to system change over time | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Initial feelings of anxiety, fear, frustration, anger, have diminished over time, as people have now gotten used to the system. | Yes | | Yes | | Yes |
| Feelings of frustration resurface when changes are made to the templates. | | Yes | Yes | Yes | Yes |

**General sources of medical errors**

| 7-1. Data presentation in SIMS | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Nurses do not have knowledge of and understand why presenting data information in SIMS would be helpful. | | Yes | | Yes | |
| Information is easy to find. | Yes | | | | Yes |
| Information in the chart is difficult to find, and it is routine to continue to phone the next receiving unit with information that is critical. | | | Yes | | Yes |
| Clinicians are now comfortable with where to find information, unless it is something out of routine. | Yes | | | | Yes |
| Nurses can change the way that they view the data by altering the resolution (the way that data are presented within a report, within a given time frame), but this is not a well understood functionality. | | | | | Yes |
| Recent changes to the templates in SIMS including the removal of defaulted items have made it difficult to find and retrieve information. | | | | | Yes |
| Information is not always documented, similar to the paper record. This causes confusion and possible patient safety issues. | | Yes | Yes | | Yes |
| It is possible to be overwhelmed by the volume of information in the system, since it is so lengthy | | | | Yes | |
| Issues of missing data from a report, including cumbersome methods for adding an update to a chart persist. | | Yes | | | Yes |
| The templates in SIMS are designed to make data entry easier. | | | Yes | | |

| **7-2. Notable differences between the system being used on a daily basis and the system on which clinicians are trained?** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| After a year of use with the system, changes in templates are a difficult adjustment. | | | | | Yes |
| The entire workflow has been difficult to envision from the training classes. | | | | | Yes |
| Training did not provide a difference in terms of the timing of the various interconnected systems. The end result was that the vitals were entered into SIMS at a time that they were not expected. | | | | | Yes |

| **7-3. Errors that could be made based on the use of the system.** | **PAU** | **SDA/ SDCU** | **OR** | **Anesthesia** | **PACU** |
|---|---|---|---|---|---|
| Perception that more errors are caught with this system than previously easily spotted on paper documentation. | | | Yes | | |
| Entry of data extremely complex. | | | | | Yes |
| Confusion between the ward and the OR/PACU about what medications are given, and how they are documented since the ward does not have access to the medications documented in SIMS. | | | | | Yes |
| It is possible to 'discharge' a patient by mistake which can be a nightmare, since a nurse will have to revert to paper charting. | Yes | | | | Yes |
| Electronic transfer workflow within SIMS prohibits downstream users from accessing or modifying the record. | | | | | |
| Perception that it is easier to initially make a mistake, but easier to find the mistakes than on paper. | | | Yes | | |

| 7-4. Data presentation computer screens configurations | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| The screens in the application have been customized as much as possible to follow workflow. | | | | Yes | |
| Screens are fairly well laid out. Each hospital has different patient populations. The majority of the work can be documented on two flow-sheets for PACU. For more complex patients, there are additional templates that can be used. Screens are fairly intuitive. | | | | | Yes |

| 7-5. Description of the data entry process | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Data entry process provides helpful reminders. | Yes | | | Yes | |
| Data entry is faster with improved knowledge of the system and computer skills. | | | | Yes | |
| Easier and quicker to remove a drug that was added incorrectly to a profile, but difficult to remove when committed. | | | | Yes | |
| Medication lists are unwieldy and difficult to use. | Yes | | | Yes | |
| Some data entry elements are very intuitive, whereas others are not and require specific instructions. | | | | Yes | |
| Some templates in SIMS facilitate data entry relative to others (i.e. easier for anesthesia to enter meds than PACU nurses). | | | | | |
| The system does not adequately capture medication orders in a way that the hospital actually administers the drug. | | | | Yes | |
| Expectation of more automation within the system that is not there. | | | | Yes | |

**Overdependence on technology**

| 8-1. Description of dependence on the system | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Nurses are very dependent on the system and not appreciative when it is down. | Yes | | | | Yes |
| Availability of patient information during unscheduled downtime. | | | | | Yes |

| 8-2. Ability to revert to downtime procedures | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Clinicians can retain the paper forms as required for downtimes, and can revert to them in minutes. | Yes | | Yes | | |
| Downtime procedures are known, and started in advance of planned downtimes as required. A reference is made in the electronic chart in advance of the downtime to refer to the paper (scanned) record. Planned downtimes happen approximately once per month. | | | | | Yes |

| 8-3. Impact on patient care based on the event of a system downtime (planned vs. unplanned). | PAU | SDU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Documentation is a little bit more broken up, especially if the system goes down after documentation has already begun for a patient's visit. However, there is still information available for the patient, since part of the information available in the system that just went down. | | | | | Yes |

**Reliability and quality of information**

| 9.1 Reliability and quality of the information in the implemented system | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Data is received more timely and accurately than the paper based transaction. | | | Yes | | |
| Time in the system is not as accurate as it could be. | | Yes | | | |
| Data transferred and received from the electronic system is perceived as more reliable than manually entered data. | | | | Yes | |
| The documentation in the system is cleaner, more complete, and the information is legible. | | | | Yes | Yes |
| Users have to improvise when there is a drop-down menu, and the option that they want does not exist. | | | Yes | | |
| Memo fields are routinely used when there is not an obvious place to document something, or to provide a narrative, to describe the situation. | | Yes | | | |

| 9.2 Other Outcomes | PAU | SDA/ SDCU | OR | Anesthesia | PACU |
|---|---|---|---|---|---|
| Overall patient experience has improved due to improved information sharing, more complete charts, and the fact that charts are not missing. | | | | Yes | |
| Better standardization across units. | | | | Yes | |
| Care improvement due to nurses performing more of a prompted assessment, and fewer forgotten steps. | | Yes | Yes | | |
| Patient safety improved - due to speed of information access, information legibility, increased access to perioperative information. | Yes | | | Yes | |
| Patient safety has not change. | | | | Yes | |
| Liability reduced due to the system's ability to keep track of nurses break times. | Yes | | | | |
| Collaboration has led to improved sense of teamwork. | | | | Yes | |
| System is user-friendly & works well. | Yes | | | | |
| The vast majority of people would not return to paper-based documentation. | Yes | | Yes | Yes | |